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BIOMEDICAL AND BEHAVIORAL SCIENCES

(FOUO 13/81)

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CONTENTS

BIOCHEMISTRY

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DECENTRALIZED CONTROL SYSTEMS FOR PERIODIC MICROBIOLOGICAL SYNTHESIS

Moscow KHIMIKO-FARMATSEVTICHESKIY ZHURNAL in Russian Vol 15, No 6, Jun 81 (manuscript received 19 Jun 80) pp 98-102

[Article by A. A. Oprishko, V. V. Aleshechkin, A. V. Babayants, V. P. Davydov, Ya. A. Khanukayev and S. M. Cherner, All-Union Scinetific Research and Design Institute for Automated Systems of Control of Continuous Technological Processes, Groznyy: "Principles Involved in the Design of Decentralized Systems for Control of Periodic Processes of Microbiological Synthesis"]

[Text] Most technological biosynthetic processes in the microbiological and chemicopharmaceutical sectors of industry are periodic.

Figure 1 illustrates the general block diagram of the technological process of biosynthesis. The number of elements in the groups is shown by the alphabetic subscripts. For most processes $b \leqslant 2$, $c \leqslant 2$, $d \leqslant 2$, $k \leqslant 2$, $l \leqslant 2$, $m \leqslant 2$, $n \leqslant 14$, $p \leqslant 14$, $q \leqslant 30$, $r \leqslant 3$, $s = t = u = v = w = 2$. Nutrient media are transferred from tanks through continuous sterilization units to inoculators, culturing apparatus and fermenters. Increasing volumes of microorganism cultures are successively raised in the inoculators and culture apparatus. In addition to build-up of culture, in the fermenter there is the direct process of biosynthesis, which is associated with accumulation of antibiotic. Sterile foam suppressor, solutions of nutrients and titrants pass into the fermentation units from tanks.

The main distinction of periodic processes is intermittent treatment of the product by means of performing the required sequence of technological operations. Periodic processes are run in groups of units connected in parallel and sequence. In each of the units, the technological operations are performed in the established order, implemented by means of discrete control actions on the shut-off and adjustment fitting of the unit. The base products and semi-finished products are transferred from unit to unit in batches. During several operations, there is also formation of analogue control action directed at stabilizing specific technological parameters of the process or change therein according to the specified law.

The operation of the units is characterized by a high degree of autonomy. Most technological operations in a unit are performed regardless of operation of other units, and their operation is coordinated only when products are transferred.

In Soviet plants of microbiological synthesis, automation is usually represented by local systems of regulating individual technological parameters. The time-consuming and important operations of sterilizing apparatus and nutrient media, loading, unloading, etc., which are of a logical-program nature, are performed by hand. For example, to perform such operations in only 1 fermenter requires that service personnel handle more than 40 units of shut-off fittings, which must be done in a strictly defined order. Even an insignificant change in this order impairs sterility of the process, which lowers activity of products of biosynthesis, and often leads to utter rejects. Analysis of production reveals that the loss is rather high due to infraction of the procedures for switching the fittings in the case of manual control.

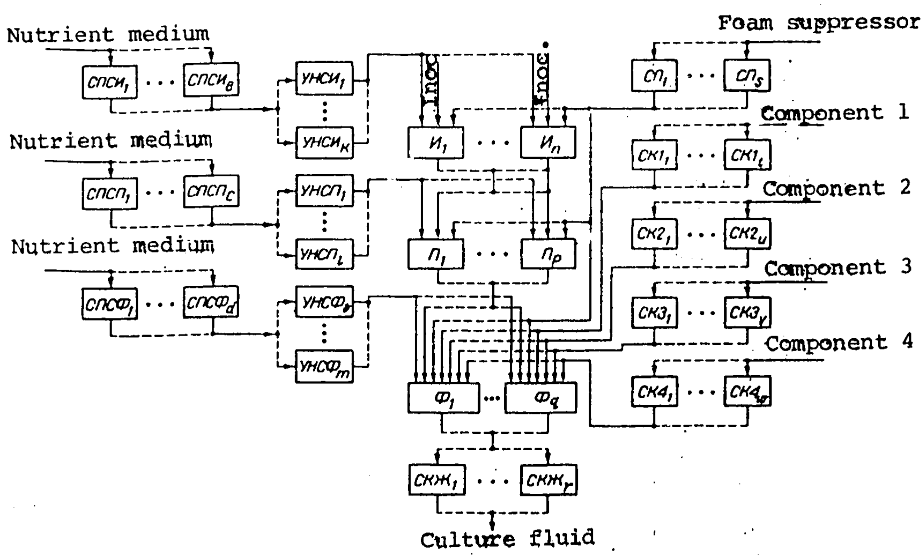

Figure 1. General block diagram of technological biosynthetic process

Key:

СПСИ, СПСП, СПСФ, СКЖ, СП, СК 1, СК2, СК3, СК4) tanks of nutrient medium for inoculators, culture apparatus, fermenters, culture fluid, foam suppressor, nutrient components 1 ... 4, respectively

УНСИ, УНСП, УНСФ) units for continuous sterilization of nutrient media for inoculators, culturing appratus and fermenters, respectively

И, П, Ф) inoculators, culturing apparatus, fermenters, respectively

Inoc.) inoculation

It is possible to raise substantially the technical and economic indicators of biosynthetic processes only by automating the aggregate of functions of logical program control, regulation of technological parameters, as well as optimization of technological mode.

In addition to the above functions, it is imperative to have centralized display of technological information, information about deviation of the technological process from the specifications and impaired operation of different elements of the automatic control system for technological processes (ASU TP), as well as centralized input of corrections by the operator-technologist.

In Soviet practice, ASU TP, which partially perform the above functions, have been developed for the chemical and other branches of industry [1]. We also know of several foreign systems for the control of processes of microbiological synthesis. For example, a system was developed and is operating in Japan for logical programmed control of the fermentation department in production of acid glutamate, which controls more than 1000 valves and 15 electric motors [2]. The Biolafitte Firm has developed a control system for fermenter units based on a minicomputer T.2000/20. This system also contains devices for handling fermentation sheets [strips?]. The system provides automatic control of sterilization of units, fermentation and other operations. We also know of systems for the control of biosynthetic processes developed by other foreign firms [3, 4].

The above-mentioned systems (with the exception of [2]) are based on one central minicomputer. Such a structure cannot fully meet the requirements of control systems for biosynthetic processes, in particular those referable to reliability and flexibility.

In view of these circumstances, it was necessary to search for new designs that were based on the principle of decentralized control [5]. The actual construction of decentralized systems became possible thanks to the advances in Soviet microelectronics and microprocessor technology.

The following are advantages of decentralized systems [5-7]: simplified programming because of distribution of programs among several microcomputers, as a result of which it is immeasurably simpler to organize program interaction than in ACU TP with one processor; greater reliability of the control system; ease of building up the computer capability of the system by connecting additional microcomputers; ease of change and distribution of the programmed provision of materials during the entire period of system operations; possibility of placing the system in operation in parts; linear correlation between the cost of the system and volume of functions performed.

The decentralization principle implies distribution of the aggregate of monitoring [checking] and control functions referable to different departments, units, parts, stages of the technological process among different units of the control equipment.

In the ASU TP for biosynthesis of antibiotics, we can single out two groups of control tasks: control of one technological unit and control of a group of units (technological stage).

The following functions must be performed for the task of controlling one technological unit (inoculator, culturing apparatus, fermenter, etc.):

a) Primary processing and display of information about the values of technological parameters, regulator settings, number of program in progress, operations and time of their performance, position of actuating mechanisms (gates, valves, electric motors).

b) Detection and reflection of information about disruption of technological mode and malfunction of system elements.

c) Action by operator-technologist.

d) Exchange of information with equipment on the higher level.

e) Logical programmed control in automatic and semiautomatic modes.

f) Regulation of technological parameters.

g) Remote control of actuating mechanisms and regulators.

In view of the fact that the units interact with one another by means of transfer of material over common pipes (collectors), steam sterilization of the latter and the need to maintain a specified temperature in them to preserve sterility, it is necessary to solve problems of coordinating the operation of the units and controlling the collectors. The functions required for these tasks coincide with the functions for control of the unit.

The above-mentioned independence of operation of technological units serves as the objective basis for distributing the most important functions of control of the units among the control instruments according to the technological feature. The functions of monitoring and controlling each unit are implemented by a separate control device. It is also expedient to have a specialized coordinating device to perform coordinating functions. The aggregate of self-contained means of controlling units and coordinating units forms the bottom hierarchic level of the ACU TP. The following should be listed among the main tasks on the second level of control: estimation of technical-economic and operating parameters; evaluation and forecasting the course of the technological process; optimum control of the technological stage and units on the basis of an overall [generalized] control criterion; immediate [operational] display of recommendations on running the technological process; unsealing the fermentation sheets.

As we see, the list of tasks for the top level includes control of the technological stage, as well as control of a unit. The reliability requirements for these tasks are less rigid than for those referable to the lower level of the ASU TP, since loss sustained due to failure to perform these tasks is relatively small. Moreover, to implement many of these tasks, the computer must have a large memory and well-developed software, and for this reason they are performed in a centralized manner, by means of minicomputers (SM-EVM series).

Figure 2 illustrates the block diagram of a set of equipment in a decentralized system for controlling periodic biosynthetic processes, which was developed on the basis of the above-mentioned principles.

The operator's control console implements functions of centralized display of information and input of control actions from the technological personnel.

The exchange unit performs procedures of exchange of information between unit control devices, coordination devices and the operator's console.

Each of these devices is based on a microcomputer with its own program.

The main advantages of the developed structure of the ASU TP are its high reliability and functional viability. Decentralization of monitoring and control functions, as well as a back-up for some main functions, reduce drastically losses due to malfunction of hardware in the ASU TP, and make it possible to use technological personnel efficiently as a means of operational reservation of performance of functions. This is attributable to the fact that the probability of simultaneous failure of several independent units of equipment is low, and if one unit is reserved the volume of control functions additionally performed by the operator-technologist does not exceed his mental and physical capabilities.

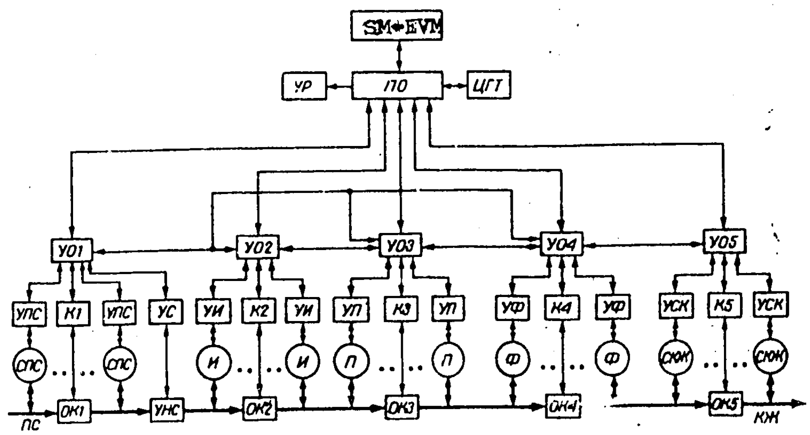

Figure 2. Block diagram of the set of hardware of the ASU TP for biosynthesis

Key:
- ПС) nutrient medium
- КЖ) culture fluid
- СПС, СКЖ) tanks of nutrient medium and culture fluid
- И, П, Ф) inoculators, culturing apparatus, fermenters
- ОК1, ОК2, ОК3, ОК4, ОК5) common collectors
- УПС, УС, УИ, УП, УФ, УКС) individual control devices for nutrient medium tanks, continuous sterilization unit, inoculators, culture apparatus, fermenters, tanks of culture fluid, respectively
- К1, К2, К3, К4, К5) coordinating devices
- УО1, УО2, УО3, УО4, УО5) exchange of information devices
- ПО) operator-technologist's console
- УР) recording device
- ЦГТ) colored graphic terminal

If there is a malfunction of the control console, the operator does not lose contact with the technological process because there is duplication of functions of display of information and input of control procedures by the devices to control the units and for coordination. In this case, there could only be partial worsening of the quality of operator performance due to worsening of working conditions, and in the case of automated control this does not have an appreciable effect on the quality of running the technological process.

In the event of failure of one of the sensors of technological parameters and retention of efficiency of other elements of the ACU TP, while this transformer is being repaired the operator implements remote control of the corresponding actuating mechanism, providing for regulation of the technological parameter measured by the transformer that failed. Information about this parameter is read from a local measuring instrument. If this parameter is part of the conditions for changing operations, the transfer of the device to the new operation is effected by the operator with the logical program control unit in a semiautomatic mode.

If the monitoring and control unit fails, logical programmed control is effected in the semiautomatic mode. Monitoring of the readings of technological parameters is effected by means of the spare display unit on the basis of a multichannel, secondary measuring instrument.

If the logical program control unit fails, the operator effects control with shut-off actuating mechanisms by means of the remote control unit. Failure of the regulating channel is also compensated by remote control of regulatory actuating mechanisms.

The above principles of structural organization were implemented in the hardware for control of groups of units that operate periodically in the fermentation departments under the name of Biocycle, which is the basis of the hardware for the ASU TP for biosynthesis of microbiological and chemicopharmaceutical products. Experimental production testing of this complex on a 63 cubic meter fermenter confirmed the efficiency of its operation. Analysis of the results of industrial operation thereof for 1 year revealed that the time spent on preparatory and finalizing operations was reduced by a mean of 67%, overall duration of the cycle of fermenter operation decreased by 14% and activity of the product increased by 5-10%. Operation of this complex also demonstrated its high reliability, as well as adequate reliability of the remote-controlled shut-off and regulating fitting.

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BIOTECHNOLOGY

UDC 62-50:531.3

BIOMECHANICS OF HUMAN VISUAL APPARATUS

Moscow IZVESTIYA AKADEMII NAUK SSSR: TEKHNICHESKAYA KIBERNETIKA in Russian No 3, May-Jun 81 (manuscript received 30 Jan 80) pp 56-62

[Article by Ye. V. Aleksandrovich]

[Text] This work uses the methods of human mechanics [1] to study certain eye movements in the visual process. The study was brought to computation of the efforts made by the eye muscles in the framework of the adopted model.

We will model a system consisting of a head and two eyeballs with the help of three solid bodies, and we will assume that the eyeballs have a spherical shape (fig 1). We will consider that the head has a fixed center of rotation A_1 or one which is moving in an assigned manner in relation to the system of fixed axes Ox_i. Points A_2 and A_3 which are located in the geometric centers of the eyeballs are fixed centers of eye rotation in relation to the head. If D is a point which can be fixed by the eyes, then A_2D and A_3D are called visual axes of the left and right eyes respectively.

We will designate through ζ_{2k}^0 and ζ_{3k}^0 the coordinates of points A_2 and A_3 in relation to the system of axes $A_1\zeta_{1i}$ associated with the head. We assume that $x_{A1i}=b_i(t)$, in particular, it may be that b_i=const. Then the equations of contact of the examined system of bodies are written as follows:

$$x_{A1i}=b_i,\quad x_{A2i}=b_i+a_{1ki}\zeta_{2k}^0,\quad x_{A3i}=b_i+a_{1ki}\zeta_{3k}^0,\qquad (1)$$

where a_{1ki}--matrix of orthogonal transform consisting of guide cosines of the axes $A_1\zeta_{1i}$. Here a_{1ki}--constants if the head is at rest or moves progressively, while they are assigned functions of time if the head makes an assigned rotating movement.

As the reference coordinates ξ^p (p=1,2,...,18) we will select the coordinates $x_{A\mu i}$ (μ,i=1,2,3) of the rotation centers A_μ and Euler's angles $\phi_{\mu i}$ of each of the bodies in the system, and as the generalized coordinates η^λ (λ=1,2,...,9) we will select Euler's angles $\psi_{\mu i}$. Then the contact equations (1) can be rewritten in the following compact form:

$$\xi^p=\xi^p(\eta^\lambda, t).\qquad (2)$$

The motion equations of the system of three free bodies are written in the form

$$(m\ddot{x}_{Ai})_\mu + (G_{ik}\ddot{\psi}_k)_\mu + \left(\frac{\partial G_{ik}}{\partial \psi_l}\dot{\psi}_k\dot{\psi}_l\right)_\mu = F_{x\mu i},$$

$$(G_{ki}\ddot{x}_{Ak})_\mu + (J_{ki}\ddot{\psi}_k)_\mu + \left[\left(\frac{\partial G_{ki}}{\partial \psi_l} - \frac{\partial G_{kl}}{\partial \psi_i}\right)\dot{x}_{Ak}\dot{\psi}_l\right]_\mu + \tag{3}$$

$$+\left[\left(\frac{\partial J_{ki}}{\partial \psi_l} - \frac{1}{2}\frac{\partial J_{kl}}{\partial \psi_i}\right)\dot{\psi}_k\dot{\psi}_l\right]_\mu = M_{\mu i}{}^*.$$

With each fixed value of the index μ, equations (3) are Lagrangian equations of the second order of movement of a free solid body with number μ. Here m_μ is the weight of a body with number μ, while $F_{x\mu i}$ and $M_{\mu i}{}^*$ are the main vector and th main moment of the assigned forces which are acting on the body with number μ. It

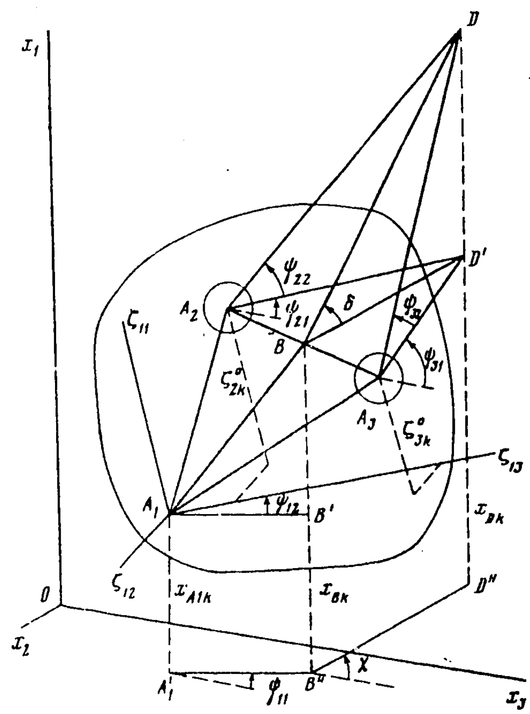

Figure 1.

is easy to show that $J_{\mu ik} = J_{\mu ki}$. The elements of the objects $G_{\mu ik}$ and $J_{\mu ik}$ depend on the geometry and distribution of masses of the examined system of bodies and are easily computed. It is easy to see that the system (3) can be written in a compact form

$$b_{pq}\ddot{\xi}^q+B_{p,\,qr}\dot{\xi}^q\dot{\xi}^r=X_p \quad (p,q,r=1,2,\ldots,18).$$

The motion equations of the linked system of solid bodies of the structure described above in the reference coordinates ξ^p will be

$$b_{pq}\ddot{\xi}^q+B_{p,\,qr}\dot{\xi}^q\dot{\xi}^r=X_p+Z_p, \tag{4}$$

where Z_p designates the forces $R_{x\mu i}$ and the moments $L_{\mu i}{}^*$ of the reaction forces. The reaction forces act on each of the bodies in the system at the sites of their connection with other bodies, i.e., at points A_μ. Since all the moments in the motion equations must be computed in relation to the corresponding points A_μ, the moments of the reaction forces $L_{\mu i}{}^*$, thus computed, will equal zero.

We now assume that the examined system of solid bodies makes a movement in accordance with the program

$$f_\sigma(\eta^\lambda, t)=0 \quad (\lambda=1,2,\ldots,9;\ \sigma=1,2,\ldots,S). \tag{5}$$

These equations can be viewed as additional bonds placed on the system. They are called control bonds. Then additive control forces $P_{x\mu i}$ and moments $N_{\mu i}{}^*$ are introduced into equations (4). They are designated together through S_p. Therefore we have

$$b_{pq}\ddot{\xi}^q+B_{p,\,qr}\dot{\xi}^q\dot{\xi}^r=X_p+Z_p+S_p. \tag{6}$$

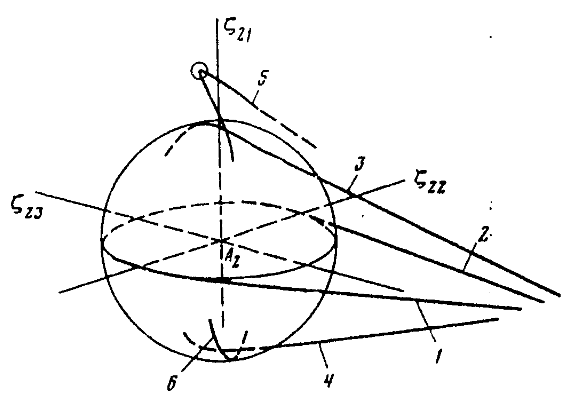

Figure 2.

The equations of the programmed movement of the examined system of solid bodies in the generalized coordinates are obtained by the convolution method [2]. We multiply (6) by $\partial\xi^p/\partial\eta^\lambda$ with convolution according to the index p, and we use the axiom of the ideal bond. We obtain

$$b_{pq}\frac{\partial\xi^p}{\partial\eta^\lambda}\ddot{\xi}^q+B_{p,qr}\frac{\partial\xi^p}{\partial\eta^\lambda}\dot{\xi}^q\dot{\xi}^r=\frac{\partial\xi^p}{\partial\eta^\lambda}X_p+\frac{\partial\xi^p}{\partial\eta^\lambda}S_p.$$

As a result of replacing the variables in the case of reonome bonds (2) we obtain equations of programmed movement of the system in generalized coordinates in the following form

$$c_{\lambda\sigma}\ddot{\eta}^\sigma+C_{\lambda,\sigma\rho}\dot{\eta}^\sigma\dot{\eta}^\rho+C_{\lambda,\sigma}\dot{\eta}^\sigma+C_\lambda=Y_\lambda+\Pi_\lambda, \qquad (7)$$

where, in particular, $\Pi_\lambda=S_p\partial\xi^p/\partial\eta^\lambda$. With b_i=const (fixed head) equations (7) will look like

$$c_{\lambda\sigma}\ddot{\eta}^\sigma+C_{\lambda,\sigma\rho}\dot{\eta}^\sigma\dot{\eta}^\rho=Y_\lambda+\Pi_\lambda. \qquad (8)$$

These equations are given in the simplest case in [3]. If program (5) is complete, then it can be used to determine the programmed law of movement, i.e., the relationships $\eta^\lambda=\eta^\lambda(t)$, and from equations (7) or (8) we immediately find the generalized control forces $\Pi_\lambda=\Pi_\lambda(t)$.

In modeling, the head was considered fixed. With this condition, it is sufficient to view movement only of one, for definiteness the left, eye. The motion equations of the left eye in the reference coordinates are obtained after asssuming in (3) that μ=2 and $\dot{x}_{A2i}=\ddot{x}_{A2i}=0$. It is easy to show that in this case, the last three equations (3) will be equations of natural eye motion in generalized coordinates. Consequently, the equations of programmed motion of the left eye in generalized coordinates will look like

$$J_{2ik}\ddot{\psi}_{2k}+\left(\frac{\partial J_{2ik}}{\partial\psi_{2l}}-\frac{1}{2}\frac{\partial J_{2kl}}{\partial\psi_{2i}}\right)\dot{\psi}_{2k}\dot{\psi}_{2l}=M_{2i}^*+N_{2i}^*, \qquad (9)$$

where $N_{2i}^*=\varphi_{ki}N_{Ak}$. Here N_{Ak}--components of the main control moment according to the axes of the system associated with the left eye, ϕ_{ki}--certain matrix whose elements are known. With complete program, we immediately find from (9) $N_{2i}^*=N_{2i}^*(t)$ and this means that $N_{Ak}=N_{Ak}(t)$.

The eyeball is moved by six muscles. The areas of attachment of the muscles on the eyeball have fairly significant dimensions. Therefore individual fibers of the same muscles do not at all have the same directions of action. However, a number of authors [4] consider it possible to replace the body of the muscle with a line of action of muscle stress, and this line passes approximately in the center of the corresponding muscle. Therefore in modeling, each muscle is replaced by a thin thread. The muscle stress is simulated by tension of the thread. The adopted model of the muscle apparatus is depicted in figure 2.

On the next figures, the curves which refer to the eye muscles are numbered as follows: 1--m. rectus lateralis; 2--m. rectus medialis; 3--m. rectus superior; 4--m. rectus inferior; 5--m. obliquus superior; 6--m. obliquus inferior.

In order to find the quantities of muscle stresses that we designate through Q_p (p=1,2,...,6), and $Q_p \geq 0$, it is necessary to express the components of the main control moment $N_{Ak}(t)$ through the quantities of muscle stresses. We have

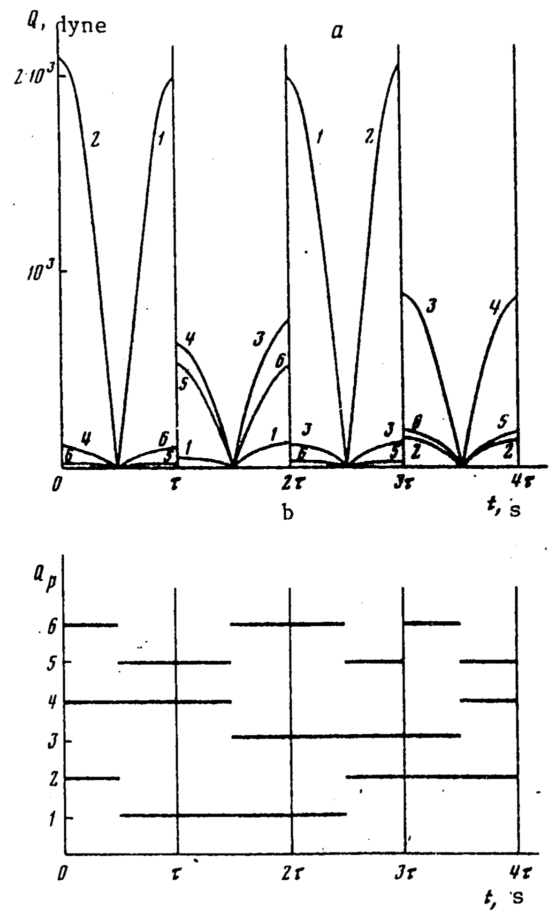

Figure 3.

$$N_{Ak}(t) = h_{pk} Q_p, \quad (k=1, 2, 3; \; p=1, 2, \ldots, 6). \qquad (10)$$

where each of the coefficients h_{pk} depends on the coordinates of the contact point between the muscle with number p and the eyeball , and the guide cosines of force acting on the eyeball from the side of the muscle with number p. All the quantities are assigned in the system of coordinates linked to the left eye.

Equations (10) are a system of three linear equations in relation to six unknown quantities Q_p. Thus, the laws of mechanics result in a smaller number of equations than there are unknown muscle stresses. The muscle apparatus of the eye is superfluous from the viewpoint of dynamics. Therefore additional hypotheses are necessary to determine the forces of all six eye muscles.

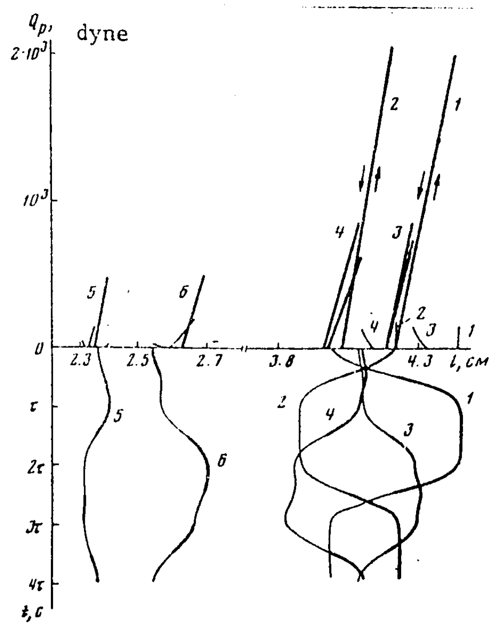

Figure 4.

As the simplest, but not the only possible hypothesis, it was assumed in the modeling that at each moment in time, only three of the six eye muscles are working, and for the remaining three muscles we have $Q_p=0$. As another, more complicated hypothesis, we can assume that certain correlations exist between six Q_p. In this hypothesis, all six muscles will always be working. The final selection of the most probable hypothesis must be made in accordance with the experiment. Unfortunately, these experiments have not yet been set up. Mathematical modeling in any case does not represent difficulties, however, the results presented in this work refer to the indicated simplest hypothesis.

We will examine eye movement in by-passing a certain rectangle with apexes 1-4. The beginning of the fixed system of coordinates Ox_i is placed in the geometric center of the left eye. Points 1-4 have the following coordinates in centimeters: 1--(10, -20, 100), 2--(10, 20, 100), 3--(-10, 20, 100), 4--(-10, -20, 100). The program of motion between each two points was adopted in the form

$$\begin{aligned} s &= s_н + \frac{1}{2}(s_к - s_н)\left[1 + \sin\frac{\pi}{\tau}\left(t - \frac{\tau}{2}\right)\right], \\ \chi &= \chi_н + \frac{1}{2}(\chi_к - \chi_н)\left[1 + \sin\frac{\pi}{\tau}\left(t - \frac{\tau}{2}\right)\right], \\ \delta &= \delta_н + \frac{1}{2}(\delta_к - \delta_н)\left[1 + \sin\frac{\pi}{\tau}\left(t - \frac{\tau}{2}\right)\right]. \end{aligned} \qquad (11)$$

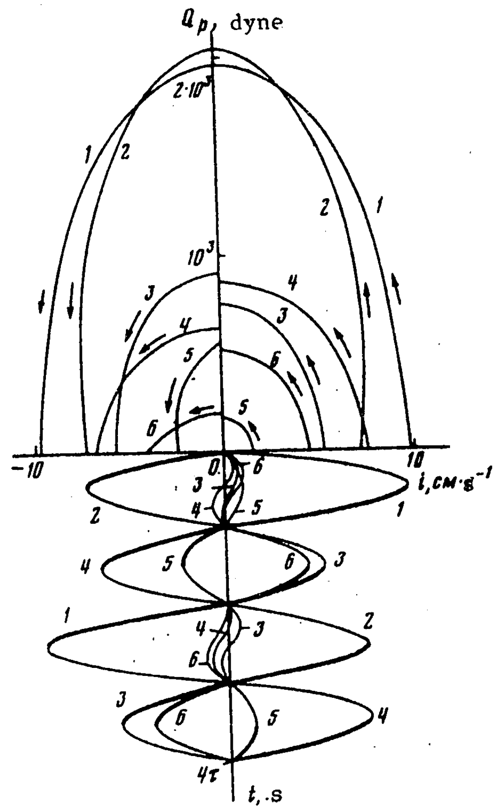

Figure 5.

Here s=BD (fig 1); $s_{\text{н}}, \chi_{\text{н}}, \delta_{\text{н}}$ and $s_{\text{к}}, \chi_{\text{к}}, \delta_{\text{к}}$ --starting and final values corresponding to the starting and final angular points of the trajectory. At the angular points, the six quantities $s_{\text{н}}, \chi_{\text{н}}, \delta_{\text{н}}, s_{\text{к}}, \chi_{\text{к}}, \delta_{\text{к}}$ were switched, and without stopping, motion on program (11) began with new parameters. It is known from experience [5] that in the examined case, the trajectory of the point of intersection of the visual axes of the eyes between the angular points of the contour is a straight line. This means that in all three equations (11), the quantity τ must be selected the same. The parameter τ was evaluated by empirical formula for duration of the jump presented in [5], and selected equal to 0.06 s.

The presented program is not the only one possible. This program was adopted because it is apparently closest of all to the experiment.

In computing the muscle stresses, the computer made a reselection of all 20 possible realizations of the generalized control moment with the help of three out of six muscles. Of these realizations, the permissible are considered those for which the efforts of all three muscles are non-negative. As a rule, on each section of motion, more than one triplet of muscles was obtained for which all the Q_p are not negative. Since it is still impossible to say precisely which of these triplets man uses to realize the actual motion, the presented graphs of muscle stresses refer to the triplets with minimum stresses. We note that the stresses of muscle triplets thus selected are less than the stresses of other triplets for which all $Q_p \geqslant 0$, as a rule, by one-two orders.

Figure 3,a shows the obtained dependencies of the muscle stresses on time. In the time interval from 0 to τ, the eye moves between points 1 and 2. In the time interval from τ to 2τ, the eye moves between points 2 and 3, etc. It should be noted that the presented relationships are a direct consequence of the adopted motion program. In another program, these relationships will be considerably different.

Figure 3,b shows the corresponding plan for switching the muscles. In this plan, the dark line designates the time intervals in which each of the six muscles is working, i.e., those time intervals where the corresponding Q_p is positive. It is apparent from this plan that at each moment in time, only one of each pair of muscles (pair of horizontal straight muscles, pair of vertical straight muscles, pair of oblique muscles) is working, i.e., each pair of muscles acts as a pair of "muscles-antagonists."

Figures 4 and 5 show the dependencies of the muscle stresses on the length and rate of contraction or elongation of the corresponding muscles. On the curves for the dependencies of length and rate of change in the muscle length on the time, the dark line isolates those time intervals where the corresponding muscle is working. It is apparent that the muscles can work both during contraction and during elongation.

We note that the results presented in this work agree well with analogous results obtained for purposeful movements of the human hand [6].

It is impossible tc assert that the eye muscles work precisely in the way shown on the graphs. These results should be viewed only as one of the actually possible methods of operation of the muscle apparatus. This indefiniteness is a consequence of the dynamic excessiveness of the muscle apparatus of the eye and the lack of experiments with stresses of the eye muscles.

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ENVIRONMENT

UDC 591.5

DISPERSION OF ANIMAL POPULATION DENSITY

Moscow DOKLADY AKADEMII NAUK SSSR in Russian Vol 259, No 3, 1981 pp 759-762

[Article by A. L. Borodin, A. N. Severtsov Institute of Evolutionary Morphology and Ecology of Animals, USSR Academy of Sciences, Moscow, presented by Academician V. Ye. Sokolov on 26 March 1981]

[Text] Distribution of animals in place and time is generally in groups. The mathematical model which corresponds to this case has been known for a long time [1]. However, ecologists gained possession of a negative binomial distribution comparatively recently [2, 3]. It has the following dispersion

$$s^2 = \bar{x} + \bar{x}^2/k \qquad (1)$$

where

$$k = \bar{x}^2/s^2 - \bar{x} .$$

Here s^2 and $\bar{x}$ are the dispersion and sampling mean respectively, k is the parameter of distribution which depends on their density and the size of the calculated unit [4,5].

Exceeding by the dispersion of the average ($s^2 > \bar{x}$) is a characteristic feature of aggregate nonrandom distribution. The accuracy of the sampling studies with this distribution is extremely low. This precisely determined the development [6] of a method to optimize the size of the calculated unit. Its author convincingly proved that a small sample in the situation where $s^2 > \bar{x}$ is always more effective than a large, although the sampling from them is of a somewhat greater volume. With random (Poisson) distribution, the samples of different sizes are the same in effectiveness. Studies [7,8] have confirmed this fact.

The presented method [6] for optimizing the size of the calculated unit is equivalent to the calculations from formula (2) with the same plan for setting up the ecological experiment (a number of standard samples are set which are divided into small samples; for each size of sample, s^2, $\bar{x}$ and k are computed)

$$s^2_{m,\ ha} = a^2 s^2_{np}, \qquad (2)$$

where a--constant showing how many times the small sample fits into the standard (m^2, ha), while s^2_{np} is the dispersion of this sample.

Conversion of the dispersion by (2) into a standard sample using estimates of small samples yields strong positive systematic displacement of s^2. This displacement occurs because of the significantly curvilinear bond [7, 9-11] between s^2 and $\bar{x}$, and results in a solution with the inevitable conclusion that for equal accuracy of computation of the small samples, one should use more than of large samples.

Resolution of the problem of evaluating dispersion for large samples based on small ones was so tempting that a number of studies appeared [12-14] which attempted to derive a common formula for its change with a change in the size m of the unit of calculation ($s^2 = am^g$, $g > 0$). From a theoretical viewpoint, this formula is not without reproach [15] since with an increase in the sample size m, the dispersion also rises without limit.

However, this conversion is possible [9] if a careful study is made of the tendency to change in the dispersion of animal population density in samples of successively larger size whose limit is the standard (m^2, ha). The existence of aggregations in animals reveals the fact (fig 1) that points noticeably deviate from the straight line $s^2 = \bar{x}$ which is typical for Poisson's distribution, and are arranged around the parabola $s^2 = \bar{x} + \bar{x}^2/k$ corresponding to the negative binomial distribution. This also explains the exceeding of $s^2 > \bar{x}$.

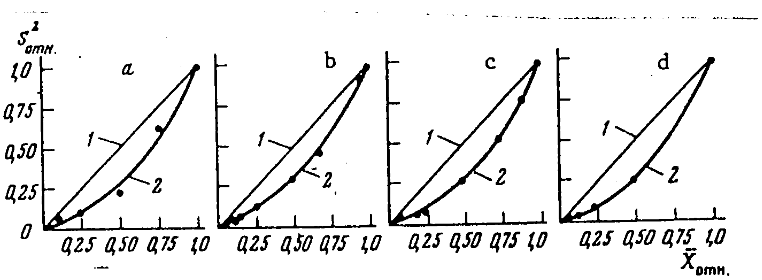

Figure 1. Link between Dispersion (s^2) and Average ($\bar{x}$) in Populations

Key:
a. fox (Vulpes vulpes)
b. small ground squirrel (Citellus pygmaeus)
c. red pine saw fly (Neodiprion sertifer)
d. ground beetle (Calatus melanocephalus)
1. random (Poisson) distribution $s^2 = \bar{x}$
2. negative binomial (nonrandom) distribution with dispersion $s^2_{ct} = a^2\bar{x}^2_{np}(\frac{1}{k} + \frac{1}{a\bar{x}_{np}})$. Here for comparison of the populations of different animals, s^2 and $\bar{x}$ are presented for a single scale and are given in the figure in fractions of a unit.

Formula (1) has little information for the ecologist, therefore it is expedient to study it in terms of an optimal (small) sample. Dispersion of the sample equals $s^2 = \bar{x} + \bar{x}^2/k$, and its area (u) is a times (const) smaller than the standard so that a = 1/u and u = 1/a. Then $s^2_{np} = 1/k(u\bar{x}_m 2)^2 + u\bar{x}_m 2$. We will remove u^2 from the parentheses and we have

$$s^2_{np} = u^2\left(\frac{1}{k}\,\bar{x}^2_{m^2} + \frac{\bar{x}_{m^2}}{u}\right).$$

We will add and will subtract $\bar{x}_{m^2}$ in the parentheses of the last equation

$$s^2_{np} = u^2\left(\frac{1}{k}\,\bar{x}^2_{m^2} + \bar{x}_{m^2} + \frac{\bar{x}_{m^2}}{u} - \bar{x}_{m^2}\right).$$

The first two terms in the parentheses are $s^2_{m^2}$, and expanding them, we obtain

$$s^2_{np} = u^2 s^2_{m^2} + u\bar{x}_{m^2} - u^2\bar{x}_{m^2}.$$

Now we replace u by 1/a

$$s^2_{np} = \frac{1}{a^2}\,s^2_{m^2} + \frac{1}{a}\,\bar{x}_{m^2} - \frac{1}{a^2}\,\bar{x}_{m^2}.$$

Freeing ourselves from the fraction by multiplying by a^2, and transferring $s^2_{m^2}$ to the left side, we obtain

$$s^2_{m^2} = a^2 s^2_{np} - a\,\bar{x}_{m^2} + \bar{x}_{m^2},$$

but

$$\bar{x}_{m^2} = a\bar{x}_{np}.$$

After substitution and simple procedures of transforming the latter equality, we finally have

$$s^2_{m^2,ha} = a^2(s^2_{np} - \bar{x}_{np}) + a\bar{x}_{np}. \quad (3)$$

Equation (3) is the optimizing calculation of the formula which permits direct conversion using s^2_{np}, $\bar{x}_{np}$ and k of the sampling of the estimate of dispersion (s^2_{np}) from a small sample into successively larger ones, or immediately into the standard. Estimates of dispersion from the sampling and those computed from formula (3) practically coincide (the Kokren test did not show significant differences). The conclusion is exceptionally important for practice, since a real possibility is afforded for calculation by small samples in a quantity that is approximately equal to the large (m^2, ha). In this case, the area of examination is significantly reduced (10-16-fold) as previously reported [9].

In formula (3), the term $a^2(s^2_{np} - \bar{x}_{np})$ is the component of dispersion which evaluates the conditions (temperature, degree of illumination, humidity, properties of soil, macro and microrelief, etc.) of small sections. In these sections, groupings of animals of varying density are observed. Whereupon, s^2_{np} minus $\bar{x}_{np}$, random (Poisson) distribution, represents the dispersion of the negative binomial distribution. The second term in (3) $a\bar{x}_{np}$ is random (Poisson) distribution of groups of animals on a large, ecologically uniform section of space (forest, field with different crops, etc.).

It is impossible to evaluate directly from formula (3) the percentage contribution to the total variation which is made separately by the random (Poisson) and negative binomial (nonrandom) distribution. However, this separation of the distributions can be obtained by transforming the formulas for parameter k as follows. We have

$$k = \frac{\bar{x}^2}{s^2 - \bar{x}}.$$

After reduction to a common denominator, we obtain for a small sample

$$k(s^2 - \bar{x}) = \bar{x}^2 \text{ and } s^2 - \bar{x} = \bar{x}^2/k.$$

For a large standard sample, the latter equation is written as:

$$a^2(s^2_{np} - \bar{x}_{np}) = a^2\bar{x}^2_{np}/k.$$

Consequently, the right side of the equation has the same ecological interpretation as the first term in formula (3). This equation not only proves once more the correctness of formula (3), but also confirms the fact that if the distribution is approximately random, and this situation is encountered fairly often in samplings made of natural animal populations, then dispersion of an ecologically uniform section does not make a significant contribution to the general variation.

We will rewrite (3) as

$$s^2_{m^2,ha} = \frac{a^2\bar{x}^2_{np}}{k} + a\bar{x}_{np}.$$

After reduction to a common denominator, removing $a^2\bar{x}^2_{np}$ and k from the parentheses, we obtain a final version of the optimizing formula (4)

$$s^2_{m^2,ha} = a^2\bar{x}^2_{np}\left(\frac{1}{k} + \frac{1}{a\bar{x}_{np}}\right).$$

The obtained equation is equivalent to (3) and has the same ecological interpretation. However, (4) has a significant advantage over (3), since it permits separate computation of the percentage contribution to the general variation of the negative binomial (1/k) and the random ($1/a\bar{x}_p$) distribution. This percentage is immediately evaluated for the standard sample. All the discussions presented above are based on the hypothesis that k is constant. In actuality, k can change in fairly broad limits.

For the practical application of formulas (3) and (4), it is sufficient to know the mutual changes of s^2, $\bar{x}$ and k for a sample of any size which was made by the sampling. Then, by using the corrections given below for nonrandom distribution, and by having information of only one sampling, one can compute the dispersion evaluation from a sample of any small size for successively larger areas, or directly for the standard

Case 1.

$$s^2 \cong \bar{x},\ s^2 < \bar{x},\ \bar{x} < 1,\ k = 0,\ k \to \infty,$$

$$s^2_{ct} = a^2(s^2_{np} - \bar{x}_{np}) + a\bar{x}_{np}.$$

Case 2.

$$k < 0.5,$$

$$s^2_{ct} = [a^2(s^2_{np} - \bar{x}_{np}) + a\bar{x}_{np}]k.$$

Case 3.

$$0.5 < k < 1,$$

$$s^2_{ct} = [a^2(s^2_{np} - \bar{x}_{np}) + a\bar{x}_{np}]k^2.$$

Case 4.

$$1 < k < 3.0,$$

$$s^2_{ct} = \frac{[a^2(s^2_{np} - \bar{x}_{np}) + a\bar{x}_{np}]}{k}.$$

Case 5.

$$k > 3.0,$$

$$s^2_{ct} = a^2(s^2_{np} - \bar{x}_{np}) + a\bar{x}_{np}.$$

All the procedures listed for formula (3) are also correct for formula (4).

One should stress in particular that the described link between s^2 and $\bar{x}$ was established for animals that are distant both ecologically and taxonomically. Nevertheless, formulas (3) and (4) are suitable to optimize their calculation. These formulas have a sufficiently general nature, since they are based on strict mathematical theory [1-5] of random and negative binomial distribution.

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HUMAN FACTORS

UDC 612 "735" : 613.6

BIORHYTHMS AND WORK

Leningrad BIORITMY I TRUD in Russian 1980 (signed to press 1 Feb 80) pp 2-5, 142-143

[Annotation, foreword and table of contents from book "Biorhythms and Work", edited by A.D. Slonim, USSR Academy of Sciences, Izdatel'stvo "Nauka", 5,500 copies, 144 pages]

[Text] The book examines the features of rhythms, work actions and work capacity in man, along with changes in biorhythms in the work process, as part of the general study of biological rhythms and at the same time as a section on the physiology of work and ergonomics. A special chapter deals with methodology in the study of rhythms associated with work activity, and there is also an appendix in which some of the mathematical aspects of rhythms in work processes are described.

Foreword

Work activity is engaging the attention of physiologists as the basic form of active behavior in man. At the same time research on the physiology of work is of great applied significance. The condition of the working man and the features of his work activity must be taken into account in all measures implemented to make production healthier and more efficient. Physiological findings are used extensively in ergonomics, the organization of labor, and labor hygiene and safety.

Among the large amount of information of this kind, the links between biological rhythms in man and his work activity occupy an important place. Work alters the rhythms of many physiological processes. Therefore, information on biorhythms is now considered in the resolution of the most varied problems in the field of labor organization and education and general behavior in man. This interest has undoubtedly been aroused by the great successes and rapid development rates in the study of biological rhythms during the latter half of this century. Biological rhythms are now of interest to broad circles of researchers as a promising subject and as important aspect of scientific research.

The links between biological rhythms and work activity are of considerable interest in theoretical research on human physiology. Work is for people a most important exogenous factor influencing the formation and restructuring of rhythms in the various physiological processes. In addition to restructuring and synchronization, under the influence of work, impairment of many rhythms is also possible; this is sometimes transient and insignificant and in some cases prolonged and seriously affecting the health.

The nature and conditions of work constitute a powerful factor influencing man's condition and his health and development. These influences affect the broad range of rhythms from the high-frequency rhythms in the electrical activity in muscles and the brain to the circadian, and even monthly and annual rhythms in the activity of the entire body. Rhythms changes are frequently early, and sometimes the first sign of the effect of work on a person. At the same time, periodicity is observed in the work activity itself. The duration and other parameters of isolated work actions and human work capacity do not remain constant in the same work process but are all the time varying, and it is in these variations that the periodic component--the work rhythm--is seen. Special interest is being evinced by the links between the rhythms of random work actions and the changes they cause in the rhythms of the various processes in the body of the working operator.

Information on biological rhythms is essential for substantiating decisions on many questions of production practice. The study of the various biological rhythms is opening up prospects for evaluating both the effect of work on man and the effect of the entire aggregate of factors in the way of life--work, everyday activities and leisure. A consideration of the biorhythms reveals important features in human behavior in production, namely its effect in the man-machine-production medium system. Determination of the rhythms in work actions is becoming a special task in the optimization of work that takes place in conditions in which an external rhythm is imposed by technological processes such as conveyer lines and semiautomatic technical devices. Planning of the regime of work and rest is associated with a consideration of the periodic variations in human work capacity. The organization of shift work and night work is determined from information on circadian variations in the condition of working people. Although it is still attracting less attention, the significance of low-frequency rhythms with periods measured in days, weeks and months is considerable. Such rhythms have significance, for example, for planning days off and holidays, especially when it is not possible to observe a standard duration for the working week or to organize regular days off because of the production conditons prevailing.

The progression of rhythms in arbitrary work actions and changes in the high-frequency physiological processes are of significance as indicators that characterize the level of functional work stress and the degree of fatigue in an operator. The term stress is used to describe the entire aggregate of changes in an operator's condition caused by work activity. Like work capacity, work stress as characterized by the features in the progression of and changes in high-frequency rhythms varies depending on the phases of the slow rhythms, on the time of day and to some degree or other on the day of the working week and lunar and seasonal rhythms.

The fact that a link exists between biological rhythms and human work activity has been known for a long time. During the last decades a systematic study has been initiated on these problems, particularly the question of the role of the circadian rhythm as a factor to be considered in the organization of labor. Generalizations of research work have been published on circadian rhythm and its connection with work both specifically on the physiological plane and in the field of ergonomic applications for physiological information. The start made on the study of biorhythms in aviation and space physiology and medicine was a significant step in development along this avenue. Changes in high-frequency rhythms and in various processes when affected by work activity and in laboratory modeling of various kinds of work are now being studied quite extensively. It is therefore fitting at this time to review the links between work activity and the entire spectrum of biological rhythms found in man. In terms of spatial ideas, the spectrum of biological rhythms is a single whole, a complex subsystem in the total system that regulates physiological processes in the body. This provides grounds for thinking that a review of information on biological rhythms in working people can be both of theoretical interest and useful in production practice.

The brevity of this book has induced us to present only the most important findings on the problem. Various biological rhythms are examined as they apply to problems of labor organization: the rhythms of random work activity, the high-frequency rhythms in the electrical activity of the brain and heart, circadian rhythm, and finally, low-frequency rhythms. The material is divided into chapters on the basis of the existing classification of rhythms according to frequency (duration of period). The presentation of all findings is prefaced by some of the theoretical considerations and a summary of the main requirements of the methodology in research on biorhythms in the study of work activity in man. Taking into account the significance of mathematical methods for processing results from biorhythm research, some questions of the substantiation and selection of such methods are reviewed in an appendix.

Because of the small size of the book it has been necessary to omit a review of the role of biorhythms in aviation and space physiology and medicine. There was no intention of merely mentioning these questions in a cursory manner but no space was available for a detailed presentation. The published sources on the problem have not been fully examined. Wherever possible the authors have tried to use Soviet sources and have also referred to reviews and summaries instead of their own experimental research. Nevertheless, all illustrative material has been presented with references to the original work. The main aim in presenting all the information selected has been to examine it in terms of ergonomics with a view to using it in the organization and improvement of labor. The individual chapters and sections of chapters have been compiled by different people. Authors' names are given in the table of contents. The collective of authors recognizes the imperfections in the work presented and will be glad of criticism.

Contents

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PHYSIOLOGY

UDC 613.693

EFFECT OF HYPERBARIC MEDIUM ON MAN AND ANIMALS

Moscow PROBLEMY KOSMICHESKOY BIOLOGII, TOM 39: DEYSTVIYE GIPERBARICHESKOY SREDY NA ORGANIZM CHELOVEKA I ZHIVOTNYKH in Russian Vol 39, 1980 (signed to press 24 Oct 80) pp 4-7, 254-259

[Annotation, foreword, conclusion and table of contents from book "Problems of Space Biology Vol 39: The Effect of a Hyperbaric Medium on Man and Animals", edited by academician V.N. Chernigovskiy, Izdatel'stvo "Nauka", 900 copies, 260 pages]

[Text] The book contains results from research on basic problems in underwater biology and medicine. Special attention is given to questions of tissue saturation and desaturation by inert gases in changes in atmospheric pressure and the composition of the gaseous medium, the function of respiration in a dense medium, the toxic effect of elevated oxygen pressure, the effect of inert gases on the nervous system in hyperbaric conditions, and heat exchange in humans underwater in elevated pressure. The authors have not set themselves the task of discussion these questions comprehensively.

The book may be of interest to a broad range of biologists, physicians and specialists in the field of underwater and space medicine.

Foreword

A new field in the natural sciences has now been firmly established; it is underwater biology and medicine, which studies the functional status of the bodies of man and animals when acted upon by the complex of adverse factors arising under load in water. The goal of this research is to find protective methods that make it possible for man not only to work successfully under conditions of high pressure but also fully to maintain his health.

Underwater biology and medicine came into being on the basis of classic physiology during the second half of the 19th century when man began to engage in a special type of work activity, namely work under pressure in caissons and underwater.

Under conditions of raised atmospheric pressure a range of factors affects the body and these had not been encountered before in human evolution: high hydrostatic pressure, elevated partial pressure for oxygen and other gases in the medium being breathed and increased density of the gases in the respiratory mixture.

The most complete information on this was first presented in Paul Bert's classic work "La pression barometrique" (1878). Human physiology was enriched with new data on the toxic effect of oxygen, the processes of tissue saturation and desaturation of body tissues with inert gases in changes in atmospheric pressure, and impaired bodily functions during and after decompression. Hyperbaric physiology was subsequently supplemented with the ideas on the narcotic effect of inert gases (nitrogen, argon, neon, krypton), the specific effect of helium, the safe limits for the use of nitrogen and helium under pressure, and the possibility of man's adaptation to the prolonged effect of a hyperbaric medium.

The possibility of mastering the world's oceans depends on the successes of underwater biology and medicine. The growing interest in hyperbaric physiology is also connected with the development of new therapeutic methods, as for example oxygen barotherapy, and man's possible flight to the planets of the solar system, such as Venus where the atmospheric pressure on the planet's surface is about 96 kg/cm2.

The most complex biological problems now impeding man's descent to great depths are those of overcoming impairments in the respiratory function and the neurologic disorders occurring when the air pressure is raised to more than 6 kg/cm2, that is, at depths greater than 60 meters. At these depths, when divers breathe air the condition of nitrogen narcosis occurs; this is characterized by lowered work capacity, drowsiness, hallucinations and loss of temporal and spatial orientation. Most researchers consider that the main cause of this condition is the specific effect of increased partial nitrogen pressure; however, it has also been shown that there is a potential effect from increased oxygen and carbon dioxide pressure and the general cooling of the body on the initiation of nitrogen narcosis. One of the main factors promoting the buildup of carbon dioxide in the body and the increased cooling properties of gases under hyperbaric conditions is the increased density of the gases, which affects gas diffusion in the lungs and heat exchange.

When the breathing mixture contains a less dense gas--helium--instead of nitrogen, it is possible to eliminate the phenomenon of nitrogen narcosis, and thanks to this, to increase the depth considerably. However, if submersion is too rapid, at depths of 300-350 meters neurologic disorders occur that are different from the condition of nitrogen narcosis. These neural disorders are characterized by a set of symptoms that indicate increased excitability in the various structures of the central nervous system (tremor, hyperkinesia and so forth). The occurrence of a condition of increased excitability under hyperbaric conditions while breathing helium-oxygen mixtures is now known as high-pressure nervous syndrome [HPNS]. Possible reasons suggested for this condition include the pressure itself, the effect of helium under pressure, thermal stress, and the buildup of carbon dioxide in body tissues under conditions of the increased density of the breathing mixture. On the basis of studies of HPNS several researchers have concluded that the maximum depth to which man can descend when using a mixture containing helium is 300 meters, similar to the way in which the maximum depth is 60 meters when a breathing mixture containing nitrogen is used. However, it appears that it is possible to create conditions that eliminate the adverse effects of high pressure. Thus, it is possible that HPNS can be overcome in man and animals at depths greater than 300 meters.

In this book the findings are presented from research done by the authors themselves to study the effect of high pressure breathing mixtures on the body of man and animals. In the discussion of research material, it is mainly the findings of foreign researchers that are used.

The collective of authors expresses its heartfelt gratitude to USSR Academy of Sciences academician V.N. Chernigovskiy, USSR Academy of Sciences academician Ye.M. Kreps, professor I.A. Sapov, professor G.L. Zal'tsman, professor A.G. Zhironkin, professor V.B. Malkin, professor V.S. Farfel' (deceased), doctor of medical sciences I.S. Breslav, candidate of medical sciences Z.S. Gusinskiy, candidate of biological sciences G.A. Kuchuk, and candidate of medical sciences A.I. Selivra for their useful comments and help in the preparation of this book.

Conclusion.

During the past century it has been possible to increase from 10-30 meters to 501 meters the depth to which man can descend, and to increase the duration of the stay underwater from several minutes to a month. This has become possible thanks to the work of Paul Bert on the toxic effect of oxygen and the causes of decompression sickness; the research of John Haldane on the processes of saturation and desaturation of body tissues with inert gases in hyperbaric conditions and the causes of decompression; the work of collectives headed by L.A. Orbeli in the USSR and Albert Behnke in the United States on the specific action of nitrogen, helium and other inert gases under conditions of increased atmospheric pressure; and the research conducted during the last 25 years in the USSR and abroad that has shown that it is possible for man to remain for long periods under conditions of high pressure.

Despite the successes that have been achieved, the "physiological barriers" that prevent man from descending to great depths still exist. Of these barriers, the most significant is the set of symptoms known as high-pressure nervous syndrome [HPNS]. To prevent HPNS when they were making their record descent to 610 meters the French research workers from COMEX had to lower the divers very slowly so that total compression time was 264 hours. Reducing the rate of compression during descents to great depths is now the most extensively used method for preventing the development of HPNS at depths greater than 200 meters. However, in the search for new methods of preventing HPNS research is also being conducted along other avenues. For example, a considerable reduction in the compression period for divers going to a depth of 475 meters was obtained without marked signs of HPNS by the use of breathing mixtures made up of antagonist components, namely helium and nitrogen in the ratio of 10:1. Of late, much attention has been given to the prevention and treatment of HPNS with the use of drugs. Using gas anatagonists and drugs it has been possible for higher animals (primates) to descend to depths down to 1,000 meters without marked signs of HPNS. In recent years at the Department of Underwater Medicine at the USSR Ministry of Health Scientific Research Institute of Water Transport Hygiene successful neurophysiological research has been conducted with the aim of detecting the early signs of HPNS with the aid of a rapid diagnostic system for determining the conditions of animals at various rates of compression and, in the future, of controlling the parameters for hyperbaric chambers on the basis of these data. Many researchers have suggested that a major role in solving the problems of overcoming HPNS will be played by

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the selection and training of people who are most resistant to the effects of hyperbaric conditions. Studies on the mechanisms involved in the development of HPNS and on ways of preventing it are now advancing so rapidly that most specialists working in this field think that the problem can be solved in the next 5 to 10 years. If the problem of HPNS is solved, real opportunities will become available for humans to make descents to great depths using gas mixtures containing helium as a breathing mixture. Until recently this kind of prediction was not possible because of the lack of convincing experimental data on the possibility of humans overcoming another "physiological barrier"--the high density of the gas mixture. As shown earlier in the book, until recently it was supposed that the function of respiration in man both at rest and particularly under physical stress with an increase in the density of the gaseous medium by a factor or more than 10--the sort of density found at a depth of 100 meters--could not insure adequate gas exchange, while the density of helium-oxygen mixtures was likewise inadequate at a depth of 600 meters. On the basis of data on the physical patterns involved in the diffusion of gases under conditions of increased density, and also on the basis of results from experimental studies, a theory has been formulated, according to which hypoxic states under hyperbaric conditions are associated with inadequacy in the function of respiration. However, studies have been conducted in which when divers in a pressure chamber at 37 kg/cm^2 switched to breathing gas mixtures containing neon they showed no signs of hypoxia either at rest or during heavy muscular exercise. In these studies in which gas mixtures containing neon were breathed, the density of the medium was more than 28 times greater than normal density. Thus, the possibilities of the human respiratory system to successfully insure gas exchange when the density of the breathing mixture is the equivalent of breathing a helium-oxygen mixture at a depth of 1,500 meters have been modeled. The problem of overcoming the toxic effect of oxygen in hyperbaric conditiions still remains important and complex. Increased oxygen content in breathing mixtures for divers and caisson workers was first used by P. Bert. He used hyperoxic mixtures to prevent and treat decompression sickness occurring after work under high pressure. Later, the oxygen content in gas mixtures for divers was increased in order to reduce the amount of inert gases contained in them and reduce decompression periods. The safe limit was established for the use of high concentrations of oxygen under pressure for short periods. However, in deep and prolonged descents under hyperbaric conditions the adverse effect of the prolonged action on man of relatively small increases in oxygen concentrations in breathing mixtures, essential to maintain gas exchange in a high-density medium, became apparent. Whereas before an increased oxygen content of up to 0.35 kg/cm^2 was considered acceptable in a gas medium under hyperbaric conditions, and a content of 1 kg/cm^2 in a diving bell, it has now become clear that the oxygen content in a diver's breathing mixture should be as close as possible to the normal. It has been shown that as a result of hyperoxic effects in hyperbaric conditions, both at rest and particularly during muscular activity, hypercapnia and respiratory acidosis develop as a result of changes in the sensitivity of the respiratory center to the pH and the CO_2 in the hyperoxic medium at increased atmospheric pressure, together with blocking of the hemoglobin mechanism for the elimination of CO_2 and a drop in the efficiency of pulmonary circulation. Thus, one of the main questions that must be resolved is now to determine the lower limit of oxygen's toxic effect, particularly in prolonged action in the medium in increased atmospheric pressure. In this respect, in our view, one promising avenue of research is the study of the possibilities of the enzyme systems and the body's biological antioxidants.

Another physiological barrier preventing man's descent to great depths is insuring temperature homeostasis in the body under load in a barometric chamber, especially when divers exit into the surrounding water. It is now known that as pressure increases the zone of temperature comfort is increasingly constricted, approximating in magnitude the body temperature.

In order to create comfortable conditions at high pressure in a helium-oxygen medium is it necessary to raise the ambient temperature more than under normal conditions. Recent findings have shown the inadequacy of the heat-sensitive human in a hyperbaric medium relative to the actual thermal state of the body. Moreover, it is known that the zone of temperature comfort changes considerably under conditions of rest and work. It depends largely on the level of energy generation in a human, that is, on the nature of his activity. In this connection, as barometric pressure rises or depth increases the problem of evaluating the true thermal condition of the body and immediate regulation of the microclimate in diving bells becomes increasingly urgent.

Despite the more than one hundred years of study, the problem of decompression has still not been solved. It will evidently remain urgent while man dives under conditions in which breathing takes place under pressures corresponding to the depth of the dive. The first studies done on the possibility of breathing liquid mixtures were greeted with enthusiasm, but their realistic use by humans remains far off. In this connection, research aimed at reducing decompression periods after being under pressure and the early diagnosis, treatment and prevention of decompression sickness remains urgent. In the search for ways to reduce decompression periods, studies have been made of body tissue saturation and desaturation in hyperbaric conditions with the aim of working out regimes that move smoothly and close to the physiological curves. Great attention is being given to studies of the possibilities of reducing the decompression period by periodically switching the diver's respiration to different inert gases. Research aimed at developing equipment that makes it possible to monitor the course of the desaturation in individuals, with subsequent correction of the decompression conditions, is also urgent. The latter is also of great significance in the prevention and early treatment of decompression sickness.

Thus, summing up the results of available information on the functions of the human body and of animals under hyperbaric conditions, as found in the Soviet and foreign literature at this time, we may conclude that the possibilities for the body's biological systems to overcome the factors involved in hyperbaric conditions are far from exhausted.

Contents

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RADIATION BIOLOGY

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BIOCHEMICAL FUNDAMENTALS OF THE ACTION OF RADIATION PROTECTORS

Moscow BIOKHIMICHESKIYE OSNOVY DEYSTVIYA RADIOPROTEKTOROV in Russian 1980 (signed to press 3 Jul 80) pp 2-5, 167-168

[Annotation, list of adopted abbreviations, foreword and table of contents from book "Biochemical Fundamentals of the Action of Radiation Protectors," by Yevgeniy Fedorovich Romantsev, Vera Dmitriyevna Blokhina, Zoya Ivanovna Zhulanova, Nikolay Nikolayevich Koshcheyenko and Igor' Vladimirovich Filippovich, Atomizdat, 1190 copies, 168 pages]

[Text] This book covers an analysis of the mechanism for the action of radiation injury modifiers on a molecular level. It focuses a lot of attention on an examination of molecular interactions between radiation protectors, radio sensitizers and biologically important endogenous macromolecules. It develops an original concept regarding the complex biochemical mechanism for the action of radiation injury modifiers. It focuses especial attention on processes of temporary inhibition of replication processes and stimulation of the DNA reparation processes. It analyzes data on the importance of temporary formation of mixed disulfide bonds between the radiation protectors, aminothiols, and protein-enzymes that have a sulfhydryl group. The existing hypotheses on the mechanism of action for the radiation-protective resources are critically examined.

The book is designed for radiation biologists, biochemists, physicians and students of senior courses in biological VUZ's and medical institutes.

One table, 14 illustrations, 570 bibliographic entries.

List of Adopted Abbreviations

cAMP--cyclic adenosine-3' 5'-phosphate
APAETP--aminopropylaminoethyl thiophosphate (gammaphos)
ATP--adenosine-5'-triphosphate
AET--2-aminoethyl isothiouronium
BSA--bovine serum albumin
GTP--guanosine-5'-triphosphate
GED--guanidoethyl disulfide
dATP--desoxyadenosine triphosphate
dGTP--desoxyguanosine triphosphate
Diamide-bis-(N,N-dimethyl amide)--diazene dicarboxylic acid

DTNB--5,5'-dithiobis-(2-nitrobenzoic acid)
DNA--desoxyribonucleic acid
DTT--dithioerythrite
dCMP--desoxycytidine monophosphate
dCTP--desoxycytidine triphosphate
mRNA--messenger RNA
MPA--β-mercaptopropylamine
MEA--β-mercaptoethylamine
MEG--2-mercaptoethylguanidine
NADN--nicotinamide adenine dinucleotide
$NADPN_2$-nicotinamide adenine dinucleotide phosphate
OMP--orotidine monophosphate
PGPS--prostaglandin-like compounds
PPS--peroxide-like compounds
PCMB--η-chloromercury benzoate
RNA--ribonucleic acid
rRNA--ribosomal RNA
nRNA--nuclear RNA
TMP--thymidine monophosphate
TTP--thymidine triphosphate
UMP--uridine-5'-monophosphate

Foreword

The problem of changing the body's radiation sensitivity with the help of various chemical compounds, modifiers, continues to remain one of the most urgent and intensively worked-on in modern radiobiology.

The Soviet Union is concentrating a lot of attention on this problem. The first monograph which analyzes the state of the question of chemical protection of organisms from ionizing radiation was published by Ye. F. Romantsev and A. V. Savich in 1958. Since then, many books have appeared which cover aspects of the modification of radiation injuries using chemical compounds (Yu. B. Kudryashov, P. G. Zherebchenko, A. G. Sverdlov, N. N. Suvorov, V. S. Shashkov, S. P. Yarmonenko, L. Kh. Eydus, A. S. Mozzhukhin, F. Yu. Rachinskiy and others).

However, radiobiology is developing so intensively that there is an urgent need for periodic coverage of the achievements of this field of natural science in the form of generalizing works. This book presents the concept worked out by the authors on the complex biochemical mechanism for the action of modifiers of radiation injury and analyzes the state of the whole problem.

Study of the molecular mechanisms for the action of the radiation injury modifiers has fundamental importance for an understanding of the trigger effects of radiation. At the same time, interpretation of the molecular mechanisms for the radiation effect on the cell affords an opportunity for new approaches to search for effective radiation protectors and radiation sensitizers. In this respect, we consider it expedient to cover a number of basic sections of radiation biochemistry, concentrating attention in this case on the biochemical mechanisms for the interphase death of irradiated cells. Modifiers actively interfere practically in all biochemical processes that define the individual and species radiation sensitivity.

Therefore the appropriate chapters analyze data on the effect of radiation protectors and radiation sensitizers on DNA metabolism, biosynthesis of ribonucleic acids, processes of replication and reparation of DNA, protein synthesis in the animal body, and energy processes in the cell. It was acknowledged that it is necessary to briefly cover the state of the question regarding the possible role of cyclic adenosine monophosphate and prostaglandins in the mechanism of radiation protector action. A lot of attention is concentrated on analyzing molecular mechanisms for the manifestation of activity of radiation injury modifiers, questions of temporary inhibition of the replication processes and optimizing of the conditions of DNA reparation. The end of the book presents certain general laws governing the molecular mechanism for the effect of radiation injury modifiers and presents a chart of the individual stages of their biological activity.

It has happened historically that radiation protectors have been studied as compounds that are designed to protect eukaryotes from absolute minimum-lethal doses of ionizing radiation ("hemopoietic form" of radiation sickness). At the same time it is already clear that there is a basic possibility of protection from penetrating radiation in considerably large doses. This increases the interest in the modifying of radiation effects with the help of chemical compounds.

Modern molecular radiobiology and radiation biochemistry are developing very quickly. We therefore realize that by the time this book is published, new data will have appeared on the mechanism for action of the radiation injury modifiers.

The authors will be grateful to all readers for critical remarks.

Contents

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PSYCHOLOGY

PSYCHOMUSCULAR TRAINING--A METHOD OF MENTAL SELF-REGULATION

Moscow PSIKHOMYSHECHNAYA TRENIROVKA--METOD PSIKHICHESKOY SAMOREGULYATSII in Russian 1979 pp 1-28

[Book "Psychomuscular Training--a Method of Mental Self-Regulation", by Anatoliy Vasil'yevich Alekseyev, Tsentral'nyy ordena Lenina institut usovershenstvovaniya vrachey Ministerstva zdravookhraneniya SSSR, 3,000 copies, 28 pages]

[Text] Introduction

The intensity of the struggle at athletic competitions is rising continuously from year to year. It reaches its maximum in the most important competitions of our times--the Olympic Games. Experience has shown that the mental factor--the ability of the competitors to become and be the sort of people needed in the rivalry of sports is paramount to victory. The strength contained in autosuggestion can be of great assistance to athletes in setting their mind to fight without quarter and to give their all. There are many variants of this method of mental self-regulation today. Most of them were created for therapeutic purposes. It is only since the 1960's that we have started developing autosuggestion systems taking account of the unique features of athletic activity.

The 1970's are now drawing to a close. Sports today differ in many ways from the way they were 10-15 years ago. Thus new requirements are also imposed on the methods of mental self-regulation employed. They must be simpler, easy to assimilate, and highly effective.

Considering these requirements, a new technique of mental-self-regulation--"psychomuscular training" (PMT)--was devised in the course of 5 years of work with sportsmen.

About Mental Self-Regulation

Mental self-regulation (MSR) is defined as influence of the individual, upon himself, by means of words and by mental images corresponding to these words.

It is a commonly accepted fact that words and mental images corresponding to them are capable of a purposeful influence upon body functions: If, for example, one were to say (aloud or to one's self), "a juicy, sour slice of lemon" and think about this slice in one's mouth, saliva would begin to flow involuntarily--more copiously as the mental image of this lemon slice becomes clearer.

Using words and the mental images corresponding to them, we can also elicit many emotional reactions, for example fear or joy, and thus alter the activities of various systems, including respiratory and cardiovascular. We know that both in the presence of fear and in a moment of joy, breathing becomes deeper and the heart beat quickens.

It is universally recognized today that words may be associated, via conditioned reflexes, with many body functions, and that they are capable of having both a useful and a harmful influence upon them. Most methods of mental self-regulation are based on the positive influence speech has on the way an individual feels and acts.

When in the second half of the last century doctors became interested in the possibilities of mental self-regulation, it came into use mainly for therapeutic purposes. Many different MSR systems were proposed at that time and later on, but "autogenic training"--a method created by the German psychiatrist J. G. Schultz in the late 1920's and early 1930's--acquired the greatest popularity. Different variants of autogenic training are used today as well, mainly to normalize various functional disorders of the nervous system.

As we know, the last few decades have been distinguished by an ever-increasing flow of information, which is having an extremely tangible effect upon the nervous system of healthy people. Because of the difficulties of life, the mind finds itself rather often in a state of extreme stress, elicited by some stressful situations or others.

High loads are also imposed on the nervous systems and minds of modern athletes as well, especially ones who participate in top-level competitions. Statistics show that the number of persons with certain functional disorders (disharmonies) in the activities of the central and autonomic nervous systems is rising from Olympics to Olympics. Consequently the need has arisen for developing, specially for athletes, a system of mental hygienic and preventive measures by which to shield their nervous systems and minds from the traumatizing influence of stressful situations, which are so frequent in the "major leagues".

Among the methods by which athletes can shield their minds from harmful influences and set their minds to surmount the difficulties of competition, mental self-regulation should be in first place. Armed with its possibilities, the athlete would be able to help himself better than by any other means, considering that the situations in competitive struggle change so quickly. It is precisely with the assistance of MSR that the athlete can most effectively achieve the main goals of regulating his mental state, the ones most important to athletic activity:

1. Relaxing oneself, if mental overarousal occurs.

2. Mobilizing oneself to the required level of activity when it is insufficient for some reason or another.

3. Recovering strength by means of autosuggested sleep-rest, the time of which may be of any length--from a few seconds to several hours.

Thus MSR is the easiest and most convenient way to arrive at that optimum mental state at which all physical, technical, and tactical possibilities accumulated through training and from previous competitions are realized in the best fashion.

Practice has shown that in view of a large number of reasons, Schultz's classical variant of autogenic training is ill-suited to athletic activity. This is why other MSR methods are used in modern sports, many of them being unique modifications of autogenic training.

This training aid for athletes suggests an MSR method created in 1973-1975 (by physician-psychotherapist A. V. Alekseyev), one which has come to be called "psychomuscular training" (PMT). Creation of this method was dictated by the following need. As we know, the ages of athletes has decreased noticeably in recent years. Today, athletes begin preparing for many forms of serious competition as boys and girls 8-10 years old. They also experience certain nervous and mental disharmonies on occasion. It would be difficult for young athletes to use "adult" methods of mental self-regulation to combat these disharmonies--they would be too complex for them. This circumstance served as an impetus for creating a "children's" variant of mental self-regulation. Thus psychomuscular training came into being as a result.

It became clear rather quickly that adult athletes also prefer psychomuscular training over other methods of mental self-regulation. This can be explained by the fact that PMT is significantly simpler than other MSR methods, it requires less time for its mastery, and its effectiveness is high. Psychomuscular training has been employed most often in recent years for psychological preparation of both juvenile and adult athletes.

We need to distinguish two basic directions in mental self-regulation--self-peruasion and autosuggestion. These differ in the following way. In persuading himself of something, the individual relies on certain logical arguments. Suggesting something to himself, meanwhile, the individual may act even in avoidance of logic, using mainly those possibilities which are contained within unquestioning faith--a powerful mental process.

Thus for example if we are in a room, there is no way that we can persuade ourselves that at the given moment we are lying on the beach beside the sea, even through the most distorted conclusions of logic. But we can achieve this effect through autosuggestion. In the same way, we cannot persuade ourselves that an injured organ is not hurting. But suggestion to ourselves that there is no pain is not a difficult task. In this manual we will be referring only to the possibilities of autosuggestion.

The method of autosuggestion presented here--psychomuscular training--was developed in conjunction with the training of both juvenile (10 persons) and adult (12 persons) gymnasts, juvenile (15 persons) and adult (10 persons) swimmers, competitors in different styles of wrestling (15 juveniles and 35 adults), target shooters (7 persons) and marksmen (8 persons), weight lifters (10 persons), and divers (10 juveniles and 30 adults). Thus 162 athletes with different qualifications--from second rank juveniles to masters--underwent instruction in psychomuscular training.

To determine the effectiveness of psychomuscular training, we objectively recorded the states of individual body functions during work with the athlete; this involved tremorometry, pulsometry, recording of electrocutaneous resistance, measurement of the tone of skeletal muscles and skin temperature, and maintenance of medical and psychohygienic observation of the state of persons undergoing instruction in mental self-regulation.

Experience showed that one can master the basics of PMT in 5-7 days. During this time, athletes study the abc's of the method, and from then on they use the obtained knowledge both when recommended by their trainers and at their own discretion. It stands to reason that the degree to which autosuggestion is mastered depends on how seriously, systematically and purposefully the athlete utilizes the possibilities embodied within the suggested method of mental self-regulation.

In order for the sequence of learning the habits of PMT to become more understandable, we should first acquaint ourselves with some of the premises from the science of nervous system functions.

The Main Mechanisms in the Action of Autosuggestion

Life has long suggested, and science recently confirmed, presence of the following phenomenon: When the brain is in a drowsy state, a very important property appears within in--it becomes highly sensitive to words and to mental images associated with them. Consequently in order that words would acquire their maximum force, they must act upon a brain in a drowsy state. It is mainly because of this feature--the action of words upon a passive, drowsy brain--that autosuggestion differs from self-persuasion.

Drowsiness is defined as a state in which the brain is no longer active, as in daytime, but it is not yet asleep, as at night. In other words this is a transitory state between alertness and sleep in the course of falling asleep, and between sleep and alertness in hours of awakening. The duration of these periods of naturally arising drowsiness varies in healthy people--from seconds to several minutes.

But for the purposes of autosuggestion, the drowsy state must persist as long as required to achieve a certain end. Thus we must know how to control drowsiness--its duration and depth, without "falling" from it into sleep and without returning to normal alertness.

Placing himself in a drowsy state, the individual acquires a possibility for influencing, with words, body functions which do not yield to willful orders directed at oneself in a normal, alert state. Thus for example, were we to instruct the heart: "Beat slower," its rhythm would not change. But if we first immerse ourselves into drowsiness and mentally say (and correspondingly, mentally "see"): "My heart is beating slower and slower...," the heart beat would in fact become slower. Thus the possibility arises for acting, in a drowsy state, upon the autonomic nervous system, the functions of which are known to be consciously controllable.

And so, the first main mechanism at the basis of autosuggestion is as follows. In order that words and the mental images corresponding to them would acquire the greatest force, they must influence the brain in a drowsy state. Consequently the first step in mastering the habits of autosuggestion is to learn to place oneself in a drowsy state, while remaining under the control of one's own consciousness.

The second main mechanism in the action of autosuggestion entails the ability to maximally concentrate our sharpened attention on that which we are doing at the given moment. We all know that the more intensively we do something, the more successful we are at it and the greater is the efficiency of our work. When we concentrate intensively upon some one thing, our brain automatically turns itself off from all other things, and everything else is simply unable to "enter" our consciousness. This explains, in particular, the fact that by absorbing our attention completely with an interesting book, we can forget about everything, for example an important appointment.

Being maximally concentrated, in autosuggestion the attention must nevertheless remain relaxed. It is only when the attention is calm and relaxed that a drowsy state can be maintained. Any mental tension, including that caused by attention, disturbs drowsiness and causes us to slip from it into a state of some sort of activity.

These two main mechanisms (a drowsy state and concentrated, relaxed attention) lie at the basis of most autosuggestion methods. The only difference is in the paths leading to both drowsiness and concentration, in the methods used to master these mechanisms. In order to understand how a drowsy state can be achieved in psychomuscular training, we would need to acquaint ourselves with those mutual relationships that exist between the brain and skeletal muscles--muscles which cloak the bones and power the whole diversity of movements of which man is capable.

Brain and Muscles

We are built in such a way that at a time of mental arousal, our skeletal muscles involuntarily contract. And on the other hand when the brain is calm, the skeletal muscles involuntarily relax.

The relationship between the brain and the muscles is two-sided. Signals from the brain control the muscles, and impulses passing from muscles to the brain inform it of the state of the given muscle or the given joint. Thus for example, it is not difficult for us to state, without looking at our hand, what the position of our fingers is--straight or clenched into a fist.

Biological impulses passing from the muscles to the brain not only carry information about the state of the "body's periphery", but they are also unique stimuli which generate activity in the brain, arousing it. The more the muscles are tensed, and the more active they are, naturally the more impulses pass from them to the brain and the greater is its activation. This in particular is what happens in morning drill, where through physical exercises the brain, which had calmed down and rested during the night, is actively turned on. The warming-up exercises performed by athletes in preparation for both training and competition have a similar arousing action.

And on the other hand, the less active and the more relaxed the muscles are, the fewer impulses pass from them to the brain. But when the brain begins receiving fewer and fewer stimulatory signals from the body's periphery, it begins to relax, dropping first into drowsiness, and then into deep sleep. This physiological law is what we capitalize on in psychomuscular training to consciously achieve a drowsy state, and to control it. Consequently in order to achieve drowsiness, we would need to learn how to relax our skeletal muscles to the appropriate degree--such is the path to mastery of the first main mechanism of autosuggestion. But before we can relax our muscles well, we need to know how to "see" this process, to get a mental picture of it.

Visualization and Imagination

These two mental processes play an extremely important role in the mastery of autosuggestion. Important because words used in autosuggestion must always be accompanied, as was mentioned earlier, by the corresponding mental images. And these mental images are realized mainly by visualization or imagination.

The difference between visualization and imagination is as follows: If we look at a pencil for example, and then, looking away, we elicit its mental image in our consciousness, this would be a process of visualization. And so, a visualization is an image arising on the basis of information reaching the brain from real phenomena or objects.

But if we were to mentally see the same pencil, but bent into a ring (our brain is capable of this and more), this image would now be the fruit of imagination. Consequently imagination is a mental process in which mental images are recreated in that form in which they cannot be perceived in reality by means of our senses (vision, hearing, olfaction, and so on).

Let us suppose that we have decided to make ourselves warm by capitalizing on the possibilities of autosuggestion. By first immersing himself into a drowsy state and saying to himself: "I am becoming warm", an individual who is calmly concentrated should either visualize himself in a situation in which he had once been warm before, for example in a steam bath, or he should imagine himself to be somewhere he had never been but where it is always known to be very warm, for example under the scorching sun of equatorial Africa. And the more precisely and clearly visualization or imagination is used, the more distinctly the autosuggested warmth would be felt.

The First Practical Exercise

For learning convenience, all muscles of the body are divided into five groups in psychomuscular training--muscles of the arms, legs, torso, neck, and face. Imagine that you are in a room with five large lamps suspended from the ceiling and a small dim night lamp in the corner. The ceiling lamps are the groups of muscles, and the night lamp represents control by calmly concentrated consciousness. When you relax, or turn off the power from the arm muscles (in the same way that you would turn off one lamp), it becomes somewhat darker. When you turn off the leg muscles--a second lamp shuts off, and it becomes even darker. Without hurrying, by gradually relaxing the muscles of the torso, neck, and face, we in a sense turn off one lamp after another and drop into a pleasant darkness--drowsiness, which is kept under the control of relaxed consciousness--the small night lamp that remains lit.

The hardest thing to do in this procedure is to weaken your muscles without losing control over the developing drowsiness, without "dropping off" into sleep. There are two ways to do this: Either weaken all muscles to some point below maximum, or completely turn off one or two groups of muscles while leaving the rest normally but not completely relaxed. This difficulty may arise only in the first while. Later on, a student will find his own optimum method for achieving drowsiness, controlled by relaxed consciousness.

A student of autosuggestion usually assumes one of three postures. The most comfortable is lying on the back, with the arms, slightly bent at the elbows, lying palms downward alongside the body, and with the feet 20-30 cm apart. Thin and long-armed people may sometimes find it more comfortable to place the arms palm upward. The second position is assumed in a soft chair with a headrest and armrests, upon which the individual places his relaxed arms. The third is the most uncomfortable at first glance, but it is possible to assume in most situations. Schultz, the creator of autogenic training, called this position the "waiting coachman's posture", since this posture was brought into being through the centuries-old experience of the numerous army of coachmen who have been compelled to wait for passengers, for extremely great lengths of time on occasion, snoozing in their coach-boxes. It is namely in this position that mastering the habits of autosuggestion is the most reliable of all.

The essence of the "waiting coachman's posture" is as follows: Sit down on the edge of a chair without resting on its back. Place the feet flat on the floor, slightly forward so that a 120-140° angle would form between the back of the thighs and the calf muscle. Place the hands on the thighs, which should be spread in a relaxed position, so that they would not hang down between the thighs (otherwise the fingers will swell). Tilt the head forward slightly, turning it neither left nor right. But the most important thing is the position of the torso. Bend the back in such a way that the shoulder joints are precisely above the pelvic joints of the thighs. Were the shoulders to lean forward, the body would begin to fall toward the knees when a drowsy state is achieved. And if the shoulders are behind this imaginary vertical line, the body would begin to fall backward. When the position is correct, as the muscles weaken the back will simply bend more and more, and the body will retain its vertical posture.

The content of the first practical exercise boils down to the following. First assume one of the basic postures. Then close your eyes--this will help you to concentrate on yourself better. Now relax all muscles as much as you can; "shake them loose". Then start turning off the first group of muscles--the muscles of the arms. These muscles are the most "obedient", and it is easier to master the abc's of psycho-muscular training with them. This is done as follows: The students take an average breath, slowly draw their fingers into a fist, and contract all muscles of the hands--from the palm muscles to the shoulder muscles, or deltoids--to half of maximum power. They maintain this tension for 2-4 sec while holding their breath, and then they quickly release the muscle tension and exhale slowly and calmly. If after this the student "heeds" the muscles of his arms, he may sense a unique feeling of relaxation drifting from top downward. This preparatory, purely physical exercise--tensing the muscles while holding the breath and subsequently relaxing the tension while calmly exhaling--should be repeated two to four times. After the physical actions are mastered, the mental elements--the words and the mental images corresponding to them--are added to them.

The words of the first PMT formula are used as follows: While inhaling and tensing the arm muscles, think: "My arms...", and after they are relaxed in the course of leisurely inhalation, continue the formula with just two words: "...are relaxing..."; these words must be thought very slowly, and still better, in syllables--"are re-lax-ing...". The mental images must correspond to the words of the formula. Saying "My arms..." to yourself, mentally "see" your hands, together with all of the unique features of their structure. And while saying "are relaxing...", visualize or imagine complete, maximum relaxation of the arm muscles to the consistency of "rubber" or

"Jello". Initial tensing of the muscles helps to visualize such maximum relaxation; after it, it is easier to sense relaxation proceeding to its maximum. And of course, the clearer the mental image accompanying this process, the more pronounced relaxation would be.

To go on. As we know, when it is cold we tighten up our body into a compact posture, while when it is warm, on the other hand, we relax and open up. This is why the word "warming...", together with its accompanying mental images, is added to the autosuggestion formula as an aid to relaxation. This word may be associated with many pictures. The simplest is warm water flowing along the arms from the shoulders to the fingers, as if in a shower. Whoever finds it hard to visualize this should stand beneath a warm shower in such a way that the water would flow along the arms, and memorize this sensation well enough that it could subsequently be recreated by purely mental means, by visualizing a shower. Of course, other mental images associated with experienced sensations of heat may be used as well--being in the sun at the beach, going to a steam bath, and so on.

People who know anatomy and physiology may imagine--and not just visualize--that the muscles are permeated by numerous blood vessels, arterial in particular, through which warm arterial blood is coursing from the heart to the periphery. When the muscles are tense, the vessels contract, and after relaxation they dilate, allowing warm arterial blood to begin flowing freely through them from top downward, warming the arms, and especially the fingers.

Now let us bring the elements of the first formula together. Take an average breath, slowly tense the muscles to half of their power while inhaling, and think to yourself: "My hands...". Perform these three elements simultaneously. Then maintain muscle tension at the peak of the inhalation cycle for 2-4 seconds, after which quickly release the tension while simultaneously exhaling calmly and slowly, and at the same time mentally pronouncing the words "are re-lax-ing...", accompanying this with the idea of well-relaxed muscles in both arms. Heeding the sensations in the arms, persuade yourself that they have in fact relaxed. Only after this, while inhaling gently, say the conjunction "and...", and while exhaling calmly and slowly, the word "warming...", accompanying it with a mental idea of warmth flowing along the arms, or imagining it.

Throughout the entire time, concentrate calm, relaxed attention on both arms simultaneously, and slowly "look" at the different parts, "verifying" their degree of relaxation and warming; then fix your attention on the relaxed and warmed hands and fingers of both arms together. In autosuggestion, the attention process can be compared with the beam from a pocket flashlight, which moves at times and remains still at others, and the light spot it creates on the surface toward which the beam is pointed. The role of the flashlight in this comparison (more precisely, flashlights) is played by the eyes of the individual undergoing autosuggestion--his "mind's eye". If for some reason attention "slips away" from the hands at the moment the formula is being used and if other incidental thoughts appear, the individual must return the "light spot" of attention to its previous place calmly, without irritation, and then calmly continue the autosuggestion procedure.

The formula "My arms are relaxing and warming" is a preliminary one. In order that the effect of switching off the arm muscles would be maximally full, the formula should subsequently be expanded somewhat; in its final version it would be: "My arms are completely relaxed..., warm..., motionless...", in which case a mental impression of a pleasant numb sensation in both arms should be associated with the word "motionless".

Here is a detail you should consider: In the preliminary variant of the formula, the process of relaxation and warming is only in motion ("my arms are relaxing and warming"), while in the final version it is already finished, and the needed state is asserted--"my arms are completely relaxed..., warm..., motionless...". After the initial inhalation and subsequent slow exhalation, breathing should be very calm and shallow. When the final formula is used, it should no longer require special control, and it should proceed spontaneously.

Do not go on to the final version of the formula until the preliminary version begins to elicit a clearly pronounced effect (without the assist provided by tensing of the muscles). After mastering the final version of the preliminary formula--"my arms are relaxing and warming", it can be dropped completely, using only the final version--"my arms are completely relaxed..., warm..., motionless...". The words in this formula are separated by ellipses in order to recall to the student that he should not go on to the next word (and the mental image associated with it) until the previously uttered word produces a distinct effect. But if a very deep degree of arm muscle relaxation is not required, the student may limit himself to just the preliminary formula, and even abbreviate it by removing the word "warming".

The ability to turn off the arm muscles, to make them relaxed, warm, and motionless is the first, most important stone in the foundation of psychomuscular training. It must be laid extremely securely. Only after this will everything else proceed easily and successfully.

Most students of autosuggestion are able to both relax and warm their arms quite distinctly in the very first exercise. But in order to develop and reinforce this result, they must practice every day--they should play with their muscles and the appropriate mental processes (words, visualizations, imagination, attention) for at least 3-5 minutes three or four times a day, the last time being in bed, prior to night sleep. Here the word "play" is used deliberately, since PMT exercises must always proceed as a game, and not as dull, boring work. And of course the more frequently the student plays this game and the more consciously he tackles it, the sooner it will provide not only the desired results but also a unique sense of pleasure.

It should be pointed out that appearance of a sense of pleasure as a result of autosuggestion exercises indicates that mental self-regulation has already started having its useful, harmonizing influence upon the body.

Subsequent Practical PMT Exercises

Having mastered the formulas for the arms, the student can now proceed to turning off his leg muscles. The principle of using preliminary muscle tension, breathing, words, visualizations, imagination and attention is exactly the same here.

Tense the leg muscles as follows: While inhaling, slowly tighten the muscles of the feet, and simultaneously tense the muscles of the calves, thighs, and buttocks to half of maximum power. As you do this, think the following: "My legs...", and keep their image within the field of your calm attention. While exhaling slowly, quickly release the tension and begin mentally pronouncing the words "are re-lax-ing...". On seeing that at least some relaxation occurred, inhale gently, think the conjunction "and...", and then, while calmly exhaling, add the word "warm-ing...", accompanied by the corresponding mental image (visualized or imagined).

With every subsequent exercise, the preliminary auxiliary tensing of muscles should start becoming weaker and weaker, and later it should be excluded completely from the autosuggestion procedure. Only after this should the student go on to the final variant of the formula, which is used as described earlier ("My legs are completely relaxed..., warm..., motionless..."). Thus the second group of muscles--the muscles of the legs--are switched off precisely in the same way as the muscles of the arms are switched off. All other muscle groups are switched off in the same way as well. Thus the procedure of psychomuscular training is extremely simple, and students master it rather easily.

Having mastered the formulas for the legs, the student can go on to muscles of the torso. These are switched off in accordance with the principle described above. Auxiliary tensing of the muscles, which is needed only in the initial period of training, is performed in the following fashion. While inhaling slowly, tense the muscles of the back, abdomen, and chest, as in response to the command "Attention!", and then quickly relax the muscles while exhaling calmly and slowly, as following the command "At ease!". The idea of warmth may be visualized in the most diverse ways depending on personal experience--as everything from heat enveloping the body in a steam bath to the burning rays of the sun. Movement of warm arterial blood can be imagined through the muscles of the torso. The attention, which is calm and relaxed as always, should slowly "survey" the muscles of the back, the lateral surfaces of the torso, the abdomen and the chest, promoting their relaxation, warming, and then their motionlessness as well.

The formulas for the torso muscles are as follows: "My torso is relaxing and warming...", "My torso is fully relaxed..., warm..., motionless...". One quick note: Despite the word "motionless", the breathing movements of the rib cage and abdomen should persist, though only to the most negligible degree. In terms of the muscles of the back surface of the torso, however, the sensation of motionlessness may be quite distinct.

The neck muscles are switched off after the torso muscles. For the purposes of PMT their boundaries are: in back--from the hair line to the top of the shoulder blades, and in front--from the chin to the collar bones. Tense the neck for subsequent relaxation as follows: Draw the head in toward the shoulders, which should be raised a little toward the ears. After this tension is released, the sensation of creeping relaxation is extremely clear. The idea of warmth is selected from individual experience. In particular one might recall the sensation created by streams of water beating against the back of the head, shoulders, and neck, or the warmth of a furry scarf covering the back and front of the neck. One might also imagine arterial blood coursing through dilated vessels in this region.

Relaxed as always, the attention "surveys" the entire neck. And the formulas follow the previous pattern: The preliminary formula is: "My neck is relaxing and warming", and the final version is: "My neck is fully relaxed..., warm..., motionless...". The neck muscles are isolated as a separate group because in mental fatigue (as research conducted by Moscow State University showed) these muscles are extremely tense. Consequently by relieving their tension we provide the tired brain a possibility to rest.

And finally, the last group--the muscles of the face. Although they are smaller in size than all other muscle groups, a very large flow of impulses passes from them to the brain. After all, most of the sense organs are located about the face, and we "aim" them by contracting certain muscle fibers and relaxing others, for example when we squint or when we open our eyes wide. But the muscles of the lower part of the face are the most active during eating and sleeping. And because we are thinking almost constantly while not sleeping and our thoughts are shaped by words, muscles participating in word pronunciation, even "silently", are in almost continuous activity, sending abundant impulsations to the brain. This is why it is very important to know how to relieve the tension of this group of muscles, if we are to achieve a relaxed state.

Facial muscles are tensed insignificantly in PMT training: While inhaling, furrow the brow slightly, squint the eyes, and clench the teeth and lips slightly. During subsequent relaxation while slowly exhaling, smooth out the muscles of the forehead and around the eyes, and release the tension on the teeth and lips slightly. Thus we arrive at the "mask of peace", which must subsequently be made warm and motionless with the help of the appropriate words and mental images. The formulas used here retain their former structure. The preliminary formula is: "My face is relaxing and warming", and the final formula is: "My face is fully relaxed..., warm..., motionless...".

Visualizations of a warming face may be extremely diverse. Thus one of the subjects thought of the warmth of a steamed whisk in a bath, another thought of a heated towel after shaving, a third thought of the warmth from a campfire, a fourth thought of the warmth produced by steam rising above a boiling teapot when its top is removed, and so on. Of course, the face can become warm, and it may even redden, if we recall a previously experienced sense of shame, but the use of negative emotions is prohibited in PMT practice, since they are harmful. As with other muscle groups, the face may also be warmed by imagining dilation of arterial vessels in this region.

In cases where the individual is unable to remember useful images eliciting warming of the face, or when mental recall of such images does not produce the needed effect, he should proceed as follows: Closing his eyes, he should bring his face near a table lamp (or bring the lamp near the face), close enough to experience the sensation of pleasant heat; then, after moving away from the lamp, he should recall (visualize) this heat. After several such training sessions, the needed sensation will appear simply through mental recall of the heat emitted by the lamp. Its image will subsequently become the source of the required sense of pleasant warming of the face.

There is one extremely important thing to consider when "playing" with muscles of the face: Learn to warm the face area by area--warm the forehead separately from the lower half of the face beneath the eyes, since sometimes situations arise, for example in the presence of high blood pressure, when it would be useful to elicit even the opposite sensation of coolness in the forehead. The formula for autosuggestion in this case would be as follows: "My face is relaxed..., the lower part is warm..., motionless..., the forehead is pleasantly cool". In other situations, for example in the presence of certain variants of migraine associated with spasm of blood vessels, a sensation of warmth--a rather distinct one at that--must be elicited in both the forehead and in those areas of the head in which the pain is concentrated. The "light spot" of relaxed attention must be fixed in this case on the place of pain, and at first, the autosuggestion formula should be as follows: "My face is fully relaxed..., warm..., my attention is fixed on the painful area..., the feeling of warmth is growing strong here..., growing strong..., the blood vessels are dilating..., dilating..., the pain is decreasing..., decreasing..., it's going away..., the pain has stopped...".

But we should not forget, however, that in every case we must "see" the mental images corresponding to each of the words we use. Thus when thinking the phrase "The forehead is pleasantly cool..." we must visualize either a cooling compress on the forehead or the wafting of a cool breeze, or some other phenomenon of similar action. It is only when words are firmly associated with the images corresponding to them (it would be useful to recall this on more than just one occasion!) that the desired effect may be achieved. And finally, before using such formulas, ones having a therapeutic nature, the student should master those that make up the basis, the abc's of PMT.

As we know, the word "motionless" is contained in the final formula for facial muscles. The idea of motionlessness is associated here with a sensation of pleasant numbing of all facial muscles upon which the "light spot" of calm, relaxed attention is fixed.

When switching off one group of muscles after another, follow this rule: After switching off the arms, for example, proceed to the legs in such a way that the arm muscles would remain completely relaxed, warm, and motionless. Those muscles which are already relaxed, warmed, and rendered motionless should not be tensed, even a little, or moved during "play" with the next group of muscles. And here is something else that should be remembered: Do not go on to the next group of muscles until the previous one is truly "obedient", until it is sufficiently well trained.

Practice shows that within just a week of regular exercises, most athletes find it no longer necessary to cause preliminary tensing of the muscles or to hold their breath after inhaling: The muscles begin to relax and warm up well in response to just the mental resources of influence alone (the words of autosuggestion and their accompanying mental images). But if for some reason a long break in PMT exercises occurs, on resuming them, in the first few days it would be better to tense the muscles and hold the breath at least a little--these physical elements will help make the sensation of subsequent relaxation of muscles and their warming clearer.

After switching off all five muscle groups, as a rule students begin experiencing a state of pleasant calmness. This calmness is reinforced by a special formula: "A state of pleasant (complete, deep) rest". We use the concepts "pleasant", "complete", or "deep" rest depending on the quality of the relaxation.

But as was noted earlier, all words used in the autosuggestion procedure must be accompanied by the corresponding mental images. What sort of images may be used for this "rest formula"? We suggest it would be best of all to "see" (visualize or imagine) a smooth, monochromatic surface of gray, light blue, or soft green color. As we know, these colors have a soothing effect on us. The screen of a television that is switched off is an example of a monochromatic surface appropriate to our needs. Looking at it and memorizing its appearance and color, we can subsequently use this visualization together with the formula "state of pleasant rest".

One can visualize, as if viewing a slide, some sort of pleasant, soothing, panorama before the mind's eye. Various interference arising during the use of the "rest formula"--spots, dots, and lines on a colored background, especially if they are moving, and unexpected distortions in the selected panorama indicate that the brain has still not achieved a true state of rest, and the centers of arousal hindering rest still persist within it.

It is very important to master the "rest formula" well--in such a way that when it is said to oneself it would lead the brain assuredly to a necessary degree of passiveness, to a strength-recovering state of rest. This passive state is the basis of the first main mechanism in the action of autosuggestion. It is experienced subjectively as a pleasant drowsy state that remains under the control of calm attention.

And now that all muscles have become "obedient", now that a drowsy state is firmly maintained under the control of calm consciousness, the time has come to learn that PMT formula which, although it is assimilated last, subsequently becomes the first, and remains so forever. This formula reads as follows: "I am relaxing and quieting down". We can of course begin the training with it, but then the process of mastering PMT begins to be perceived rather frequently as something complex and difficult, especially by a little athlete. But when students acquaint themselves with this formula at the end of the series of exercises, they assimilate it easily and simply.

Use it in this way: While saying to yourself "I", take an average breath and simultaneously tense all of the muscles of the body to half their power, as if stretching. After keeping the muscles tense and holding your breath for 2-4 seconds, relax all contracted muscles instantaneously and think the words "am re-lax-ing..." while exhaling calmly and slowly. Then think the conjunction "and" while inhaling gently, and then the words "quieting down..." while exhaling calmly and slowly.

Distribute your attention here as follows: Concentrate it on the face during the word "I". Then survey all muscles with it during the words "am relaxing", checking the degree of their relaxation. Return the attention back to the face with the word "and", and during the words "quieting down" direct it toward that point in the body which is causing the greatest disturbance at the given moment, leaving it there as you would a light spot from a flashlight. If you have a toothache for example, focus your attention on it, and by simultaneously thinking the words "qui-et-ing down..." you could reduce the sense of pain. But in cases where there is nothing specific that is disturbing, keep your attention on the heart area or on the forehead.

In PMT training practice, the first formula is usually thought out twice--without preliminary tensing of the muscles the second time. Later on among well-trained people, the first formula--"I am relaxing and quieting down"--in a sense "absorbs" all of the other formulas, and the individual can use just it to place himself in the needed state of consciously controlled drowsiness within a few seconds.

Now let us bring all of the formulas of psychomuscular training together. Here they are:

1. I am relaxing and quieting down...

2. My arms are relaxing and warming...

3. My arms are completely relaxed..., warm..., motionless...

4. My legs are relaxing and warming...

5. My legs are completely relaxed..., warm..., motionless...

6. My torso is relaxing and warming...

7. My torso is completely relaxed..., warm..., motionless...

8. My neck is relaxing and warming...

9. My neck is completely relaxed..., warm..., motionless...

10. My face is relaxing and warming....

11. My face is completely relaxed..., warm..., motionless...

12. A state of pleasant (complete, deep) rest...

During mastery of PMT, each preliminary formula eliciting the two sensations--relaxation and warmth--may be thought out two, four, or six times in succession. Moreover this should be done with the least possible haste, even at a deliberately slow pace, and of course with the appropriate intonations. If for example the words "quieting down" are pronounced quickly and with an alert tone, there would be no useful effect. If for some reason the desired result does not come about, think calmly, without changing your body position, about what might hinder attainment of the needed sensations, and then think out the formula two to four times once again. The usual cause of failure is insufficient concentration of attention, in view of which the association between the words of the formula and the needed mental images breaks apart.

Exercising four to six times a day for 5 to 10 minutes a session is recommended. As was mentioned earlier, going on to the final versions of the formulas, the ones calling for all three sensations--relaxation, warmth, and motionlessness--is permitted only after the preliminary formulas produce a well-pronounced result, since there is no sense saying, for example, "My arms are completely relaxed..., warm..., motionless..." if they are still having a hard time "relaxing and warming". Experience shows that it would be reasonable to use only the preliminary formulas for the first 3 or 4 days, adding to them the first and 12th. It is only after feeling that they are well assimilated that the student should go on to the final formulas.

As soon as the preliminary formulas begin to distinctly elicit the needed sensations (without the need for tensing the muscles and holding the breath), using each of them once would be sufficient. And those students who are finding it easy to master mental self-regulation may drop all of the preliminary formulas and begin using just the final formulas after just a week.

The twelve formulas of the complete variant of PMT, when said to oneself without haste, require 7-10 minutes, while the abbreviated variant consisting of seven formulas requires only 4-5 minutes:

1. I am relaxing and quieting down...

2. My hands are completely relaxed..., warm..., motionless...

3. My legs are completely relaxed..., warm..., motionless...

4. My torso is completely relaxed..., warm..., motionless...

5. My neck is completely relaxed..., warm..., motionlesss...

6. My face is completely relaxed..., warm..., motionless...

7. A state of pleasant (complete, deep) rest...

It would be good to know how to work with just two formulas: The first--"I am relaxing and quieting down"--followed immediately after by the last--"A state of pleasant (deep, etc.) rest". This variant requires not more than a minute and, for a highly trained person, 10-15 seconds.

If there are no special objectives to be reached, as will be discussed later, the psychomuscular training exercise should be ended after the formula "A state of pleasant rest" as follows: While maintaining a state of rest, think out the following formulas: "I have rested and quieted down...", "I feel well...". After this, stretch out the entire body in leisurely fashion, take several deep breaths, stand up, and go on about your business.

That sums up the entire course on the abc's of psychomuscular training. Athletes taking it master both of the main mechanisms at the basis of mental self-regulation: 1) They learn to place themselves into a consciously controlled drowsy state and 2) they acquire the capability for maintaining relaxed, concentrated attention on the words they are using and on their mental images. It is only after mastering these main mechanisms that they can go on to all of the tasks arising before them during mental preparation for competition.

Figuratively speaking, "a state of pleasant (complete, deep) rest", of drowsiness remaining under the control of the consciousness and calm attention, is in a sense the launching pad. From it, using the rules of autosuggestion, we can shoot for the most diverse objectives. This possibility is based on the phenomenon which, as we said earlier, entails heightened sensitivity of the drowsy brain to words and their mental images. After achieving a drowsy state, the second main mechanism in the action of PMT--relaxed, concentrated attention--assumes the forefront. A task brought within the scope of concentrated, calm attention is subsequently completed with much greater ease and speed than in a state of ordinary alertness. Let us now examine those tasks which are most important to athletics.

Mental Desensitization

"Desensitization" is defined as reducing or eliminating unpleasant feelings and certain negative emotions, such as pain, fear, hunger and thirst. Because with autosuggestion the needed result is achieved simply by mental means--through the power of words and their mental images--desensitization is called "mental" in PMT practice.

Let us assume that we need to reduce a feeling of pain caused by injury of the left shoulder. The first thing to do is to calm down the brain by relaxing the muscles, or still better by entering into a drowsy state; then the calm attention should be focused on the point of injury. If the injury is recent, after relaxing the muscles of this area, do not visualize warmth in any event, since this would elicit additional hemorrhaging. Consequently, visualize that the injured area is becoming cold, that a bag of ice is lying on it, for example. The autosuggestion formula for this case would be: "My left shoulder is becoming motionless..., motionless.... It is becoming cool..., cool..., cold.... The pain in it is decreasing..., decreasing..., passing..., passing.... The pain has passed..., passed...".

Each formula has to be repeated slowly, two to four times, accompanying the words with the corresponding mental images, and in a minute or two the feeling of pain will in fact begin to vanish. Of course, the better the individual has mastered the habits of mental self-regulation and the more firmly he can maintain a state of drowsiness controllable by the consciousness, and concentrate his relaxed attention on the needed mental images, the faster this will happen. Naturally at times when the symptoms of chronic injury become acute, the idea of warmth should be substituted for the idea of cold.

The next task is to relieve the sense of fear and anxiety prior to an event. In this case it is very important to relax the skeletal muscles to the limit. This process alone will soothe the brain, from which excessive pre-event arousal will begin to drain through the relaxed muscles, as if through a lightning rod. The self-regulation formulas for this case may be: "My attitude toward the event is calm..., calm.... I am fully confident of my strength.... Everything will be O.K..... My attention is completely concentrated on the forthcoming event.... Only on it.... Nothing can distract me...". It would be very useful to add another formula, one which should "activate" athletes with the same certainty and inevitability as a bullet shooting from a rifle after the trigger is squeezed. This formula, which every athlete should use, is: "All obstacles, all difficulties only mobilize me for action!".

Mental self-regulation may also be very useful to athletes needing to lose weight. To keep from experiencing the acute sensations of hunger and thirst, immerse yourself into a drowsy state, focus relaxed attention on visions of all that you would want to eat and drink, and use these formulas: "I am indifferent to food and water.... Entirely indifferent.... Food and water are absolutely indifferent to me.... Complete calm.... I feel well...". This same principle can also be used by persons who want to quit smoking. The formula here is: "I am indifferent to cigarettes.... I have no desire to smoke.... Smoking is very bad for me...". The mental images arising in connection with such formulas generate the needed attitude--first an indifferent one, and then a negative attitude toward the given stimulus. After this, the urge to satisfy the interfering desires disappears.

Athletes prone to excessive anxiety will find it very useful to include the following exercise in their mental preparations for competition: Immersing themselves into a drowsy state, they should concentrate their calm attention on visions associated with the concrete circumstances of the forthcoming event. Thus for example, a boxer must mentally see the ring in which he will appear, and the opponent he will have to fight. A diver must "see" the specific swimming pool, the equipment, and the particular dive which produces the greatest apprehension. The main thing in this mental exercise is to maintain a calm attitude toward the forthcoming event that causes this anxiety. Such mental training lasts 2-4 minutes, and it is performed five or six times each day. If it is started several days before the event, it may help the individual to maintain the required self-control in the hour of reckoning.

A situation requiring special discussion may arise when using the formulas of mental self-regulation: When an individual concentrates his attention on the needed mental images, his brain may become activated. This is felt subjectively as disappearance of the feeling of drowsiness, as quick awakening and "clearing" of the head. If this happens, the individual should once again relax his muscles, without irritation, immerse himself in a drowsy state, and reconcentrate his relaxed attention on the needed mental images. This may happen several times, especially at first. But gradually even situations that cause very high anxiety will cease to activate the brain; this, by the way, will be an implication that the needed effect is being achieved, and that a correct, sober attitude toward that which had previously caused anxiety, and which served as an obstacle, has been developed.

Regaining Strength

The loads--both physical and mental--of modern sports are such that one can simply not do without regular and timely replenishment of spent energy. Mental self-regulation offers considerable possibilities for doing so. Just the "state of deep rest" alone is able to produce the sensation of being rested, were one to remain within it for 5-10 minutes. But it would be still better to recover strength through autosuggested sleep. Therefore it is very important for every athlete to learn how to immerse himself into such sleep for a certain, previously prescribed time, and to emerge from it on his own, rested and alert.

The duration of autosuggested sleep may vary considerably. It may even be used for 30 seconds, such as during the minute break between rounds fought by boxers and by wrestlers, who fight three 3-minutes rounds with 1-minute breaks. Of course, during this time the athlete does not sleep in the usual sense of the word, but he calms his brain down to such an extent that both his nervous system and his entire body are allowed to rest. Moreover in these moments of drowsiness, during which the brain becomes highly sensitive to words, the athlete can better perceive the instructions of his trainer.

Autosuggested sleep lasting 20-40 minutes recovers strength especially well. Before immersing himself in such sleep, the individual should first note his intended time of arousal. Assume that you need to fall asleep during the day for a half hour, from three to three-thirty. In this case, before falling asleep with the help of PMT formulas, visualize the clock dial with the arrows pointing to three-thirty, and say to yourself: "Wake up at three-thirty!", and repeat this thought as you pass into the stage of drowsiness, before dropping into autosuggested sleep. After this your biological clock, which was placed in our bodies by Mother Nature, will wake you up at the appointed time. Of course, you may be off by 2 or 3 minutes either way. As in everything else, your precision will depend on your degree of training, and on your proficiency in the techniques of mental self-regulation.

The formula for autosuggested sleep should follow immediately after the last PMT formula, "a state of deep rest". The order of the formulas is as follows:

1. I am beginning to feel drowsy...

2. I am getting drowsier..., drowsier...

3. Drowsiness is getting deeper... and deeper...

4. My eyelids are getting pleasantly heavy...

5. It is getting pleasantly dark...

6. Deeper and deeper...

7. I am going to sleep... sleep..., calm sleep (until such-and-such a time--at this moment, think the desired time of awakening)..., deep sleep..., continuous sleep..., sleep..., sleep...

Each of these "soporific" formulas should be thought out very slowly, monotonously, several times, accompanying them with the same sort of unhurried mental images that generate the onset of sleep.

The duration of restorative autosuggested sleep-rest and its depth depend on many factors, particularly the way the athlete feels and the specific features of the given sport. During half-time, for example, soccer players could relax themselves well and snooze for 8 or 10 minutes, which will doubtlessly increase their strength. In target shooting, there is a possibility for resting with autosuggested sleep between series; in this case the sleep can be deep, and much longer--up to 30-40 minutes. "Sleep breaks" of the needed duration may be repeated several times throughout the day. This would restore strength well in cases where the training process continues from morning until evening with occasional breaks, as well as in all-around competitions. Thus for example, expert divers are able to immerse themselves into refreshing drowsiness for the needed number of minutes, even after each dive. This gives them a feeling of freshness and lightness, which is so necessary in this form of sports, and especially in competitions. A similar state of "clear-headedness", as some athletes call it, and of maximum concentration may be created in other forms of sports as well, for example before each shot in "slow" sharpshooting. But do not think that this ability can be acquired in just a week or two, though some people are able to do so. It is only through systematic, daily use of the possibilities offered by mental self-regulation in the course of about one season that the desired results may be, and will be, attained. A long break in mental self-regulation exercises also has a detrimental effect on mental preparations for events, in the same way that interruptions in physical training affect the athlete's sense of physical well-being.

Activation

In a number of cases a distinct feeling of alertness does not arise right away after emerging from autosuggested rest. A feeling of reduced activity and weakness persists for some time after, as following ordinary sleep. To get rid of it, we need to use special autosuggestion formulas that have come to be called activating formulas. It would be best to begin the activation procedure while the brain is still in a drowsy state--this would mean that the return to high activity would occur faster. Here are the formulas aimed at achieving this goal:

1. My whole body is resting...

2. And gaining strength...

3. The feeling of weakness and motionlessness is vanishing from my arms..., from my legs..., torso..., neck..., face...

4. All of the muscles of my body are rested..., light..., strong...

5. My breathing is getting deeper...

6. Ever deeper and deeper...

7. My drowsiness is dissipating...

8. My drowsiness has completely dissipated!

9. My head is rested and clear!

10. I feel great!

11. I am looking forward to going about my business!

After this, the individual should stand up and perform a few warm-up exercises for a minute or two.

Sometimes at the end of a relaxing and calming procedure, in the course of reaching "a state of pleasant (deep) rest", the muscles may acquire a sense of heaviness. To relieve it, add one more formula to the activation procedure: "The feeling of heaviness is leaving such-and-such muscles". Use it immediately after formula 3 above.

In opposition to calming formulas, the formulas of activation must be thought out at a gradually quickening rate, with growing alertness, with an intonation aimed at achieving the desired state. The number of repetitions of each formula depends on the way the individual feels. Usually thinking each formula once is enough.

Activation returns the individual to nothing more than ordinary, run-of-the-mill alertness. In sports, however, extreme mobilization of all strengths--both physical and mental--is often required. Mental self-mobilization is a special topic.* It may be approached only after mastering the "foundation" of mental self-regulation, as is represented, for example, by this manual.

In conclusion, a few words about the rules of making up autosuggestion formulas to be applied to the drowsy brain: They must not have an active tone, and moreover they should be made up with a positive, affirmative tone, avoiding negative statements where possible. Thus for example, it would be incorrect to suggest: "I do not want to smoke!"; it would be proper to say: "I am indifferent to smoking...". The latter formula has an affirmative tone, rather than an active or negative one.

Any person who seriously studies mental self-regulation will be able to gradually handle the most diverse individual tasks. But there is one task common to all athletes. Its essence is as follows. We know that athletes are able to tense and relax their muscles well. They should also know how to both arouse and calm down their brain and their nervous system just as easily. The unique features of modern sports require this most urgently.

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MEDICAL AND PSYCHOLOGICAL PROBLEMS OF CIVIL AVIATION PILOT RELIABILITY (NUMBER 1)

Moscow MEDIKO-PSIKHOLOGICHESKIYE PROBLEMY NADEZHNOSTI RABOTY LETCHIKOV SOVREMENNYKH TRANSPORTNYKH SAMOLETOV GRAZHDANSKOY AVIATSII (VYPUSK PERVYY) in Russian No 1, 1968 (signed to press 10 Sep 68) pp 1-32

[Complete translation of pamphlet "Medical and Psychological Problems of Reliability of Pilot Work in Modern Transport Aircraft of the Civil Aviation (Number 1)", by Levon Saakovich Isaakyan, candidate of medical sciences, USSR Ministry of Civil Aviation, State Scientific Research Institute of Civil Aviation, Department of Scientific and Technical-Economic Information, 32 pages]

[Text] Introduction

This work is a brief version of the author's monograph-dissertation in the form of several issues that correspond to different chapters.

It contains the results of the author's original research and that of the team he supervises in the Department of Aviation Medicine (branch) of the State Scientific Research Institute of Civil Aviation covering a period of 10 years (1957-1967).

In the first chapter, published in this issue, he deals with the problem of reliability as it relates to a human operator, in particular, the work of a pilot; after validating the use of this term, analysis is made of the possible means of quantitative evaluation of reliability, including several original approaches; there is brief discussion of factors that depend on man and determine his reliability; at the end of the chapter the general order of presentation of the work as a whole is described.

The second chapter deals with the technical characteristics of the system, in which the pilot is one of the most important elements; in addition to discussion of the general tasks of the crew, there is description of the display equipment, controls and main systems of landing approach.

The third chapter deals with the professiographic description of pilot work and, in particular, describes pilot action at take-off and landing; a general hypothetical scheme is proposed for the work, as well as one of the possible variants for algorithmizing pilot work at the final stage of a landing.

In the fourth chapter, pilot work is analyzed from the standpoint of the psychophysiological reactions observed under actual take-off and landing conditions, the latter being varied from simple to extremely complicated conditions. The study of such reactions makes it possible to demonstrate more clearly the higher nervous system and emotional stress in pilots and advance new hypotheses concerning the intimate mechanisms of this state.

Thus, the second, third and fourth chapters shed light on pilot work from the standpoint of the tasks, equipment and "tools" of flight work (second chapter), then from the standpoint of specific professional activity (third chapter) and, finally, as it relates to the study of psychophysiological reactions of pilots under normal and complicated take-off and landing conditions (fourth chapter).

The next four chapters (5-8) discuss in detail specific groups of factors that impair pilot reliability. Such factors of pilot unreliability include the following: psychophysiological, engineering design, work schedule and some sanitary and hygienic factors.

The concluding, ninth chapter lists and interprets the most important conclusions derived from this work.

The work as a whole is intended for aviation physicians in different specialties, pilots and other crew members, aviation engineers and designers, as well as management personnel of relevant departments, institutions and enterprises.

Reliability of Pilot Work

In spite of the close ties between aviation medicine and engineering psychology, the term, "reliability," as it applies to pilot work has not yet gained broad use in aviation medicine.

In engineering psychology, this term has long since gained the legal right to be used extensively (V. D. Nebylitsyn, 1964d; G. V. Sukhodol'skiy, 1964; M. Bobneva, 1961; M. A. Grodsky, 1962; S. Lincoln, 1960, and others) with reference to operator work or simply an operator (the corresponding two expressions are "reliability of operator work" or "operator reliability").

The expressiveness and conciseness of this term were appreciated by neurophysiologists and industrial physiologists (E. A. Asratyan, P. V. Simonov, 1963; K. S. Tochilov, 1964, and others).

Nevertheless, it is important to us to demonstrate the validity of using this term in aviation medicine as a convenient synonym of such cumbersome expressions as, for example, "retention of high level of efficiency [work fitness] under different working conditions," "high quality of performance of professional duties," "adequate reactions under complicated conditions," etc., in the first place, and, in the second place, as a means that settles, to some extent, the question of quantitative evaluation and forecasting of flight work performance.

In view of these circumstances, we must dwell in greater detail on validation of the use of the term, "reliability," in engineering psychology and demonstrate that the same considerations are involved in using this term in aviation medicine as well.

In addition to technical elements, every manual, semiautomatic or automatic system also has a human element. Although the operation of the technical elements is basically incomparable to the qualitative content of the work of a human operator, which is notable for being unusually integrated and flexible, there are many analogies between the two types of work, which pertain to both the general patterns of control and special mechanisms of regulation.

Let us recall that the science dealing with the most general principles of function of qualitatively different classes (living organisms, machines, society)--cybernetics--emerged expressly as an extremely fruitful means of studying the same laws of regulation in living organisms and technical equipment.

We are justified in using the same qualitative and quantitative gauges as to other technical elements for the study of a system that has a human operator as one of its elements, already from this point of view.

On the other hand, if system reliability is determined by the reliability of its components, reliability of the human element becomes the most important object of investigation, since expressly the unreliability of this element causes unreliability of the entire system in at least 25% of all cases of malfunction.

In the system of aircraft control, the pilot is a typical example of an operator in a complex control system, and it is more complex than any ground-based system with a control console; consequently, everything that has been said about an operator, in particular, the validity of using the term "reliability" with reference to him can be used to refer to a pilot as well, with complete justification.

Having recognized that this term can be used, we should provide a qualitative definition thereof and analyze methods of making quantitative evaluations.

M. I. Bobneva (1966) believes that the definition of reliability of operator work should be analogous to the technical definition of reliability, as "... the ability to perform the functions assigned to him without failure under specific working conditions and for a specific time." This definition is indeed no different from the ones we encounter, for example, in describing the reliability of radio-electronic equipment: "... reliability of radio-electronic equipment refers to its ability to perform without failure its specified functions under specific operating conditions and in a specific time"(Ya. M. Sorin, 1961; L. G. Tkachenko, 1966, and others).

V. D. Nebylitsyn (1964), who digresses somewhat from the technical definition, proposes to define reliability of operator work as "... the ability to sustain the required work qualities under conditions of possible complication of the situation or, in brief, as preservation, stability of an individual's optimum work parameters."

In this definition, the author stresses one aspect of reliability--retention of optimum work qualities under extreme conditions, deliberately disregarding another aspect of reliability--retention of a high level of efficiency [work fitness] over a specified period of work under ordinary conditions.

G. V. Sukhodol'skiy (1964) assumes that it is possible to offer a broad interpretation of reliability, observing that "... in the general case, reliability is the ability to perform certain work functions in accordance with certain criteria."

K. S. Tochilov (1964) tends to equate reliability with efficiency, disregarding the very aspect of the problem that was specially stressed by V. D. Nebylitsyn; B. F. Lomov (1966) correctly views two aspects to reliability: the existing one, pertaining to operator efficiency under normal working conditions and potential, or reserve reliability, which pertains to noise immunity [imperviousness to interference] of an operator under complicated, extreme conditions.

In our opinion, the qualitative aspect of reliability of a pilot-operator can be defined as the ability to sustain a high level of efficiency for a specific period of time under ordinary working conditions and to react optimally under complicated and extreme conditions.

This definition does not differ in any way from those quoted above, and it coincides with the definitions of foreign authors (M. A. Grodsky, 1962; D. Meister, 1962; M. A. Grodsky, C. C. Luthman, 1965).

It is apparent from the qualitative definitions of reliability that, in order to elaborate quantitative criteria, it is imperative to clearly explain what should be interpreted as "failure" [breakdown] and make proper use of methods of theory of probability, statistics and information.

In the technical aspect, breakdown refers to a defect [fault] without elimination of which it is impossible for the equipment to perform all or at least one of its main functions.

By analogy with such a definition, pilot failure should refer to complete or partial removal from piloting due to loss of consciousness, intolerable pain, effects of extreme factors, etc. In this connection, V. D. Nebylitsyn correctly observes that "... However, it would be better to take a broader definition of failure, as an action that leads to worsening of the effectiveness of the work process. In this case, the entire range of erroneous pilot actions performed under the influence of diverse causes and resulting in the wrong final action would fall into the category of breakdowns." On the basis of this broad interpretation of failure, the author divides it into two groups: final breakdown covers the cases where work is stopped, transient failure refers to all cases of operator error in the area of calculation, control, interpolation, etc.

In our opinion, the classification of pilot failure may be the most varied, but it is important for it to help to the utmost extent in describing the main content of work. We can offer that failures be divided into the following categories, from this point of view:

1) Direct failure due to erroneous decisions and actions of pilots under the influence of various causes depending primarily on the pilots themselves (judgment, attention and memory errors, flaws referable to emotional and volitional aspects, moral and characterological flaws--thoughtlessness, carelessness, excessive self-assurance and others). In turn, such failures can be divided into severe, moderate and simple, depending on the end result.

2) Indirect failure, unlike direct failure, does not have a direct adverse effect on the process of controlling the aircraft; it consists of synchronous deterioration of a number of physiological characteristics of pilots, which

lowers efficiency under ordinary conditions and could be the cause of inadequate reactions under complicated conditions. Usually, this refers to the consequences of marked fatigue during long-term flights, in flights involving numerous take-offs and landings, when physiological studies show diminished lability and sensibility of the pilots' visual analyzer, longer latency periods of visual and motor reactions, decline of muscular endurance, drop of arterial pressure and other changes of this sort. These failures are called "indirect," because they create only the potential danger of a real failure; indeed, in the absolute majority of cases, indirect failure does not change to real failure, due to the abilities inherent in man with regard to volitional exertion, emotional upsurge, "final dash," etc.

But it would be a great mistake to disregard these states of decline of physiological functions, because expressly they are the sources of a number of direct failures that would be difficult to explain and comprehend from the standpoint of common sense.

3) Forced failures, unlike direct and indirect ones, are not significantly related to any psychological or physiological state of the pilot; the chief cause of failure is referable to exogenous factors, such as poor design, device or location of controls, displays or other equipment, the effects of such extreme physical factors as acute hypoxia, intolerable accelerations and vibration, and finally prior worsening of general health status under the influence of acute diseases or gross infraction of preflight regimen.

Depending on the exogenous factors that play the leading part in occurrence of forced failure, the latter can be divided into design-related, physical and pathological forced breakdowns. Strictly speaking, as the last feat of failure, we should list piloting breakdown due to sudden exacerbation of chronic disease leading to syncope, collapse, shock, intolerable pain, unsurmountable sleepiness, disorientation, as well as the consequences of acute poisoning (nicotine, drugs, bad food); however, this special, strictly medical category of failures, which does not have great practical significance, shall not be discussed in the following. In this regard, it is opportune to note that chronic diseases, which do not hinder performance of professional duties of pilots, could have an adverse effect on pilot resistance to the categories of failure discussed, as shown by our and foreign studies (L. S. Isaakyan, 1966; C. A. Harper, 1964).

Before investigating the possibility of quantitative evaluation of reliability in the technical and engineering psychological aspects, it is expedient to give brief information about the methods of quantitative description of operator work, which are being developed intensively in engineering psychology for the last few years.

These methods are based almost entirely on the most important branches of cybernetics (theory of automated regulation, information theory, theory of algorithms, electronic computers, etc.), and the leading role belongs to theory of probability and mathematical statistics, as well as information theory. In cases where the operator's role is to detect and eliminate a mismatch between input and output signals, between which a certain relationship is demonstrable that can be described mathematically, the quantitative expression of operator performance is described, within certain limits, by means of a complex dynamic coefficient, which is called a transfer function.

Broader use is being made of information theory software [mathematics] to describe the performance of the human element. In this case, operator work is compared to the operation of a communication channel between the receiver and source of information, and it is characterized by a bandwidth, discrimination and throughput.

If an operator's work consisted, for example, of reading an instrument, the bandwidth determined the instrument scale, discrimination determined the scale division and throughput determined the maximum amount of information (in binary digits [bits])* received and processed by the operator per unit time. Consequently, the three parameters that characterize operator work quantitatively are the range of absolute sensitivity, resolution and, the most important characteristic, speed of choosing alternatives or speed of determining probability.

Mathematical models based on theory of games and statistical solutions (choice of optimum lines of behavior in conflict situations with consideration of the possible effects of the antagonistic system), queueing theory (search for optimum forms of information processing in the case of group operator work), theory of dynamic solutions [or decisions], which serves to describe the processes of isolation by the operator of threshold signal out of noise, with due consideration of prior experience, etc., are used for quantitative evaluation of different aspects of operator work.

All these theories and the formal models corresponding to them reflect the quantitative aspect of only some strictly limited aspec: of operator work and, furthermore, they occur under specific conditions. They cannot be modeled and, consequently, there cannot be quantitative expression of such complex and purely human abilities, such as foresight [anticipation], emotional reaction, adaptability, goal orientation, creative and logical thinking, imagination, etc.

These theories, which have greater limitations than areas of application, no doubt operate with elements that correspond to certain psychophysiological mechanisms of behavior and operator work. For example, there is no doubt that the cerebral mechanism of evaluation of current occurrence of some process is based on a certain calculating instrument, which takes into consideration and stores in memory the probability of different events of a given process and, consequently, the parameter of throughput, which takes into consideration the speed of evaluation of different

*Information that eliminates vagueness of choice of 1 out of 2 possible outcomes is taken as the unit of amount of information. The amount of information contained in a communication about one event equals the binary logarithm of probability of occurrence of this event ($I_1 \cdot = \log_2 P$). The amount of information contained in communications about many events with different probabilities of occurrence equals the sum of the products of probabilities multipled by their binary logarithms:

$$(I_2 = \sum_{+\,K+1}^{n} P_K \log P_K)$$

Throughput of the system element is determined by the speed of undistorted transfer of information per unit time ($R = \frac{H_{(x)} - H_{(y)}}{T}$), where $H_{(x)}$ is information inputted in the element, $H_{(y)}$ is information lost in the element, T is transmission time and R is speed of transmission.
[Translator's note: the "K" may refer to quantity, but formulas are not perfectly legible in source]

probabilities, which conforms well with the psychophysiological bases of mental activity.

Thus, at the present time, our ability to express quantitatively operator performance in a control system is rather limited, and this applies to an equal extent to objective description of reliability. Let us consider the possible means of quantitative evaluation of reliability of the "human" element of the system from the standpoint of probability theory and information theory, bearing in mind, in particular, the known criteria for reliability of technical equipment. As we know, these criteria are referable either to a piece of equipment as a whole, or to similar elements constituting its structure. In view of the extreme complexity of the system element, we are justified in using any type of reliability criteria.

1. Mean up time per failure shows the time of normal operation of equipment (operator) between two successive failures.

Mean up time per failure is expressed by the following formula:

$$T = \frac{t}{n}$$

where t is service time or equipment (operator) work time, in hours, and n is the number of failures per work time. This criterion is used in engineering to compare and assess the reliability of similar equipment operating under the same conditions. In principle, it could be used to describe operator-pilot reliability as related to any category of failures, but provided working conditions are identical to the utmost degree.

When evaluating immediate forced failure, the difficulty also refers to the need to find only comparable failures (severe failure should be compared only to severe, design-related forced should be compared to appropriate failures, etc.); in assessing indirect failures it is no longer possible to make an individual evaluation of operator reliability since, according to the definition of indirect failure, it can occur only once per flight.*

Thus, the criterion of mean up time per failure can characterize rather approximately individual and collective pilot reliability according to the parameter of direct failures with due consideration of their detailed categorization and maximum degree of identity of aircraft types, flight courses and other conditions; the same criterion can be used to assess reliability according to the parameter of indirect failure referable to two groups of pilots flying under identical conditions. We shall submit data that we calculated with the use of this criterion, on the basis of foreign statistics referable to the United States Air Force (A. Zeller and H. Moseley, 1957, and others).

During the early years of operating transport jet aircraft, up time per failure of the direct failure type (severe [s] and moderate-simple [ms] constituted:

$$T_s = 95{,}000 \text{ h/failure} \qquad T_{ms} = 51{,}900 \text{ h/failure}$$

*In rare instances, the decline of functions is repeated twice.

In subsequent years, due to the increased collective experience in operating these aircraft, the parameters increased appreciably:

$$T_s = 250{,}000 \text{ h/failure} \qquad T_{ms} = 110{,}000 \text{ h/failure}$$

As for up time per indirect [ind] type failure, which characterizes pilot resistance to fatigue, our data indicate that indirect failures in the form of combined decline of several physiological parameters were noted in 22 cases (22 crew members of all flights) among those involved in five 8.5-h flights (total of 8.5·5 = 42.5 h), consequently:

$$T_{ind} = \frac{42.5}{22} = 1.9 \frac{\text{hour}}{\text{failure}}$$

When the same crew members participated in five 6-h flights, the up time was:

$$T_{ind} = \frac{30}{12} = 2.5 \frac{\text{hour}}{\text{failure}}$$

Consequently, reduction of flying time by 2.5 h increases reliability (in the sense of resistance to fatigue) by 1.3 times.

In spite of the demonstrativeness and simplicity of this criterion, there is limited possibility of using it to evaluate and compare pilot reliability because of the difficulty of identifying failures and flight work conditions.

2. The probability of equipment (operator) work without failure over a specific period of time is the most integral criterion of reliability, which takes into consideration both the mean up time per failure and specified time for operation without failure. This criterion, which levels off to a significant extent the different operating conditions for the tested equipment (operators), is expressed by the following equation:

$$P = e^{-\frac{t}{T}}$$

where P is probability of flawless operation; e is the base of natural logarithms, which equals 2.71, t is the time in hours during which the equipment (operator) must function without failure according to prevailing standards and T is mean up time per failure (in hours).*

In this equation, which represents the law or distribution of Poisson, 2.71 is raised to a negative power, which is the ratio of normally set work time to its actual duration, which did not cause a failure.** Consequently, the lower this negative ratio, the closer the probability of work without failure -P comes to 1. If, for example, the operator should work at the console for a 4-h shift according to prevailing standards but actually worked without failure for 16 h or else

*If the operator continues to work without failure, one should use total time of failure-free work instead of T.

**Or else it equals the mean up time per failure.

there was a failure at the end of this time, the probability of failure-free work during this period equals: $P = 2.71^{-\frac{4}{16}} = 0.7738$.

If the up time for the operator up to a failure or work without failure constituted, for example, 7 h, instead of 16 h, the probability of failure-free work would be:

$$P = 2.71^{-\frac{4}{7}} = 0.4630.$$

Let us discuss the possibility of using this criterion with reference to the parameter of direct failures referable to the category of moderate and simple ones. Here, it is possible to use the criterion to characterize the reliability of a specific pilot and to evaluate the reliability of a group of pilots united by some common conditions.

It is obvious that the negative numerator of 2.71 should be a constant number characterizing up time per failure inherent in specific pilots or a group of pilots with the same tenure in flight work who work under approximately the same conditions (type of aircraft, route, meteorological conditions, etc.). Indeed, no gauge other than mean up time per failure can fulfill function t. The negative denominator should consist of a number characterizing the duration of failure-free work or specific up time per failure referable to a given pilot or the corresponding means for a group of pilots.

On the basis of foreign data (D. L. Urschel, 1963; H. S. Sell and S. P. Chunn, 1964), it can be arbitrarily considered that numerator t equals a constant of 2000 h, then the equation

$$Pms = 2.71 \frac{2000}{x},$$

where "x" -- individual or group up time per failure or duration of failure-free work -- would reflect the probability of failure-free work by a pilot or group of pilots.

If, for example, a pilot who has logged a total of 13,000 h had 5 simple or moderate failures in the first 2000 logged hours, 2 failures in the next 6000 h and 1 in the last 5000 h, the dynamics of reliability according to this criterion would be expressed as follows:

$$\text{first stage of flight work } P = 2.71^{-\frac{2000}{400}} = 0.0067$$

$$\text{second stage of flight work } P = 2.71^{-\frac{2000}{3000}} = 0.5016$$

$$\text{third stage of flight work } P = 2.71^{-\frac{2000}{5000}} = 0.6703$$

This example is also interesting because it shows how pilot reliability changes in a typical case in the course of flight work: unlike the reliability of equipment, which is low at first, then increases and again drops drastically at the end of the work period, pilot reliability increases progressively in most cases with increase in hours logged, experience and conditioning.

The probability of failure-free work, as a criterion of reliability, can also be used to evaluate indirect failures with consideration of several conditions: in the first place, duration of flights, for which the criterion is to be calculated must be at least 7-8 h, since with shorter duration the number of pilots with combined adverse changes would be small (no more than 50%); in the second place, in-flight studies would have to be made hourly in order to have sufficient information about development of failures.

Having taken an arbitrary quantity of 2 h as t (see p 8), we obtain the following equation, which is suitable for calculating the criterion according to the parameter of indirect failures:

$$P_{\substack{ind\\indiv}} = 2.71^{-\frac{-2}{x}}$$

where "x" is duration of flight after which an indirect failure occurred. Having calculated with this formula the values of $P_1, P_2, P_3, \ldots, P_n$ for different pilots performing similar flights, we can use the following formula:

$$P_{\substack{ind\\group}} = \frac{\Sigma \; P_{ind.indiv}}{n}$$

to calculate the probability of failure-free work by a group of pilots.

3. The statistical parameter of reliability or mean percentage of failures* shows the number of elements (operations) with failures related to total number of elements (operations) and time of performance thereof in hours, expressed as a percentage. This criterion is determined with the following formula:

$$K_1 = \frac{d}{S \cdot t} \cdot 100\%,$$

where d is the number of elements (operations) with failures, S is total number of elements (operations) and t is operating time for all elements (operations), in hours.

This parameter can be used to describe reliability referable to any category of failures; however, it is particularly convenient for evaluation of individual and group reliability of performance of experiments simulating the conditions of forced breakdown (for example, design-related or physical forced failures), i.e., those for which the time and repetition factor is quite important to occurrence of the breakdown itself. If, for example, pilot action "a", performed to turn off one switch [tumbler] accidentally turns off a system that is important to the flight (action "b") due to a flaw in construction, in the simulating experiment the result would depend on the number of experiments and time of each action of the "a" type.

*This criterion is similar to another criterion, which is called the intensity of breakdown $\lambda(t)$; $\lambda(t)$ is the ratio of number of operations-failures to their performance time and to number of successful operations.

4. Maintainability [accessibility to repair] is assessed by a distinctive parameter of reliability, which shows how the equipment is adapted for rapid restoration of operability after a breakdown; as it applies to an operator, this criterion shows the portion of work time spent on resting. The quantitative evaluation of this criterion of the "rest-work" ratio is made with the following formula:

$$K_2 = \frac{t_{rest}}{t_{work}}$$

where t_{rest} is the time required to restore fitness for work (rest) and t_{work} is the time specified in the standards for performance of work. It is apparent that, with reference to equipment, a reduction of K means that its profitability increases, whereas with reference to a pilot this ratio must be as large as possible and in any case no smaller than 1.

During some trips--of long duration or with many intermediate landings and take-offs--pilot work time is up to 15 h per day; consequently, the "rest-work" ratio would be:

$$K = \frac{9}{15} = 0.6$$

At the same time, under ordinary conditions when the work period does not exceed 11 h per day, the "rest-work" ratio is 13:11 = 1.18. Unquestionably, this parameter can find application as a unique criterion of pilot reliability according to the parameter of optimality of work and rest schedule.

In our opinion, probability and mathematical statistics theory also offer other possibilities for evaluating pilot reliability.

If some parameters are recorded which characterize the quality of pilot performance of operations that are important to their occupation or the current state of their psychophysiological functions under laboratory or working conditions, such experiments are apparently aimed at determining the reliability of subjects. The importance and value of such an approach are particularly apparent when the experiments have goals such as determination of general and professional behavior of pilots in simulated difficult or accident situations or degree of efficiency [fitness for work] in the course of long-term flights.

In most cases, the results of such experiments are governed by the law of normal distribution or, at least, they present distribution curves that are similar to the curve of normal distribution, and the numerical description of the results is usually described satisfactorily by the formula for probability densities,* of the following appearance:

$$f_{(x)} = \frac{1}{\sigma\sqrt{2\pi}} \cdot e_{xp}{}^{-\frac{(x-\bar{x})^2}{\sigma^2}}$$

where x is a random quantity, $\bar{x}$ is mathematical expectation thereof and σ is its standard deviation.

*Probability density refers to the product dF(x)/dx of integration distribution function F(x) of a continuous random quantity.

If the experimental results pertaining to determination of reliability are governed entirely or to a significant extent by the above equation and, consequently, the law of normal distribution, one can set the maximum permissible range of reliability with the desired level of exactingness by using the well=known rule, "$M\pm2\sigma$" or "$M\pm3\sigma$."

If, for example, numerous experiments performed to determine the speed at which pilots take instrument readings show that $M+2\sigma$ equals 18 s, the concrete result of 30-40 s obtained for pilot N. is indicative of inadequate reliability in his performance of this complex function, which is important to the pilot. We could cite analogous examples to explain the meaning of range of fitness for work.

At the same time, if the adverse changes in different physiological functions, which are demonstrated in pilots and other crew members in the course of the work day, are governed by the law of normal distribution, the rule of "two-three sigma," as well as the known rules of probability theory and linear interpolation can be used for quantitative evaluation of different degrees of fatigue.

As the duration of flights increases from 2-4 h to 8-10 h, the number of pilots and navigators in whom adverse changes in physiological functions are found due to fatigue increases, and this is associated with an increase in average severity of the changes themselves. Since the distribution of negative changes is normal, the dynamics of fatigue can be expressed in the form of three degrees of fatigue, each of which is characterized by certain incidences of ... [illegible] degrees of adverse changes in the form of $M\pm m$. Viewing these physiological functional changes as independent events occurring with a probability that equals the incidence of their occurrence and using the rule of multiplication of probabilities, as well as linear interpolation, we can elaborate a rather effective method for quantitative evaluation of fatigue in a group of flight personnel (L. S. Isaakyan, 1967).

A quantitative determination of reliability of any element in a closed control system, including the human element, can be made from the standpoint of information theory.

If we consider that there is some analogy between the operator-pilot and communication channel in the sense of information processing, the functional reliability of the operator can be defined as "... The degree of conformity between the operator's ability to process information C and the amount of information H that he must process per unit time...."* Consequently, functional reliability is defined as the degree [measure] of loss of information according to Shannon's formula:

$$H(X) = H(X) - C$$

where H(X) is mean rate of production of information by the source of the communication, C is throughput and H(X) [sic] is unreliability of transmission of information in bits (reciprocal of functional reliability).

Determination of unreliability with this formula involves great difficulties, so that it is expedient to use reaction time (Tr) as a quantity that is strictly related to difference H(X) - C.F. This link is determined by various formulas, in particular the formula of Hyman (1953):

*Department of Scientific and Technical-Economic Information of the Ministry of Civil Aviation and State Scientific Research Institute of Civil Aviation, No 8-9, 1967. M. P. Sheynin.

$$Tr = T + \frac{H}{C}$$

where T is simple reaction time, H is amount of information that the operator must process per unit time and C is throughput.

It is obvious that the greater the H-C difference, the lower the operator's reliability.

However, when measuring Tr under actual flying conditions, major difficulties are encoutered and, for this reason, it is expedient to require a special parameter to judge changes in Tr, i.e., the quality of coordinating aircraft control ("economy" and promptness of moving rudders).

This discussion of the possibility of using information theory to determine the efficiency and reliability of pilots was taken from the work of M. P. Sheynin, who has been successfully developing theory and methods of experimental-analytical and instrumental approaches to this problem for the last 5-8 years.

To assess pilot performance when making a landing approach (in the sense of reliability and efficiency), M. P. Sheynin uses such objective experimental characteristics as parameters of accuracy, quality of coordination and levels of the main physiological functions that are recorded synchronously. In spite of the fact that some initial theoretical theses are debatable, the difficulty of pursuing the studies in practice and of popularizing this method among aviation physicians, the instrumentation and analytical method developed by M. P. Sheynin is the only one thus far and a rather promising means of making a quantitative assessment of flight work.

Heretofore, we have discussed the possibility of quantitative evaluation of reliability from the standpoint of various nonbiological theories; we were able to conclude that a number of concepts and methods used in theory of reliability of technical equipment and information theory can be used beneficially in evaluating the human element of a control system, provided several assumptions are made, without which it would be impossible to use these theories.* Indeed, aside from the rather validated and tested quantitative parameters of reliability in the method of M. P. Sheynin, it can be assumed that such criteria as probability of failure-free work (P), static coefficient of reliability (K_1), ratio of rest time to work time (K_2) and permissible range of negative reactions will also play a useful part in conducting tests simulating work operations of professional importance or the extreme range of adverse changes in physiological functions associated with marked fatigue.

Let us now consider the qualitative criteria of reliability, which are factors upon which depend somatic, psychophysiological and purely psychological mechanisms, which form this complex trait--reliability.

The three following groups of factors determining the reliability of an operator were singled out as a general scheme in the works of V. D. Nebylitsyn (1961, 1964): 1) quality of equipment; 2) operator training and conditioning; 3) personal factors.

*These assumptions include the assumption that linearity of changes, discreteness of processes, independence thereof, etc., are applicable to psychological functions.

The last group of factors is divided into three subgroups: medical factors; properties of higher nervous activity and subcortical brain structures; actually psychological factors and characterological distinctions (together with volitional ones).

The author justifiably believes that the last two subgroups are the most important items in the study of reliability, and he examines in detail several properties referable to man's higher nervous activity under the name of "certain characteristics of reliability." V. D. Nebylitsyn includes among such properties "long-term endurance," "endurance of extraordinary tension and stress," "imperviousness to noise [interference]," "spontaneous distractability," "reaction to unforeseen stimuli," "flexibility [ability to switch from one thing to another]" and "resistance to the effects of environmental factors."

The author uses unique terminology to refer to these characteristics and offers a distinctive interpretation thereof, and this applies in particular to the first three characteristics, for which reason we shall discuss them in greater detail, particularly since experimental evidence of the validity of the hypothetical explanations of these features was offered in the author's subsequent works (1966).

Long-term endurance of fatigue in the course of prolonged work is, in the opinion of the above author, determined by the strength or resistance of the nervous system to excitatory and inhibitory processes.

Endurance of extraordinary tension or stress (adequacy of operator's reactions to sudden stress conditions) is viewed as an indicator of resistance [stability] of the central nervous system to the process of excitation or as a function of equilibrium of the main nervous processes.

Immunity to noise or ability to create and strengthen dominant foci (in the case of exposure to distracting stimuli) is also considered to be a function of equilibrium of the main nervous processes.

The hypothetical theses advanced by V. D. Nebylitsyn are upheld in the works of M. I. Bobneva (1961,, 1964, 1966), and she calls attention to the general features of operator unreliability such as shortage of time, shortage of information, large number of sources of information and signals, and hazardous situations, which are mentioned by M. I. Bobneva along with some foreign authors (C. H. Baker, 1963; J. C. Larson, 1955, and others).

On the basis of the importance of comprehensive analysis of the concept of "failure," M. I. Bobneva devotes much attention to the unusual failures that occur from time to time in "a healthy, untired, experienced, emotionally stable operator under ordinary, normal conditions."

Such random cases of failure, which constitute 1-2% of the total number of operations and are, perhaps, related to vigilance and composure of operators (P. M. Fitts, 1962), have a generally unclear origin, and they should be the subject of special investigation in the process of operator screening.

Referring to foreign data (M. A. Grodsky, 1962; C. H. Baker, 1963), M. I. Bobneva demonstrated that the dynamics of a change in operator reliability in the course of prolonged work differ from the dynamics of reliability of technical components in that reliability is much greater, in spite of the repeated duplication of equipment operation.

B. F. Lomov (1966) observes, with reference to the qualitative criteria of reliability (phasic changes in efficiency, level of incoming information, immunity to various extraneous stimuli, particularly in dangerous situations, synchronous performance of different activities, etc.), that "... These data do not yet enable us to determine exactly the criteria of operator reliability. However, they do point the way toward searching for them. Evidently, future studies must be pursued in two main directions in order to define the coefficient of operator reliability."

"On the one hand, it is important to measure the time, during which an operator can perform specified functions without failure, and study the distribution of errors at different times of day. In this respect, the problem of efficiency [fitness for work] is the central one. On the other hand, it is necessary to analyze the distinctions of operator work in the presence of interference. Here we are confronted with the 'noise immunity' problem, which implies that there must be studies of gnostic (speed and accuracy of perception, speed of communication, ability to extrapolate, etc.), volitional (decisiveness, composure, restraint, etc.) and emotional (primarily emotional stability) traits of man. However, these directions are not isolated from one another. Moreover, it can be assumed that efficiency and 'noise immunity' have the same basis and emerge from the same or similar properties of the human nervous system."

Among the numerous foreign works dealing with engineering psychology, with reference to special problems of theory of reliability of the human element of control systems, there is none containing any unified system of theoretical views that would permit prediction of the results of concrete studies. Most works repeat the theses that we read about in the above-mentioned works by Soviet authors. Several experimental studies pursued by Jones (1962, 1965), and Dodson (1961, 1963) and J. Szafran (1963, 1965, 1966) are of some interest with respect to establishing relationships between the degree of an operator's nervous and emotional stress and, in the first place, build-up of two components of this state (emotional and motor) and, in the second place, quality of performance of moderately difficult tasks. These studies revealed that, as nervous and emotional tension builds up, the emotional component increases much faster than the motor one, while moderately difficult tasks are performed the most easily when there is a specific level of nervous and emotional tension, which is the optimum level of tension, from this point of view.

In concluding this survey of work dealing with qualitative analysis of reliability criteria, let us mention that the operator-pilot involved in a special system of control unquestionably has some specific distinctions which will be discussed in detail in a future publication. At present, let us define the main factors, upon which reliability (or unreliability) of pilots depends, on the basis of these distinctions.

The following are factors that disrupt pilot reliability (or cause unreliability of their work:

1. Psychophysiological factors:

   a) Emotional instability.
   b) Inadequately performed professional operations (general instrument reading, choice of correct decision in an emergency situation, determination of nature of breakdown and necessary action, simulation of typical flight accidents on a simulator).

c) Negative typological features.
d) Inadequate level of some psychological functions.

2. Factors referable to design and equipment;

a) Affecting the motor field.
b) Affecting the sensory field.
c) Affecting different systems in landing approach.

3. Work and schedule-related factors:

a) Fatigue in the course of the work day.
b) Fatigue occuring the course of the work year.
c) Acute diseases or special instances of violation of work and rest schedule.

4. Certain sanitary and hygienic factors:

a) Vibration.
b) "Altitude" in pressurized cabins under ordinary and emergency conditions.

Discussion of these unreliability factors is based primarily on analysis of our own experimental data and relevant literature sources, and in most sections we have submitted diagrams of original equipment, which was developed for the studies.

In discussing the factors of unreliability, attention was addressed not only to analysis of their causes, development and internal content, but effective means of detecting, predicting and setting standards for them in the sense of setting the maximum permissible ranges.

While this approach is new and may seem debatable with regard to psychophysiological and work-schedule-related factors (determination of maximum permissible ranges), it is quite justified with regard to the sanitary and hygienic parameters (vibration, reserve time of retaining consciousness at high altitude).

The work of a pilot is very specific operator work; for this reason, discussion of these factors of unreliability will be preceded by a description of general tasks for the crew, its interaction with the air traffic control service (UVD) and, the most comprehensively, the technical specifications of pilot work, including a description of indicators, controls and systems for making a landing approach (second chapter); the next two chapters preceding discussion of unreliability factors deal with the professiographic characteristics of pilot work (third chapter) and analysis of pilots' physiological reactions under simple and complex-emergency conditions of take-offs and landings (fourth chapter). Unlike the second and, in part, the third chapters, which are essentially descriptive and analytical, the fourth contains concrete experimental data characterizing the psychophysiological reactions of pilots under different take-off and landing conditions, which offer a clearer idea about the mechanisms of marked nervous and emotional stress.

On the whole, the three chapters preceding discussion of unreliability factors constitute the logical foundation for understanding the material that follows them.

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MEDICAL AND PSYCHOLOGICAL PROBLEMS OF CIVIL AVIATION PILOT RELIABILITY (NUMBER 2)

Moscow MEDIKO-PSIKHOLOGICHESKIYE PROBLEMY NADEZHNOSTI RABOTY LETCHIKOV SOVREMENNYKH TRANSPORTNYKH SAMOLETOV GRAZHDANSKOY AVIATSII (VYPUSK VTOROY) in Russian No 2, 1969 (signed to press 1 Nov 68) pp 1-40

[Complete translation of pamphlet "Medical and Psychological Problems of Reliability of Pilot Work in Modern Transport Aircraft of the Civil Aviation (Number 2)", by Levon Saakovich Isaakyan, candidate of medical sciences, USSR Ministry of Civil Aviation, State Scientific Research Institute of Civil Aviation, Department of Scientific and Technico-Economic Information, 40 pages]

[Text] Technical Specifications of Pilot Work

1. General description of air traffic control in the civil aviation and in-flight crew work

One of the main structural entities of the air traffic control service (UVD) is the airport control center--ADP. *

The ADP manages all organizational problems related to flights, it plans and coordinates the schedule of the Air Corps and Air Defense, schedules rest periods for crews at preventoriums and grants permission for flights.

In addition to the ADP, there are other structural entities that are involved in operational management of air traffic. They include, first of all, the control centers of the landing system (DPSP) and take-off control centers--SDP.

The controllers at these centers are equipped with landing radar [scopes?] and command radio equipment, and have an adequate range of vision, which they use to control aircraft that are taking off and approaching for a landing. The SDP controllers grant permission for take-off and inform the crew about runway conditions, wind, altitude of clouds and horizontal visibility.

After receiving permission to take off, the crew of the departing aircraft effects operations required for the take-off run, aircraft take-off, retracting the landing gear and flaps.

All of these operations are performed in strict order, at specific speed and altitude of take-off run and climb.

*Translator's note: For the reader's convenience, expansions of all abbreviations are also furnished at the end of this pamphlet.

After the flaps are retracted and an altitude of 100-200 m is reached, the crew alters the flight conditions from take-off to nominal, balances the aircraft and reports that take-off has been completed to the SDP controller.

The controller instructs the crew on the procedure for leaving the airport area and to establish direct contact with the next (third) structural entity of air traffic control, and the SDP terminates entirely communications with the crew of the airborne aircraft only after it makes sure that the next structural unit is monitoring the aircraft.

This structural unit is the approach control center (DPP), and previously it was called the command control center (KDP) [control tower].

In addition to radio communication, the DPP has high power surveillance radar stations with a range of up to 350 km; the task for DPP controllers is to monitor accuracy and safety of gaining altitude and check the prompt transfer of air traffic control to the next control point, the RDP.

The RDP--area control points [or centers]--are the fourth structural unit of air traffic control, and their duties consist of monitoring the correct course of the aircraft, specified echelon and prompt bypassing of dangerous meteorological conditions.

The RDP, which performs these operational tasks in a coordinated fashion, provides information to the crew about meteorological conditions along their route and weather forecasts at the destination airport and alternate airfields. When the aircraft passes from the area of one RDP_1 to the next RDP_2, the crew informs RDP_1 that contact has been established with RDP_2, which the latter confirms over special channels.

In the course of gaining altitude and in level flight, the pilots are busy with flying the plane, the engineer monitors the aircraft systems, the navigator in close collaboration with one of the pilots and radio operator establishes communications with the above points in the control service, and concurrently solves problems of navigation. The RDP_3, in the area of which the terminal airport is located, instructs the crew (navigator) on the procedures for bringing the aircraft down to the starting point (IP) for making an approach for landing. This starting point is usually located at an altitude of 4000, 1500 or 400 m above the outer marker beacon (DPRM).

The navigator calculates the time when the descent should begin in order to reach the indicated IP altitude; however, without permission from the RDP_3, the captain, to whom the navigator relays his estimates, does not begin the descent, and he informs the RDP_3 about any of his actions undertaken in the course of descent.

Transfer of control of the descending aircraft from the RDP to DPP (KDP) takes place at an altitude of 4-5 km, after the crew and DPP confirm to the RDP_3 controller that two-way communications have been established. Having received from the crew (captain) the report that they have entered the airfield area and identified the aircraft with radio equipment, the DPP controller informs the crew of its exact location, meteorological conditions and descent conditions in the area of the airfield.

These conditions or the maneuver for descent and approach for landing may vary: in some cases, the aircraft may head for the runway "in a straight line," in others, the aircraft travels over a more or less rectangular trajectory; in other cases yet, it turns at a specified angle, etc. Having indicated the specific descent maneuver, the approach controller (DPP) transfers control of subsequent descent and approach for landing to the DPSP controller (control point for landing system). This transfer takes place, as usual, by repeatedly informing the DPP that the DPSP has taken over control, and that the aircraft crew has established communication with the DPSP. Knowing the maneuver performed by the crew (from information given by the DPP), the DPSP controller gives the crew the specific landing pattern, altitude and shape of lower edge of clouds, horizontal visibility, wind velocity and direction near the ground, atmospheric pressure and condition of the runway. Having relayed this information, the DPSP controller starts to monitor the maneuver for the landing approach. As we have noted, this maneuver may vary, but the most important and typical variant is to guide the aircraft to a course that is the reverse of the landing pattern on the DPRM beam at a steady altitude of 400 m. At this point, the crew releases the landing gear and, after flying in a straight line for 60-70 s, makes a 90° turn (to the right in the case of a right landing circle or to the left, with a left circle); after this turn (which is usually called the third turn, if it is contained in the large rectangular route) the crew starts to lower the flaps and begins the next, last 90° turn (fourth turn) to pull into the straight line that coincides with the bearing of the runway. After the last turn, the crew lowers the flaps completely and shifts the aircraft to descent, simultaneously decelerating. In the interval between pulling out of the fourth turn and flying over the DPRM, the crew (captain) requests permission of the DPSP controller for landing. Having received permission, the crew flies over the DPRM, BPRM [inner marker beacon] and the 500 m marker (between the BPRM and end of the runway) at a specified altitude and speed, levels out and holds the aircraft, touches down, effects the landing run and taxiing. After flying over the DPRM, the crew has the right to give absolutely no answers after listening to the commands and recommendations of the landing controllers.

After flying over the BPRM 1000 m from the end of the runway, control of the landing and touchdown is transferred to the SDP (SKP) controller, since he has a visual view of the runway and it is simpler to coordinate aircraft take-offs and landings.

The above-described general scheme of air traffic control and some of the most commonly used landing procedures, including the final element of the maneuvers--the route from the DPRM beam to the runway, are illustrated in Figure 1.

2. Instrument systems for landing approach

The landing approach procedure, from the starting point on, is very seldom performed visually; as a rule, the crew either does not see the ground at all, or else sees it periodically through the haze or a break in the clouds. For this reason, in most cases, the maneuvers to pull into the last straight line in the area of the inner and outer beacon markers are performed by means of navigation and flying instruments; there are three well-assimilated systems for landing approach available to the crew and DPSP controllers.

The landing approach radar system--RSP--consists of continuous issuing to the crew of corrective instructions [commands] based on radar monitoring until the inner marker beacon has been overflown at an altitude of 60-80 m, when the crew must see the approach lights and runway.

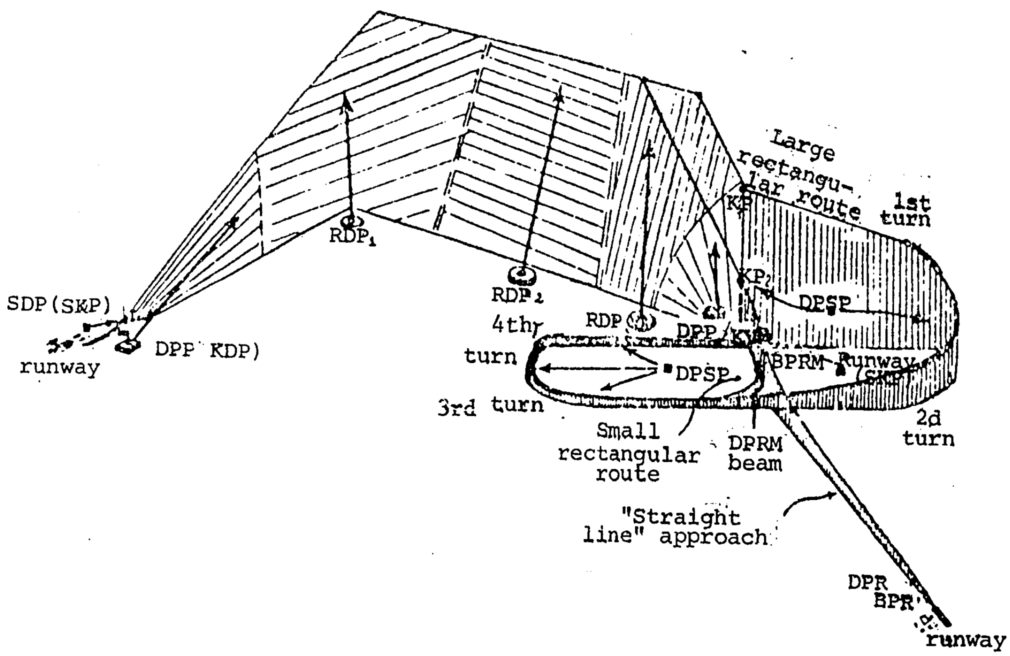

Figure 1. General diagram of UVD [air traffic control service] and some landing approach procedures

Key:

SDP) take-off control center [or point]
SKP) flight command post
DPP) approach control center
KDP) control tower
RDP) regional control point [center]
BPRM) inner marker beacon
DPRM) outer marker beacon
DPSP) landing system control center
KP) check point
KVP) expansion unknown [typo for KDP?]
DPR,BPR) expansions unknown

The radio compass landing approach system or instrument landing equipment--OSP--is the second system that the crew is guided by, according to the course angles of two radio stations situated 4 km (DPRM) and 1 km (BPRM) away from the end of the runway; the automatic direction finder [radio compass]--ARK--is the instrument indicator of this system aboard the aircraft, and it shows the course angles (angles read clockwise from the bearing of the flight to the line that connects the aircraft to the location of the DPRM or BPRM radio station)(Figure 2b).

Knowing the course angles in relation to the DPRM and BPRM (ARK readings) and the magnetic bearing of the runway (angle between magnetic meridian and heading of flight, read clockwise from the meridian), the crew can easily maneuver the aircraft to the landing line on the basis of the readings of the DGMK [distant-reading gyromagnetic compass], GPK [directional gyroscope] and other course [bearing] instruments.

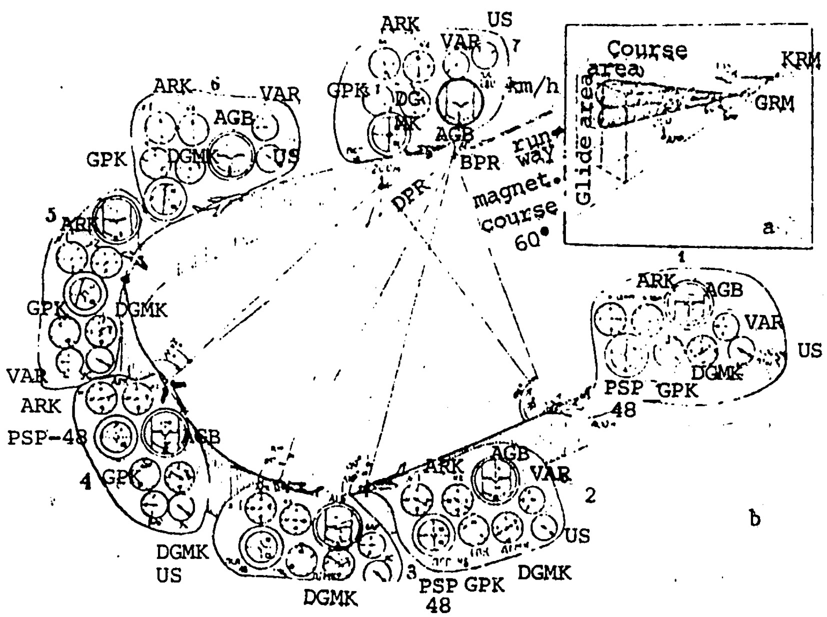

Figure 2. a) Ground-based SP-50 system equipment
b) Diagram of changes in readings of the main flight instruments of pilots when making a landing approach by the OSP-48 and SP-50 systems from DPRM cross beam
[some inscriptions are illegible]

The instrument landing system--SP or ILS abroad--is quite universal and more refined than the OSP. While in the latter case the sources of the signals for operation of radio compass indicators are radio stations situated along the landing path at the DPRM and BPRM points, in the SP the radio-range beacon (KRM, situated right behind the runway) and glide-path beacon (GRM, just in front of the runway) serve as these sources of radio emissions in the form of equisignal areas (Figure 2a).

The emissions from the KRM and GRM are received by the aircraft as it approaches the fourth turn, they are transformed into electric signals that deflect two needles on the PSP [instrument landing system] indicator (Figure 3b). If the aircraft has entered the range of the KRM, which corresponds to the start of the 4th turn, the course blinker on the front of the instrument is shut and the vertical needle, which represents the runway, moves away from the stop and starts to come closer to the middle of the horizontal marks (Figure 2b, positions 4-6). If the needle, as it slows down, approaches the circle representing the aircraft, it means that the aircraft is exactly on the runway course in the equisignal area of the KRM; if the needle deflects, for example, to the left, to the first or second horizontal marker, it means that the aircraft is to the right of the runway at a distance of 25-50 m from its axial line (Figure 3b). The horizontal needle of the PSP shows the mutual position of the equisignal area emitted by the glide path beacon (GRM) and aircraft flying in the vertical plane. When the aircraft is on the last straight line, the glide-path blinker is shut off on the PSP instrument and the horizontal needle, which is deflected upward to the stop, starts to move down, intersecting four marks, and comes close to the circle representing the aircraft. Slower movement of the horizontal needle and its stopping above the circle means that the aircraft is descending precisely on the glide path (Figure 2b, positions 6-7); if the aircraft is above the equisignal glide-path area, the horizontal needle will be above the circle representing the aircraft (Figure 3b).

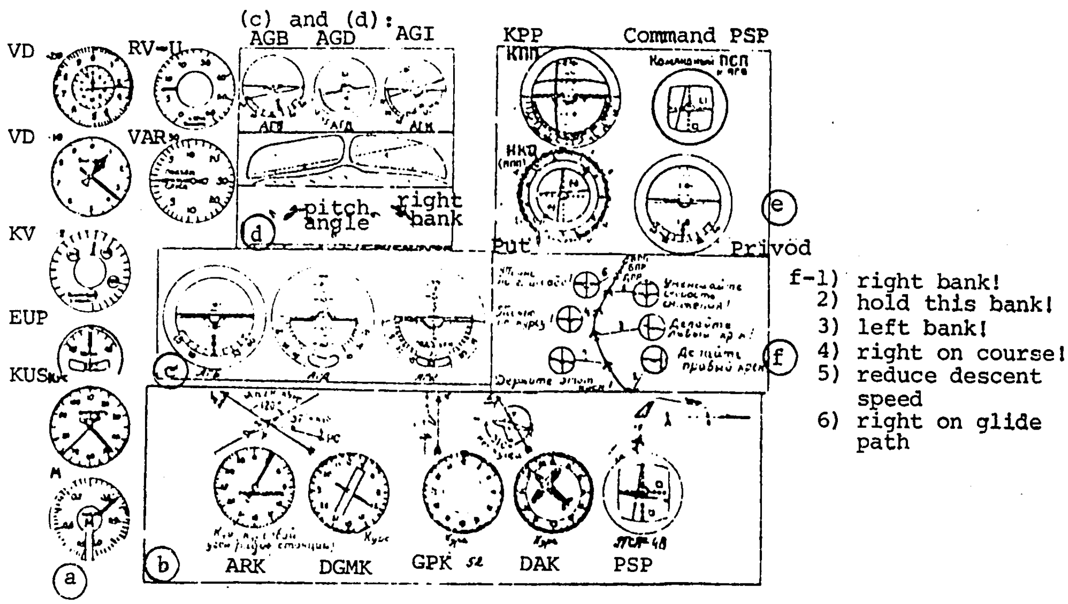

Figure 3. Diagram of flight and navigation instruments, and principle of display of readings on some of them

Two circumstances must be stressed. In the first place, none of the three systems discussed can assure a landing approach without the use of other indicators (course instruments--GPK, DGMK, UK [course indicator], artificial horizons -- AGB [bomber aircraft gyro horizon], AGD [azimuth gyro sensor?], AGI [fighter aircraft gyro horizon], speed and altitude indicators--KUS [combined airspeed indicator], VAR [rate of climb indicator], VD [barometric altimeter], RV [radio altimeter] and other instruments); for this reason, in an actual landing approach piloting involves the combined use of all three systems, or the last two systems (OSP and SP). Consequently, we are usually dealing with readings not only from the PSP and two ARK, but the 5-7 instruments that were mentioned above. Such continuous monitoring of a process that is essentially discrete is the most complex element of the pilot's analytical and synthetic activities, required to form an image of the flight, eliminate and prevent accumulating errors, as well as to complete the landing uneventfully.

The second circumstance that is important to comprehend the entire complexity of an actual landing approach using the combined SP and OSP system is that when meteorological conditions are poorer than a specific minimum none of the three systems or any combination thereof is capable of assuring the safe completion of the landing.

Minimum weather refers to the minimum ceiling [cloud base] and horizontal (inclined) visibility, at which a safe landing can still be made. For most aircraft with gas-turbine engines, this minimum (No 1) constitutes 80-100 m (for the ceiling) and 1000-1500 m (for inclined visibility). This minimum is acceptable for highly skilled pilots who have much experience in instrument flying. For less qualified pilots, a simpler minimum (No 2) is set, where the ceiling and visibility are 1.5-2 times greater.

According to the foregoing, if a crew at an altitude of 80-100 m or at a distance of 1000-1500 m from the end of the runway does not see the "start" [starting line?], approach lights or runway, they must immediately stop the descent, gain altitude and, together with the SDP controller or flight controller, determine subsequent tactics (a second landing approach on the same or opposite course, going to an alternate airfield, etc.). Some pilots have great moral and psychological difficulty in adhering to this important rule, which is also related to rapid and significant increase in nervous and emotional tension [stress].

Figure 2b illustrates instrument readings in a landing approach from the DPRM beam with the combined use of SP and OSP systems; it also helps comprehend the discussed principles involved in approaches using different systems. Figure 3 is a graphic illustration of the main flight and navigation instruments, as well as the principles of displaying information on PSP, ARK and other instruments.

In addition to the three systems for landing approaches we have discussed (RSP, OSP and SP), in recent years an automatic landing approach system has gained wide use; it operates in directorial (semiautomatic) and automatic modes.* In order to detect differences in interaction between the pilot and aircraft when landing by the combination of OSP and SP systems, on the one hand, and in the directorial and automatic modes of the new system, on the other hand, let us refer to the diagrams in Figure 4.

This figure contains two diagrams, showing interaction between the pilot and aircraft in a closed dynamic system when making a landing approach by the OSP and SP systems; this diagram corresponds to the combination of five instruments: ARK No 1. ARK No 2, AGB, UK, VAR for the OSP system, and four instruments--PSP, AGB, UK and VAR for the SP system. Under real conditions, both systems are united, forming a combination of six instruments that are shown on the pilot's panel (Figure 4, diagram A).

According to this diagram, ground-based radio equipment (KRM, GRM and radiostations situated at the DPRM and BPRM) implement operation of the PSP and ARK instruments; all other instruments on the pilot's panel (AG, US, revolution indicator, etc.) receive signals from sensors (only the bank and pitch sensors are shown in Figure 4), which pick up the aerodynamic reactions of the aircraft due to the controlling movements of the pilot. In this closed system, the PSP and ARK instruments play a leading, but not decisive part, since their readings answer the pilot's question of "what to do?" but not "how to proceed to reach the goal?" The pilot also needs the

*This system is called the BSUZP--onboard landing approach system.

readings of such instruments as the AGB, UK, VAR, etc., to obtain such concrete and, at the same time, integral evaluation.

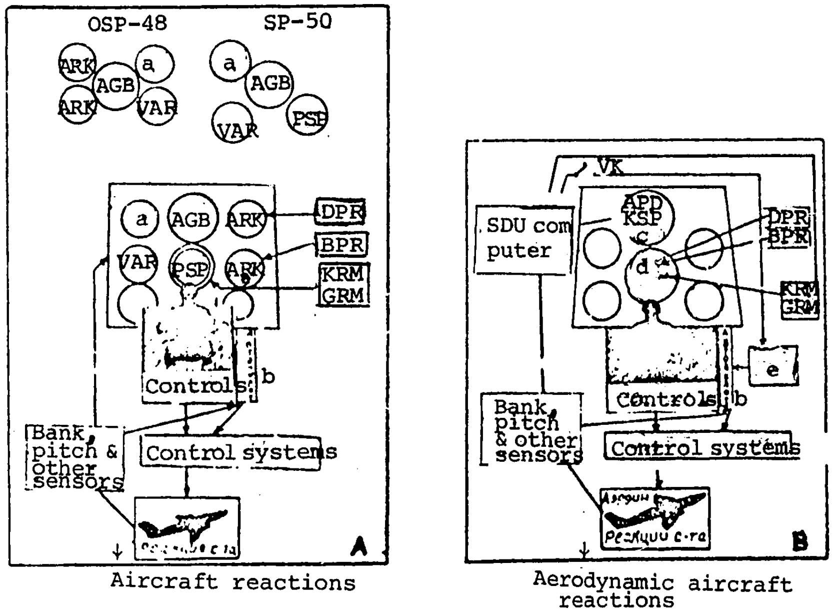

Figure 4. Diagrams of "pilot-aircraft" systems for landing approaches by the OSP and SP-50 systems (A) and BSUZP (B)

Key:
- a) DGMK
- b) autopilot
- c) (commutator)
- d) ARK, PSP, DGMK
- e) communications unit

From this point of view, the pilot can be perceived in the closed system of diagram A as the element which, having a relatively complex specified program-goal, eliminates mismatches between actual instrument readings and specified program readings, by means of diverse forms of tracking (compensation, pursuit, advance); let us mention that preservation of the required program and evaluation of the extent of mismatch are entirely determined by the pilot.

Digram B of Figure 4 illustrates the interaction between the pilot and aircraft in the case of an automatic system operating in automatic and semiautomatic modes. This diagram corresponds to one or two instruments: one of the PSP type, but with command, directorial functions and AGB (early version of semiautomatic system) or AGD with command functions (KPP [command flight instrument]) and combined navigation instruments consisting of an ARK, ordinary PSP and course indicator, for example, the DGMK (a more recent variant that can operate in semiautomatic and automatic modes).

Diagram B differs from diagram A in that the signals of sensors of bank (course) and pitch (movement of the aircraft on the glide path) are inputted in the SDU [system of directorial control) computer concurrently with the KRM-GRM signals, which characterize the equisignal areas of the course and glide path. Command signals are outputted by the computer, which first move the course command needle on the directorial PSP instrument (corresponds to starting the fourth turn), then the command glide-path needle of the same instrument (corresponds to start into glide path at 8-9 km away from the start of the runway).

If the course needle on a usual PSP is deflected to the left, it means that the runway is to the left of the aircraft and, in order to guide it on the landing path (the course needle to be set in the middle of the instrument) the aircraft must be turned in the direction of deflection of the needle (see Figure 3b), and this is done by relying entirely on the readings of the course instrument, and selecting the course by banking according to AGB to hold the aircraft in the equisignal area.

In a command instrument, for example, the PSP (which is referable to an early version of the Privod [drive] system of directorial control), deflection of the needle to the left means that the pilot must bank to the left as far and as long as necessary for the course needle to come to the middle and not be in vertical position, and there is absolutely no need then to take a bearing and select the bank.

When entering on the glide path, the horizontal needle of an ordinary PSP starts to move from top to bottom, toward the middle of the instrument, and the pilot's task is to set the needle opposite the center on the basis of AGB-pitch and the rate of climb indicator.

In the command PSP, it is sufficient to set the glide-path needle over the middle by altering the pitch and without the guidance of other instrument readings (Figure 3f).

Ultimately, the differences consist of the fact that in the command instrument deflections of needles are a function of several parameters, which the pilot takes into consideration in the SP system by means of several instruments (UK, AGB, VAR); for this reason, in the directorial and automatic modes of operation of the BSUZP, the command needles are in the middle of the instrument (at zero), not only if the aircraft is in the equisignal areas of the course and glide path, as is the case when flying by the SP system, but also when the aircraft makes the correct approach to equisignal areas (4th turn and at the time of starting on the glide path).

Heretofore, we were referring to one of the early systems (Privod) in our discussion of the directorial mode of landing approach; as can be seen in Figure 3e, this system consists of a command PSP and type AGB gyro horizon; in the more recent directorial system (Put' [route]), a type AGD gyro horizon is united with the command PSP into a single combination flying instrument--the KPP (command piloting instrument), which together with other combined NPP or NKP instruments (navigation-planning instruments which give information about the relative position of the runway and aircraft, course and course angle of the radio station) constitutes the onboard part of this system (Figure 3e). Of course, all that we have stated about flying in the directorial mode by means of a command PSP and AGB also applies fully to a KPP; however, it is obvious that when using the KPP to fly in the directorial mode, the pilot has to spread his attention less, since the command needles and gyro horizon are in the same instrument.

It is apparent from the foregoing that in a closed system illustrated in diagram B (Figure 4), the pilot can be conceived of as an element which performs the relatively simple function of compensatory tracking, without needing a complex program or searching for any mismatches.

The BSUZP can operate in directorial and automatic modes. On the example of operation of two versions of the system of directorial control ("Privod," "Put'"), we learned about the work of the BSUZP in expressly the directorial mode. The same diagram B in Figure 4 gives us an idea about the operating principle of this system in automatic mode. Diagram B shows that, when the VK is turned on, the command signals pass through the communication unit to the autopilot also, which starts to control the bank-course and pitch-glide in accordance with these signals (they also permit flying in the directorial mode as they pass to the KPP from the computer), and provides for an automatic landing approach down to an altitude of 30-60 m. For this reason, flying according to diagram B without using the autopilot is sometimes (and not quite correctly) called the system of directorial or semiautomatic landing approach, in contrast to the automatic control system, when the autopilot does the flying to certain limits (VK turned on).

The BSUZP system, which allows flying in directorial and automatic modes, is gaining broad use on well-assimilated aircraft with gas-turbine engines, reducing by almost one-half the minimum ceiling and horizontal visibility; it would be difficult to overestimate the importance of this circumstance in increasing the safety and regularity of flights.

3. Instruments and signaling devices on pilot panels

Indicators are divided into several types, regardless of their purpose. The first and most widespread type is referable to measuring or quantitative indicators (Yu. A. Petrov, 1963; V. G. Denisov and R. N. Lopatin, 1962). Instruments of this type merely give information about a given parameter; as a rule, this information is quantitative and static, in the sense that there are no directorial elements. Most instruments of pilots, as well as other crew members, are referable to the first type. However, this is not a homogeneous type, and its representatives can be divided into two subtypes, which combine the usual informative-indicating properties with either graphic, imaged features or pictography, or else with some directorial elements.

The first subtype refers, for example, to gyro horizons of different types (AGB, AGD, AGI), the radio compass (ARK) and scopes of onboard radar equipment. Each of these indicators gives not only a quantitative description of parameters, but facilitates comprehension of the meaning of these parameters because of the graphic display. If one were to observe the readings of the ARK and AGB on the diagram of a landing approach by the OSP and SP systems (Figure 2b), one could note, placing oneself mentally in the place of the pilot, that the needle of ARK No 1 and ARK No 2 always shows the pilot the direction of the DPRM and BPRM, whereas the horizon line of the AGB instrument deflects just like the real horizon when the aircraft makes turns. The image on the radar scope yields diverse quantitative information about the movement of the aircraft (range, speed, deviation from specified path, etc.), but for an experienced operator reception and interpretation of such information are easier because it is so graphic. There are also elements of graphic display in other instruments, in particular the course instruments, rate of climb indicator, altimeter, etc. Their graphic nature consists of the fact that the movement of the needle-pointer coincides with the actual direction of movement of the aircraft (the course instruments-DAK [remote reading astrocompass], DGMK), movement of the earth's surface observed from the aircraft cabin (GPK [directional gyroscope]), and in some cases graphic visualization is effected by the coincidence of changes in the parameter on the instrument and the customary symbolic indication (for example, movement of the needle up or clockwise on the rate of climb indicator, or speed and altitude indicators are readily associated with an increase in the corresponding parameters).

The instruments referable to the first subtype constitute the group of the most important flight instruments, and for this reason we shall discuss them in greater detail, referring to the drawings of the dials of these instruments in Figure 3.

The combined speed indicator (KUS) is a two-needle instrument that shows two parameters:air or true speed of the aircraft in relation to air masses (narrow needle) and instrument speed, which measures the actual thrust [dynamic head?] (wide needle).

The machmeter (M) shows the ratio of true speed to the speed of sound. The readings of this instrument are very important when flying at high speed (in horizontal flight or emergency descent), when exceeding permissible speed endangers the aircraft. For this reason, there is a light signal next to the Mach indicator to show "high speed."

The radioaltimeter (RV) shows the true altitude of flight over a given locality, and it has two ranges, 0-1200 m and 0-120 m, as well as audio and light signals to show that the altitude set by the pilot in advance has been reached. The disadvantage of the RV, which limits its use, is the variability of its readings when flying over a locality with irregular topography.

The barometric altimeter (VD) shows the relative altitude of flight in the range of 0-20 km, the small needle showing kilometers and the large one hundreds and tens of meters. The pilot uses a special rack gear to set barometric pressure on the altimeter that equals atmospheric pressure at the descent and landing point; the altimeter readings change in accordance with the set pressure. If the aircraft descends in a high-altitude region, the instrument being adjusted to standard pressure, the altimeter will show a higher altitude than in actuality, and this, of course, is a great threat to flight safety. The rate of climb indicator (VAR) shows the vertical speed of aircraft descent or climb (VAR-30) or the speed of change in altitude in the cockpit (VAR-10).

The three types of gyro horizons are intended to determine the position of the aircraft in space as it turns about the longitudinal and transverse axes; the instrument shows the angles of bank and pitch, as well as the direction and degree of sideslip (Figure 3c). In a gyro horizon of the AGB type, the display of banks and pitch angles simulates well the movement of the natural horizon and does so just like the pilot sees it from the aircraft cockpit. If, for example, the aircraft is gaining altitude with a right bank, the pilot sees the horizon and surface of the earth as being tilted to the left, and as he gains altitude the horizon gradually descends, "underneath the aircraft." This happens at the time when the angle of pitch of the aircraft changes in the direction of pitch-up. This evolution of the aircraft, the visual picture observed by the pilot and the associated readings of the three types of instruments (AGB, AGD and AGI) are illustrated in Figure 3d. It should be expected that in a visual flight such conformity between what is observed directly and indirectly on the AGB will not cause any difficulty for the pilot with regard to understanding the readings of this instrument; the situation may differ in the case of instrument flying, if the pilot stops monitoring the bank on the AGB dial, for some reason; in such a case, the pilot will associate his actions more with the movements of the aircraft than concomitant movements of the artificial horizon on the AGB instrument. If, for example, while flying by instruments the pilot sees that the instrument horizon starts to drop (climb!) in relation to the motionless silhouette of the aircraft and, at the same time, banks to the left (right bank!), the first reading is readily associated with the fact that he is gaining altitude, while the second is associated worse with the conception that the aircraft is banking to the right. The first investigators of this matter demonstrated that an instrument, in which the symbol for the aircraft moves and the horizon is stationary, which creates the direct image of aircraft movement, yields the best results, at least with regard to showing banking (Braun and Louks, 1945; Greter, 1947; Fitts, Milton, 1946, 1952). Subsequently, this opinion was confirmed (T. I. Zhukova, Ye. M. Ol'shanskaya, 1956; K. K. Platonov, 1960) and, at the same time, seriously questioned (Matheney, Dougherty, Wills, 1963).

As can be seen in Figure 3d, the reading on the AGB makes full (for both bank and pitch) use of the principle of view "from the aircraft to earth," whereas in the AGD type gyro horizon this principle is applied only to show pitch, which is quite acceptable from the standpoint of the hypothesis that we have expounded that it is expressly indication of pitch that is well associated with the actual and exhibited movement of the aircraft. A seemingly more valid principle is used to show banking in the AGD--view "from earth to the aircraft" (the moving silhouette of the aircraft banks in relation to a stationary line--depicting the horizon--just like the aircraft and synchronously with its movement). Perhaps, in the case of visual flight, when the pilot periodically checks the gyro horizon, such an instrument could cause some difficulties, since the inclination of the natural horizon will have to be correlated with the opposite direction of inclination of the silhouette of the aircraft.

The last type of gyro horizon, the AGI, does not differ in any way from the AGB with regard to showing banking (view "from aircraft to earth"), but it gives the opposite indication of pitch, as compared to AGD and AGB. This means that as the aircraft gains altitude the horizon line does not move down, as seen from the aircraft and used in the AGB and AGD, but up, and this does not conform with either of the above principles. The revolving sphere of the AGI has pictographic and display elements; the bottom hemisphere, which is light blue and has the inscription "climb," turns upward when gaining altitude, showing an apparent increase in the blue, sky part, while the top hemisphere, which is brown and inscribed "descent," rotates to the back, and the visible area of this hemisphere diminishes when gaining altitude. Moreover, there is a warning sign near the AGI to tell the pilot that the pitch readings on the AGI are the opposite of AGB readings.

Resistance to accelerations caused by strong bumps of aircraft in a turbulent atmosphere is a rather important indicator of the quality of gyro horizons.

At the present time there are tested reports that the AGD instrument, which was first installed on the AN-24 aircraft and subsequently contained as a combined element of the KPP (command flight instrument), is more resistant to accelerations than the AGB.

The electric turn indicator (EUP) shows the direction of a turn (when the aircraft turns about the vertical axis) and sideslip. When the turn is made in a coordinated manner and at specific speeds, the EUP measures banking up to 45°.

All of the course instruments (DGMK, DAK, UK, GIK), with the exception of the GPK, show the direct magnetic or true flight course. Unlike the above-mentioned instruments, the GPK can show not only the actual course, but any other preset value. The GPK is superior to other instruments, particularly magnetic course indicators, in that it is not susceptible to interference at northern latitudes and operates with greater stability. The principle involved in reading and interpreting the data shown by all course instruments, with the exception of GPK, is simple, and it is graphically illustrated in Figure 3c: if the pilot mentally visualizes a heading to the north over the meridian, it is not difficult to associate the direction of the aircraft on the course with the movement (rotation) in the same direction of a needle indicator or needle-airplane (view "from land toward the aircraft").

The GPK uses the opposite principle (view "from the aircraft toward land"), in which the symbol for the aircraft is a stationary triangle, while the movable scale moves just like the plane of the earth's surface. Although with such display there is infraction of the rule that the movement of the indicator must coincide with movement of the aircraft (Fitts, 1952, and others), the GPK is apparently rated highly by flight personnel.

The second subtype of quantitative or measuring indicators gives not only quantitative but directorial, command information. The PSP instrument is a typical example of this subtype, and we have already discussed the purpose and use thereof (p 12 [of source]). As we have already noted, the PSP is a relatively directorial instrument, since the commands it issues cannot be implemented without simultaneously checking and interpreting the readings of 2-4 other indicators (AGB, UK, VAR and other instruments*). In other words, the commands received by the pilot from the PSP contain a distinct element of "what to do" and rather vague indications as to "how to do it." It should be noted that the same directorial principle is contained in many other instruments, where the dial has a mark for the target or when there is critical, inadmissible exceeding of a parameter (indicators of operation of various systems).

The second type of instruments includes directorial or command instruments. In the civil aviation of our country and foreign countries, these instruments appeared relatively recently, and there has obviously been insufficient experience in use thereof for the pilots to be able to evaluate them comprehensively. Directorial instruments are intended primarily to facilitate the pilot's work during landings, and further refinement and introduction thereof will solve the problem of semiautomatic landings (see pp 17-19 [of source]).

*It is particularly complicated to interpret and generalize all these indicators if, as is sometimes the case, the readings of the main PSP instrument do not agree with the expected readings of the course indicator and AGB. For example, the aircraft should pull into the landing path within the next 5-10 s according to the PSP readings, whereas the course indicator shows that the turn should last much longer.

As we have already mentioned, at the early stages of development of directorial control systems, the command PSP and ordinary AGB were the typical directorial instruments; the command PSP did not differ outwardly in any way from the usual PSP, but in actuality its readings gave the pilot detailed information as to what he should do and how he must do it for proper piloting in making a landing approach. In the more recent and complex system of directorial control, which subsequently served as the foundation of the BSUZP system, the command PSP was combined with the AGD into a single command flight instrument, the KPP; there was a combination NKP instrument, containing a usual PSP, ARK and course indicator next to the KPP so that the pilot could monitor the flight in the automatic mode of landing approach or fly by the SP system.

The third type of instruments, which have gained wide use in recent times, are combined instruments. They include, for example, the instruments to monitor engine operation and related systems. In some cases, an instrument gives readings of the same parameter for two engines (revolution indicator, indicator of position of fuel throttle, etc.). In other cases, one instrument displays readings of different parameters for the same engine (three-needle fuel pressure, oil pressure and temperature gauge for one engine). Such combinations are convenient and based on logic: in the first case, checking one instrument yields information about two parameters of two engines and, since we are dealing with a common parameter, the pilot's job is merely to eliminate a mismatch between the readings of one instrument; in the second case, monitoring one instrument makes it possible to immediately assess the main parameters of one engine. The principle of meaning-related, logical combination has gained wide application as well in the design of flight and navigation instruments. An example of such combinations is the unification in one KPP instrument of a command PSP and AGD, or combination in the NKP (NPP) of such instruments as PSP, UK and ARK, which we have mentioned repeatedly. Let us note that such combinations are expedient from the standpoint of concentrating the readings of different, but functionally related instruments in the pilot's central field of vision, which reduces angular eye movements and, consequently, results in faster perception of instrument readings.

The three types of instruments we have discussed--informative, director and combination--are supplemented with appropriate signals (lamps, panels, audio signals, etc.). In addition, there are electromechanical signals on the instruments that report to the pilot in the event of malfunction of the instrument; most often, they consist of blinkers or flags, the closed or open position of which gives information about the efficiency of the instrument.

Informative signals can be divided into three types. The first type refers to signaling equipment that informs the crew about a normal mode or normal operation of various systems and units. Such signal systems include the signals of passing over markers, turning on control of front wheel, automatic brake, turning on and normal operation of deicing system, hydraulic pumps, fuel pumps, remove propellers from stop [?], release and eject brake parachutes, etc. The first type of signal lamps have white, blue or green light filters.

The second type includes signaling equipment that informs the crew about an impending undesirable or dangerous situation. Such signals include: "aircraft speed is high," excessive engine power, fuel and oil supplies are close to minimum permissible levels or allow for only 30-60 min flying time, etc. The light filters of these signals are yellow, orange or red.

The third type of signals inform the crew about presence of an emergency situation and efficacy of steps that are performed automatically in this situation or undertaken by the crew. The third type of signals report malfunction [failure] of engines, generators, feathered propellers, fire in the engines, triggering of firefighting system, icing of different parts of the aircraft, depressurization of cabins, etc. These signals have red light filters, intermittent signaling and, not infrequently, they have an audio signal back-up. Expressly these complex and important signaling elements, which combine different modes of signaling, should be classified as combined signals.

The director signals have limited significance and consist of audio and light stimuli, which must call the crew's attention to signs, such as "start TG [expansion unknown]," "lower landing gear," etc.

In order to offer a more graphic idea about instruments on pilot panels, Figure 5 illustrates photographic mockups of the left, middle and right instrument panels of the early TU-124 aircraft. The captain's panel on the left contains the following equipment: cabin rate of climb indicator [variometer] (1), parachute release-eject signal (2), Mach indicator (3), "high speed" indicator (4), radio altimeter switch (5), radioaltimeter (6) and the signal related to it, "dangerous altitude" (7), barometric altimeter (8), speed indicator (9), rate of climb indicator (10), NKP (11), AGB (12), AGI (13), EUP (14), ARK (15), GPK (16), instrument and signals of the "dome" navigation system (17), air flowmeter for cabin pressurization (18), outside air thermometer (19), signals for up-down landing gear positions (19a) and position of trim tabs (20).

The middle panel, which is primarily the concern of the flight engineer contains the following: revolution indicator of the two engines (21), engine flowmeters (22), "30-min fuel left" signal (23), temperature gauge for gases behind turbines (24), three-needle combination indicators showing high fuel pressure, temperature and oil pressure for each engine (25), pressure gauges and signal lights of the hydraulic system (26), flap and tab position indicators, signals of airtight closure of hatches and doors (27), low pressure gauges (28).

The right copilot's panel contains, in addition to the indicators present on the left panel, the following instruments and signals: fuel gauge and corresponding controls (29), deicing system indicators and controls (30), altitude system indicators and controls (31).

We have discussed various instruments and signals installed on pilot panels chiefly from the technical point of view. From the psychophysiological point of view, each indicator can be studied in different aspects: readability under stress condition and when time is short, psychological validation of instrument dial design, difficulty of identifying malfunctions [failures] and changing to back-up instruments, etc.

These interesting questions, which are the subject of investigation of many researchers (V. A. Popov, A. M. Nikovskiy, Yu. V. Krylov, 1966; V. A. Ponomarenko, A. G. Shishov, 1966; Forbes, 1946, and others), will be touched upon to some degree in our subsequent presentation.

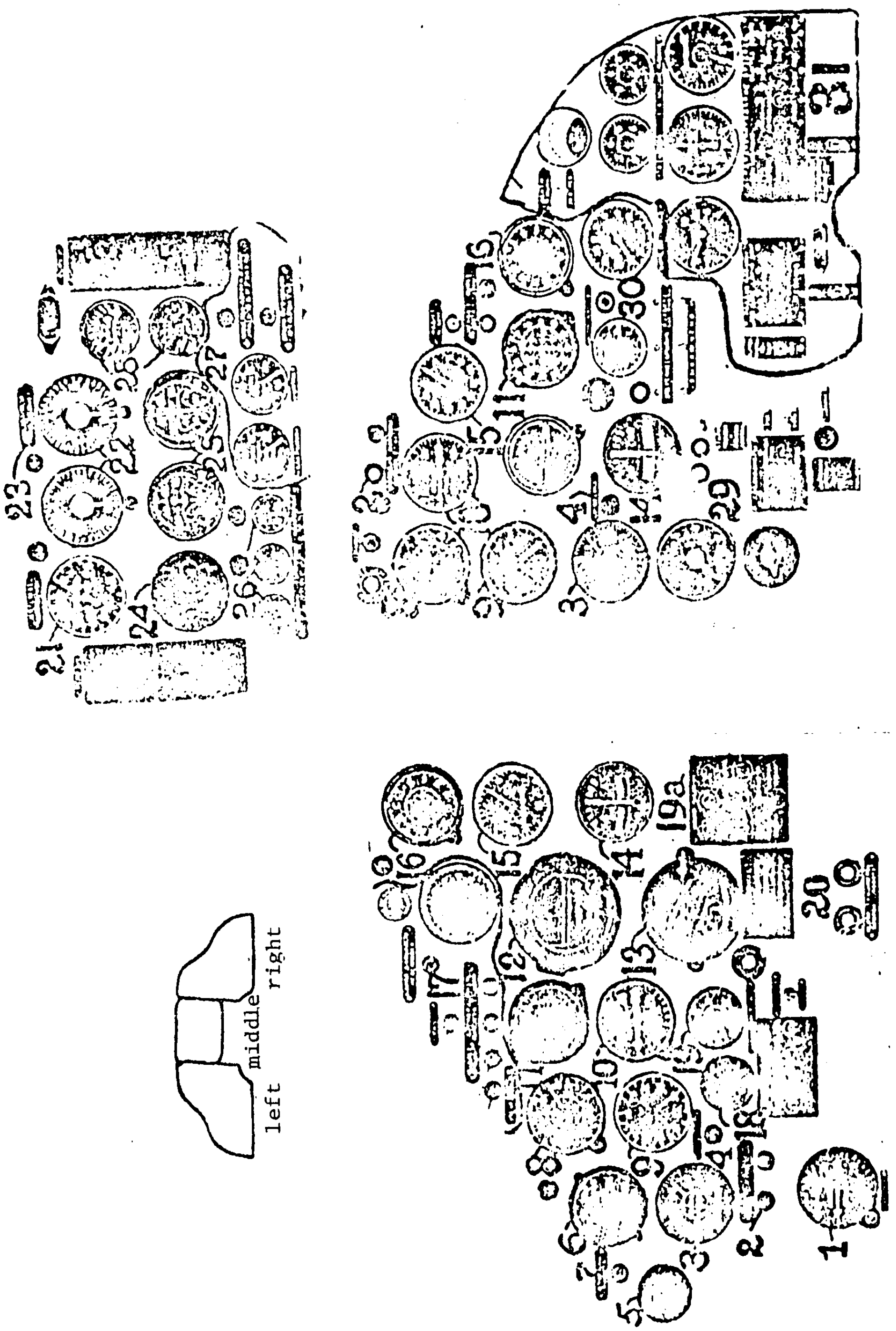

Figure 5. Photographic mockup of Tu-124 instrument panels

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4. Pilot's controls

The location of pilot controls in relation to his work place and panels is of exceptional importance.

The opinion has been voiced in the English and American literature of recent years that optimum placement of controls must be based on separating them into the main ones, which the pilot uses constantly, secondary ones, among which a distinction is made between those placed near the hand (hand fixed), those used by the free hand (hand free) [sic] and emergency controls.

The arrangement of all controls must conform with the anthropometric and psychophysiological distinctions and requirements of pilots, with consideration not only of their work during flights, but rather rapid preflight checks (Morant and Smith, 1947, 1957; Rolfe, 1965).

K. K. Platonov (1960) observed, with reference to questions of psychological rationalization of aircraft cabins, that "designers divide controls into the following groups according to usage conditions: main, used regularly; main, used during different segments of flight; auxiliary [ancillary]; emergency; those used on the ground during preflight preparations.

The author singles out the controls in accordance with the specifics of work movements performed: first group (control wheel, pedals, engine control levers), second group of controls that supplement or replace those of the first group (trimmer, autopilot control, etc.) and lists among other controls (third and fourth groups) various levers, adjustment and setting knobs, as well as button and tumbler control of the "on-off" type.

In our opinion, a quite acceptable classification is one that takes completely into consideration the functional principle, i.e., frequency of pilot use of various controls. Evidently, this factor must be taken into consideration for the most complicated phases of flight--take-off and landing.

From this point of view, the control wheel, pedals and throttles should be considered the main controls.

Trimmer, autopilot and ultrashort-wave (UKV) station controls should be considered additional controls of the first order.

We can list among additional secondary [second order] controls those used to lower and retract the flaps, landing gear, interceptors, spoilers, setting and removing propellers from the stop, etc.

Let us briefly discuss the main and auxiliary controls at the work places of pilots of civilian gas-turbine engine aircraft, on the basis of the above classification principles. As we have already noted, the main controls are the control wheel, pedals and engine (throttle) control levers.

The control wheel [stick]: When the control column is pulled toward or away from the pilot it causes the aircraft to rotate about its transverse axis due to aerodynamic reactions of the elevator. These control movements change the angle of pitch of the aircraft and put it in the climb or descent mode.

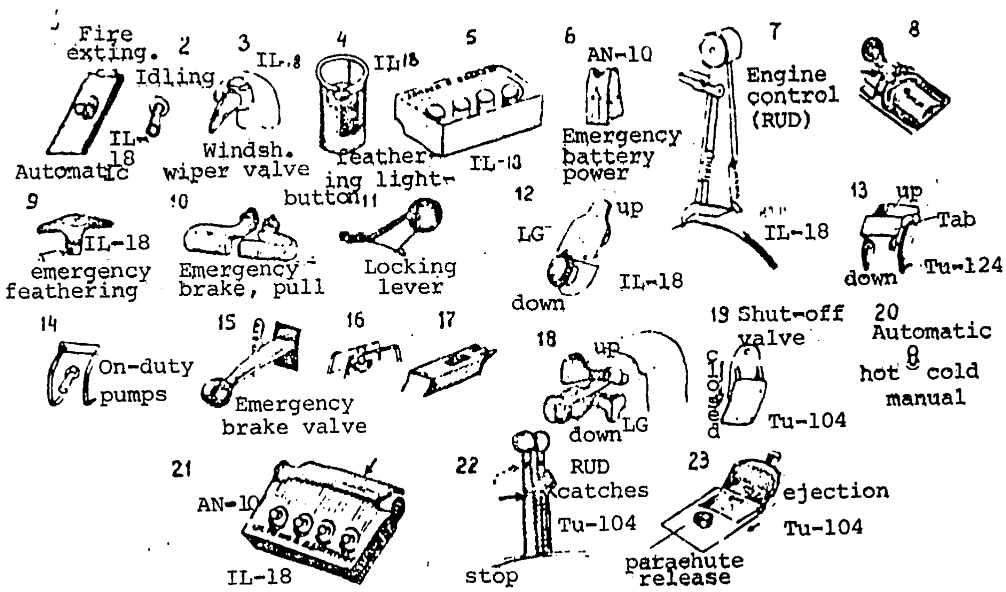

Figure 6. Drawings of some controls [LG--landing gear]

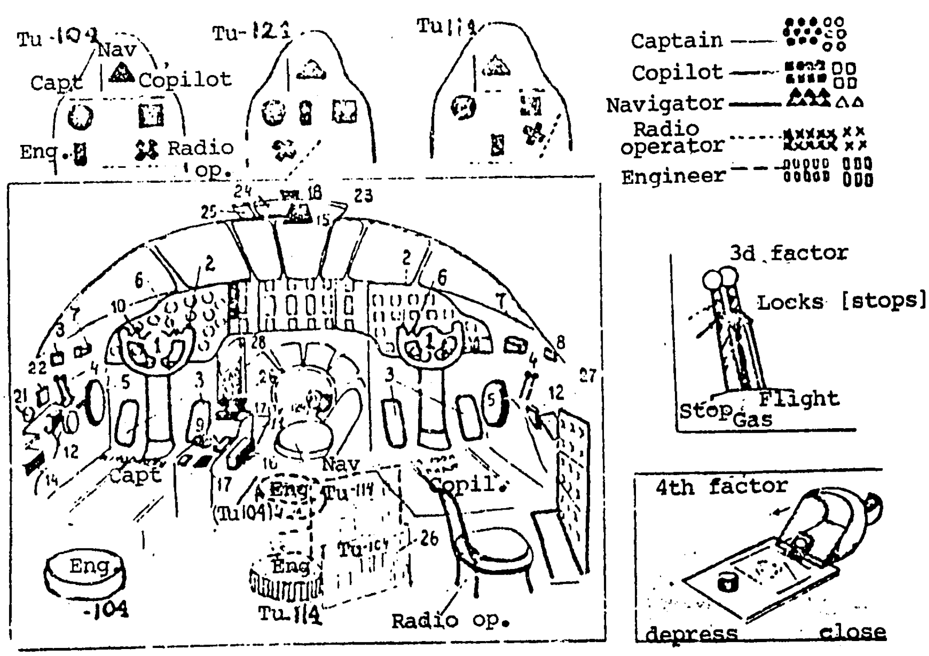

Figure 7. Arrangement of some controls and work places of crews aboard Tu-104, Tu-124 and Tu-114 aircraft

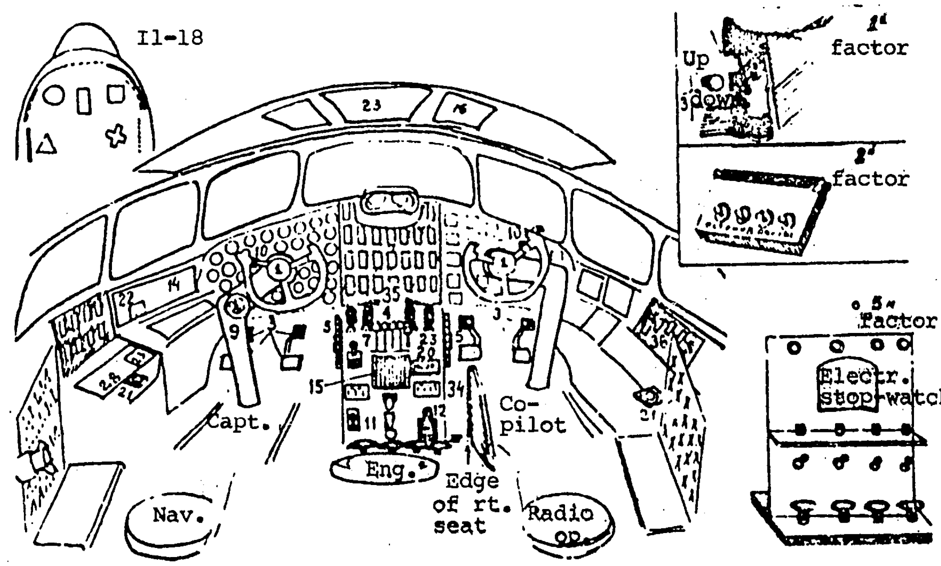

Figure 8, Location of some controls and work places of crews of the Il-18 aircraft

Moving the control wheel [stick] to the right or left causes the aircraft to turn about its longitudinal axis due to the aerodynamic reactions of ailerons, and the aircraft makes a right or left bank.

Pedals: Pressure on the pedals, which causes them to deflect, causes the aircraft to turn about its vertical axis due to aerodynamic reactions of the rudder. Control of the brakes and front landing gear wheels during take-off and landing runs is usually coupled with the pedals; however, the nature of pedal movements changes for control of the brakes: instead of exerting pressure, the front of the foot [toe] is used for separate depressing movements.

Movement of the control stick toward and away from the pilot, to the right and left, and application of pressure to the pedals with the feet require some static exertion by the pilot, which may reach significant levels, even under ordinary flying conditions (at low or high flying speed); under more complicated and difficult conditions, these exertions may exceed the physical capabilities of the pilot. Trimmers are installed on the control sticks to reduce exertion, and they are moved by the pilot mechanically or electrically. The corresponding controls (which are called elevator, rudder and aileron trimmers) are located in the immediate vicinity of the control stick, and they constitute an additional group of first-order controls used less often than the control stick, pedals and throttles; in the same group, we should include the automatic pilot with its adjustment and setting controls, as well as control of the command radio station (UKV). The additional group of secondary controls includes, in addition to landing gear and mechanization controls (flaps, tabs, interceptors, spoilers), numerous levers, lights and buttons, valves that serve to stop or start the engines, move propellers from the stop, feather them, etc.

Engine control: There are engine control (RUD) levers or throttles that regulate engine thrust. These main controls are situated on the left and right pilot panels (on TU-104, TU-124 and AN-10 aircraft) or on the flight engineer's panel in the middle (on IL-18 and AN-24 aircraft), or else on both the pilots' and engineer's panels (TU-114 aircraft).

Some of the most typical controls are illustrated in Figure 6; Figures 7-9 show the location of various controls and work places of crews for five types of aircraft with gas-turbine engines.*

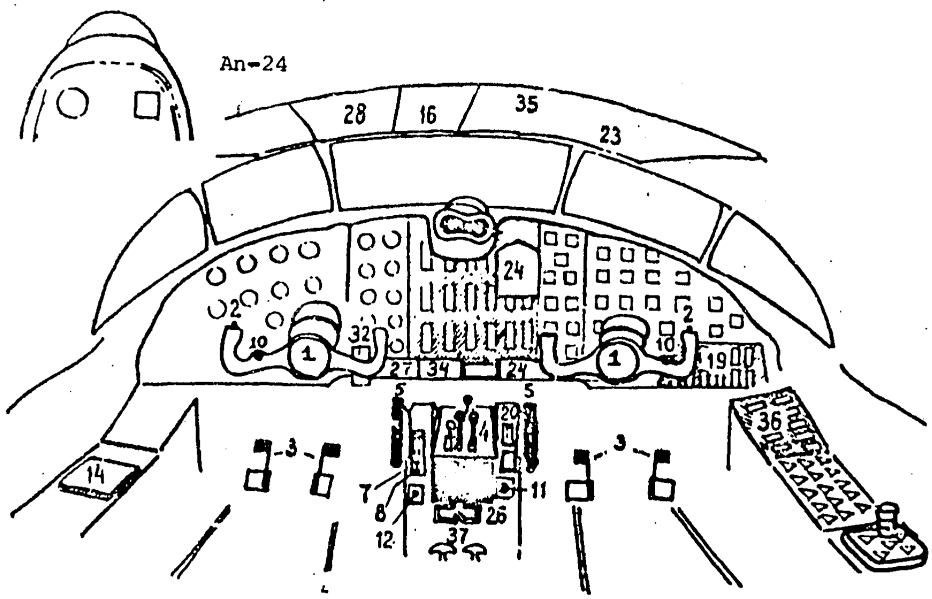

Figure 9. View of some controls and work places for crews of the An-24 aircraft

List of controls illustrated in Figures 7-9:

1) control stick
2) radio control (UKV)
3) rudder and brake control
4) engine controls (RUD)
5) mechanical control for elevator trimmer
6) electrical control for elevator trimmer

*TU-104, TU-124, TU-114, IL-18 and AN-24 aircraft. The right sides of Figures 7 and 8 show the different controls under the names of 1st, 2d, ..., 5th factors, and the meaning and purpose of these factors will be made clear in our next publication.

7) aileron trimmer control
8) rudder trimmer control
9) front wheel control
10) emergency automatic pilot turn-off
11) landing gear lowering and retraction control
12) flap control
13) interceptor control
14) engine control
15) autopilot
16) UKV station
17) parachute release and ejection control
18) emergency landing gear control
19) deicer system control
20) engine stopping control
21) oxygen
22) intercom
23) fire-extinguishing system control
24) fuel system control
25) engine starter for use in the air
26) emergency brakes
27) control for release and turning on headlights
28) location of power generator aboard the TU-124
29) location of generator aboard the TU-104
30) controls and work place of flight engineer aboard the TU-114
31) emergency battery charger
32) adjustment of instrument illumination
33) hydraulic system control
34) oil cooler flap control
35) control buttons to feather propellers
36) control for altitude [pressurization?] system
37) emergency feathering

AUTHOR'S COMMENTS

1. The UVD structure described in the first section (first 3 pages) has been recently refined.

2. It must be borne in mind that the PSP type instrument (but with command functions) and the AGB instrument described in this pamphlet are instruments of a simplified system that has not been put in operation.

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Abbreviations

ADP	airport control center
AGB	bomber aircraft gyro horizon
AGD	azimuth gyro sensor [?]
ARK	radio compass
BPRM	inner marker beacon
BSUZP	onboard landing approach system [also encountered as BSU ZP]
DAK	remote-reading astrocompass
DGMK	distant-reading gyromagnetic compass
DPP	approach control center [control tower]
DPRM	outer marker beacon
DPSP	landing system control center
EUP	electric turn indicator
GIK	gyro induction compass
GMK	gyromagnetic compass
GPK	directional gyroscope
GRM	glide-path beacon
IP	starting point
KDP	command control center
KP	check point
KPP	command flight instrument
KRM	radio-range beacon

KUS	combined speed indicator
M	machmeter
NKP, NPP	navigation system instruments
OSP	instrument landing equipment
PSP	instrument landing system indicator
RDP	area control points
RSP	landing approach radar system
RUD	engine controls
RV	radioaltimeter
SDP	take-off system control center
SKP	flight command post [?]
SP	instrument landing system
UK	course indicator
UKV	ultrashort wave [station, radio]
US	speed indicator
UVD	air traffic control service
VAR	rate-of-climb indicator, variometer
VD	barometric altimeter

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MEDICAL AND PSYCHOLOGICAL PROBLEMS OF CIVIL AVIATION PILOT RELIABILITY (NUMBER 3)

Moscow MEDIKO-PSIKHOLOGICHESKIYE PROBLEMY NADEZHNOSTI RABOTY LETCHIKOV SOVREMENNYKH TRANSPORTNYKH SAMOLETOV GRAZHDANSKOY AVIATSII (VYPUSK TRETIY) in Russian No 3, 1969 (signed to press 13 Feb 69) pp 1-31

[Complete translation of pamphlet "Medical and Psychological Problems of Reliability of Pilot Work in Modern Transport Aircraft of the Civil Aviation (Number 3)" by Levon Saakovich Isaakyan, candidate of medical sciences, USSR Ministry of Civil Aviation, State Scientific Research Institute of Civil Aviation, Department of Scientific and Technical-Economic Information, 31 pages]

[Text] Professiographic Description of Pilot Work

1. Professiographic analysis of flight work

A description of pilot professiograms with reference to educational systems and general psychological analysis is given in the works of K. K. Platonov in relation to piston-engined aircraft (1957, 1958, 1960).

In this respect, flight engineering studies and official documents describing and regulating the order and nature of pilot actions at different stages of a flight, as well as frequently encountered errors and inaccuracies, are of great interest.*

B. S. Alyakrinskiy (1958) makes a distinction between voluntary control movements, correcting automatic or reactive and correcting voluntary movements; in addition, the author makes a distinction between movements without visual monitoring and special movements in emergency situations (when there is a clash between conceptions and perception, with sudden change of sensory field, etc.).

K. K. Platonov (1960) discusses the movements of pilots from the standpoint of their accuracy, balance, smoothness, force ["vigorousness"], speed and other properties, in the belief that all psychomotor processes can be conceived of in

*Textbooks on operating various types of aircraft with gas-turbine engines, compiled by the staff of the State Scientific Research Institute of the Civil Aviation, as well as records of flight tests of this institute together with other organizations.

the form of three reactions (simple and complex sensorimotor reactions, and sensorimotor coordination).

Several studies involved registration of pilots' control movements during flights aboard different types of aircraft (Ye. A. Karpov, I. A. Kamyshev, 1958; N. D. Zavalov, 1958; T. Kh. Gurvich, Ye. A. Derevyanko, I. A. Kamyshev, 1958, and others).

These works made it possible to characterize control movements of pilots from the standpoint of speed, minimum possible exertion, trajectory and some elements of psychophysiological organization. Analogous studies were pursued in the West by Jenkins (1948), Hertel deBerlel, as well as Tufts College (1952), Orlansky (1948) and Ely et al. (1956); however, the scope of these studies was somewhat narrower, and they were limited to investigation of optimum and maximum static and dynamic force applied to various controls of piston-engined aircraft.

Professiographic analysis of flight work can be made in different ways: in one case, it can amount to determination and description of the most important work operations of pilots, with indication of their order and logical correlation; in another variant, analysis consists of step-by-step determination and description of various elements of the sensory field and control actions corresponding to them. We have used both approaches, and since the second requires comprehensive description of control actions, we found that it was necessary to also find quantitative parameters that would describe these actions fully enough.

Analysis of 843 dynamometric tracings of pilot exertion referable to the control stick (control of elevator and ailerons) and pedals (directional [rudder] control) at take-offs and landings under simple conditions convinced us that any control actions can be described quantitatively by the three following parameters (Figure 1):

F--static impulse of force [exertion]--is the ratio of the geometric area of the figure circumscribed by the envelope of the force tracing and time line to duration (time) of the phase under study. The dimensionality of this parameter is kg·s/s, while its physical and, in this case, physiological meaning consists of the fact that it shows how great the average static force is within one second (kg/s). We shall designate this parameter as F_e, F_a and F_r, keeping in mind that the subscripts "e," "a" and "r" refer to the controls to which the given static force is applied (F_e--static force to deflect elevator, which is applied to the control stick, F_r--static force to move rudder, which is applied to the pedals, etc. [F_a--same for ailerons]).

A--mean amplitude of dynamic force--characterizes the magnitude (in kg) of separate impulses in excess of 0.3 kg lasting no more than 2 s. The physiological meaning of this parameter is that it shows the mean magnitude of dynamic force per impulse, which the pilot exerts upon the controls against the background of a certain static force characterized by the preceding parameter (F). Parameter A may refer to different controls: the control stick--for deflections of the elevator (A_e), pedals--for deflection of the rudder and the control wheel--for deflection of ailerons (A_r and A_a).

n--frequency of dynamic exertion--characterizes the number of impulses or exertions per 10 s of the phase under study. The meaning of this parameter is rather clear: it shows how many times exertions occur within 10 s (n_e, n_a n_r).

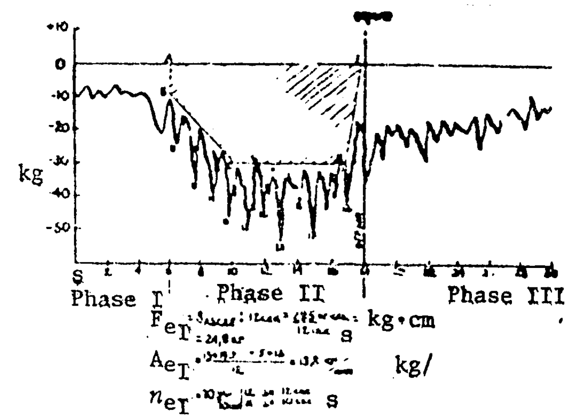

Figure 1. Tracing of force applied by captain of Il-18 aircraft when moving control stick at take-off, as an example to explain the principle involved in determining static force (F). The calculations of parameters F_e, A_e and n_e are given at the bottom of the figure [portions of inscriptions illegible in source]

Figures 2 and 3 illustrate samples of original tracings of exertion applied to the control stick and pedals during take-offs (An-10, An-24) and landings (An-10, Il-18 aircraft). Such tracings are processed by the method indicated in Figure 1 to obtain the three parameters characterizing the control actions of pilots for deflection of each of the three controls (elevator, rudder and ailerons).

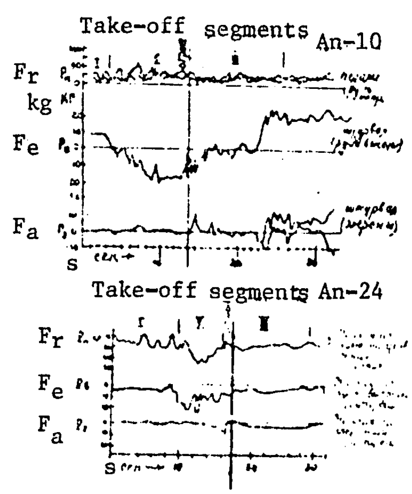

Figure 2.
Synchronous tracings of force applied to control stick (to move elevator and ailerons) and pedals (to move rudder) in 3 phases of take-off of An-10 and An-24

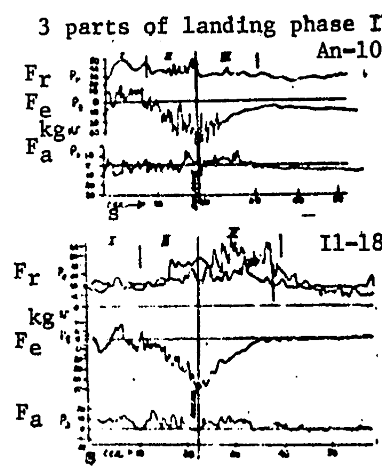

Figure 3.
Synchronous tracing of force applied to pedals (to move rudder) and control stick (to move elevator and ailerons) in last (IV) phase of landing of An-10 and Il-18

Bearing in mind the foregoing, let us discuss pilot activity in the sensory and motor fields, referring to the entire aggregate of dynamic sources of afferent stimuli that are important to the activity and that determine the specific control movements and actions.

A flight can be divided into five phases: take-off, climb, horizontal flight (in echelon), descent and landing approach.* Each phase is characterized by changing, but generally similar elements of the sensory field.

Take-off, which is the phase of flight from the start of the aircraft's take-off run until it gains an altitude of 150-200 m (when air traffic control changes from SDP to DPP [SDP--take-off system control center, DPP--control tower]**), can be divided into three segments. The first segment is from the start of the take-off run to separation of the front wheel from the ground (which requires about 30 s for an aircraft with turboprop engine); in this segment, the axial, middle line of the run way, in strict accordance with which the pilot must guide the aircraft, sighting this line in his central field of vision, as well as the speed and acceleration of the aircraft during the take-off run, are the sources of pilot perception. Perception of the last source is based on the increasing intensity of perceived vibration of the cabin and struts of the front wheel, force applied to the controls and frequency of flickering of terrestrial landmarks included in the peripheral field of vision. The geometric correlation between the line of the real horizon and bottom edge of the headlight is another important source of perception; during the take-off run the line of the edge approaches the line of the horizon. The last (fourth) source of perception is the navigator's report about current speed reached during the take-off run. At this stage, the pilot's main task is to maintain the proper direction of the run and, at the same time, obtain the required aircraft speed-acceleration to take off from the runway. For this reason, the controlling actions consist of applying impulsed force to control the brakes or smooth low force to control the front wheels; when the speed of the take-off run comes close to 150-170 km/h in the middle of the first segment and the rudder becomes more effective, the direction is maintained with the rudder. For this reason, during the first segment, the force applied to the pedals according to parameters F_r, n_r and A_r immediately acquires much importance, the values constituting 10-25 kg/s for F_r, 2-10 impules/10 s for n_r, while A_r fluctuates from 7 to 24 kg/impulses. Static ($F_{e,a}$) and dynamic ($n_{e,a}$ and $A_{e,a}$) force applied to other controls remains quite insignificant, although it does increase rapidly during the first segment.

Thus, the speed of flickering of ground-based landmarks, kinesthetic sensation of vibration and force applied to the controls, correlation between headlight edge and horizon and reaching a specific speed constitute the signals that determine the control actions of the pilot for lift-off of the front wheel during the run.

The second segment of the take-off is from the start of lift-off of the front wheel to complete lift-off of the aircraft (7-15 s). All of the sources of perceptions inherent in the first segment remain unchanged in their significance to

*The landing approach phase includes the actual landing.
**Translator's notes: These are new letters for control tower, literally, approach control center [or tower], whereas KDP was used in the past--command control center [or tower]. For the reader's convenience, expansions of all abbreviations are also furnished at the end of this pamphlet.

the pilot, but the edge-horizon, force applied to the stick and vibrations of the cabin and struts of the front wheel gain special significance. At the moment of separation of the front wheel from the ground, vibration decreases and the exertions are well perceived, while the edge-horizon space narrows down. As soon as the front wheel has separated from the ground, information about speed, retention of direction and force applied to the control stick move to the fore. After 5-10 s, during which the sources of information remain unchanged, the aircraft lifts from the ground (second deflection and immobilization of the control stick), and it moves into the third segment.

During the second [sic] segment of take-off, typical changes occur in the pilot's motor field: in the presence of unchanged or slightly increased force applied to the pedals (to control the rudder), the pilot starts to gradually pull the stick toward himself with low dynamic force, controlling the elevator (Figure 2). The static force (F_e) constitutes 7-23 kg/s, the number of dynamic exertions (n_e) is in the range of 8-11/10 s and their mean amplitude (A_e) fluctuates in the range of 3-15 kg/impulse. In the case of a normal take-off (usual centering, take-off weight, wind and runway condition), more force is applied to move the stick to the right and left, according to all three parameters (F_a, n_a and A_a) than in the preceding segment, but still it is rather low. The force applied to the pedal to move the rudder (F_r) reaches high values, but according to parameters A_r and n_r, less force is used than in the preceding segment.

The third and last segment refers to the period between lift-off of the aircraft from the ground and time it reaches an altitude of 150-200 m (20-30 s).

As soon as the aircraft starts to climb, all of the pilot's attention is concentrated on the following instruments: gyro horizon (AGB [bomber aircraft gyro horizon] and AGD) used to eliminate banks and hold the required pitch angle, rate of climb indicator (VAR), which serves to determine that altitude is being gained at a specific vertical speed (7-10 m/s), the KUS--combination indicator of acceleration, which informs the pilot about instrument and air speed or, more precisely, the changes in these parameters during the climb, and, finally, after the turning altitude is reached, one of the course instruments is in the area of the pilot's attention (DGMK [distant-reading gyromagnetic compass], UK [course indicator], GPK [directional gyroscope], etc.).* During the last segment of take-off, the captain issues orders to the flight engineer or copilot to retract the landing gear, flaps, switch the engine from take-off to nominal mode, he checks the proper operation of the corresponding systems and carefully observes the aircraft's position in space in connection with gear and flap retraction, change in mode, etc. Usually, at the same time the pilot maintains command radio communication with the SDP controller. The typical control actions of the pilot in the third segment of take-off amount to the following: vigorous force applied to the stick to deflect the ailerons and prevent banking (F_a 0.5-1.5 kg/s, n_a 1.3-0.9/10 s and A_a 2-10 kg/impulse); decreasing static force to pull the stick toward himself, against the background of which dynamic force is exerted (F_e -5.3-24 kg/s, n_e 2.7-0.9/10 s and A_e 1.5-7 kg/impulse); some decrease in dynamic and static force

*In aircraft with a high thrust-weight ratio, which have a wide pitch angle when they gain altitude (for example, Tu-104, Tu-154 and Il-62), the horizon is not visible after separation from the ground, and altitude is gained by the instruments.

applied to the pedals to control the rudder. The last segment of the take-off phase ends at the time when the pilot receives instructions from the DPP controller about the procedure for leaving the airport area and follows these instructions.

Let us consider the professiographic characteristics of pilot work during take-off in the schematic form illustrated in Figure 4, which shows the sources of perceptions, control actions and main tasks at each segment of take-off; in addition, it illustrates the specific changes in force parameters (F, n and A) during the entire take-off, calculated for work intervals of 2-4 s as they relate to movements of the elevators, rudder and ailerons.

The second and third phases of flight--gaining altitude and level flight--as, incidentally, all subsequent phases (descent and landing) are performed by the instruments up to the last landing segment, regardless of meteorological conditions.

During the period of gaining altitude and level flight, the pilots concentrate alternately on the following instruments: gyro horizon, speed indicator, rate of climb indicator, instruments that control engine operation and various course instruments. The distribution of attention among these instruments depends largely on the selected mode of climb (cruising mode, maximum distance or duration modes). In general, the pilot tries to hold within a specific range the gradually decreasing vertical speed, instrument speed and increasing air speed. Special attention is given to the course instruments (DGMK, GIK [gyro induction compass], GPK), radio compasses (ARK), radar monitoring and specific instructions from the navigator pertaining to course correction.

At the third phase of the flight--horizontal flight--the autopilot controls the aircraft if there is no turbulence, and the pilot's work is limited to monitoring the course, speed instruments, radar observation of meteorological conditions (thunder, oncoming aircraft) and making the appropriate adjustments in the autopilot (aircraft) control. If the autopilot is malfunctioning, the relatively calm work of pilots in level flight is drastically disrupted--they change to manual control which requires increased attention and considerable physical exertion.

The next to the last, fourth phase of flight--descent--is characterized in most cases by turning the autopilot off and changing to manual instrument control; the level and nature of work in this phase are comparable to the climbing phase, but mentally it elicits greater and, moreover, gradually increasing tension (awareness of the impending landing approach). Since descent to the initial point and subsequent attainment of the DPRM [outer marker beacons] beams involve frequent turns (course change) and breaking clouds, instrument flying, monitoring the operation of engines and the pilots' close communication with the navigator acquire special importance.

The last, fifth phase of the flight is the approach landing, which was discussed above (p 9, No 2 [of this series of pamphlets]) as it relates to the main principles of using the OSP and SP landing approach systems; here, referring to the figure already familiar to us [from No 2], it remains for us to trace the main elements of sensory and motor fields of pilots while performing this most difficult phase of flight [Figure 5].

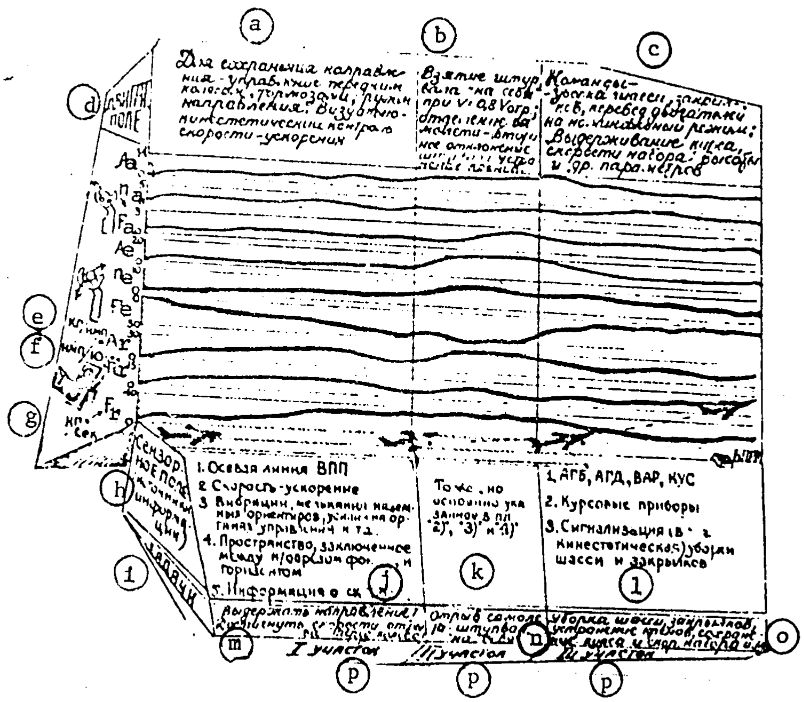

Figure 4. Explanation given in the text

Key:
- a) to retain direction, control front wheel, brakes, rudder. Visual--kinesthetic monitoring of speed-acceleration
- b) pull stick toward pilot at V = 0.8 V... [subscript illegible]; lift-off, second movement of control stick, elimination of bank
- c) commands: retract landing gear, flaps, switch engines to nominal mode; hold course, climbing speed and other parameters
- d) motor field
- e) kg/imp
- f) imp/10 s
- g) kg·s
- h) sensory field (sources of information)
- i) tasks
- j) 1. axial runway line
  2. speed-acceleration
  3. vibration, landmarks flickering on the ground, force applied to controls, etc.
  4. space contained between edge of image of headlight and horizon
  5. information about speed
- k) Same as above, but particularly items 2, 3 and 4 in (j)
- l) 1. AGB, AGD, VAR, KUS[combined airspeed indicator]
  2. course instruments
  3. signals (... kinesthetic) of landing gear and flap retraction
- m) hold direction; achieve speed for lift-off of front wheel
- n) lift-off of aircraft, pull control stick toward pilot
- o) retraction of landing gear, flaps, elimination of bank, hold course and speed of climb, etc.
- p) segment

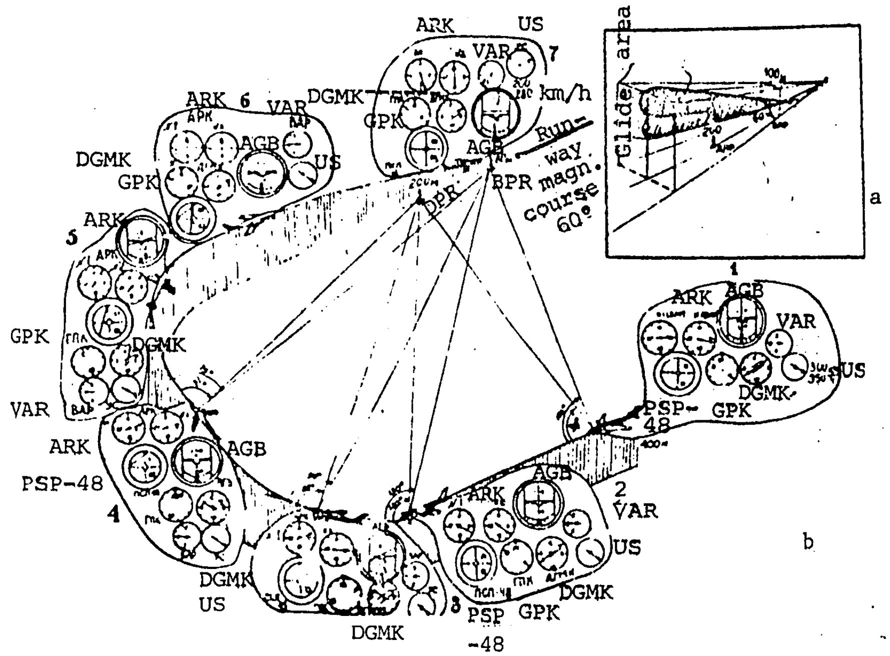

Figure 5. a) Ground-based SP-50 equipment
b) Diagram of changes in readings of the main flight instruments of pilots when making a landing approach by the OSP-48 and SP-50 systems from DPRM cross beam

This entire phase can, like the take-off phase, be arbitrarily divided into segments. The first is from the DPRM cross beam to approach into the fourth turn. In Figure 5, it corresponds to positions 1-4. In position 1, the copilot or flight engineer lowers the landing gear when so instructed by the captain; in position 4 they start to lower the flaps. Both actions are feasible when the velocity of the aircraft does not exceed a certain limit; while the landing gear and flaps are being lowered, as well as during the turn, aerodynamic aircraft reactions take place, as a result of which there is change in both the spatial position of the aircraft and, particularly, its speed. For this reason, the pilot's activity in the motor field is limited at this segment to control of throttles (RUD) (which is sometimes done by the engineer when so instructed by the captain) and reactive force applied to the control stick for compensation of aerodynamic reactions--changes in spatial position of the aircraft.

In positions 1 and 2, the pilot is governed primarily by the ARK readings; if ARK No 1 and ARK No 2 show a change in positions from 90-100° to 120-130° (for a right circle), the aircraft is maneuvered into the third 90° turn by the course instruments. After completing the third turn and changing to straight flight, course angles of the order of 85-90° change to readings of 70-75°, which is a signal to begin the fourth turn. In addition to the ARK, GPK, DGMK, altimeter and speed indicator (VD and KUS), in the first segment of this phase the pilot monitors the readers of engine, flap, landing gear, etc., indicators.

The second segment of the landing approach covers the period between maneuvering into the fourth turn to entry of the aircraft in the glide-path area. Positions 5 and 6 in Figure 5 correspond to this segment.

As we have already indicated, the readings of the ARK (70-75°) serve as a signal to start the fourth turn; performance of the fourth turn is monitored by means of the above-mentioned instruments, AGB, GPK, DGMK, KUS and others; the readings of the course instruments (DGMK, GPK), PSP (course needle approaches the center--aircraft symbol) and ARK (needle in the vicinity of the zero mark) are the signal of completion of the fourth turn. At the end of the second segment, the pilot still concentrates on the PSP, GPK, AGB, ARK and KUZ, and movement of the glide path needle of the PSP down in the direction of the center--aircraft symbol--is the signal to issue the order to lower the flaps again and switch the aircraft to the descent mode (when the needle occupies a middle position), which is monitored by the VAR. At the second segment of landing, there is some increase in flow of instructions from the DPSP to the pilots, particularly if the controller turns on the radar system for monitoring the landing approach (RSP).

The third segment goes from the start of descent on the glide path to flight past the BPRM. In Figure 5, it corresponds to only one position--7. Before flying past the DPRM, the pilot's attention is concentrated, in the first place, on holding the rate of decline at 2-4 m/s on the variometer, holding the magnetic course selected according to the GPK and selected course angle according to the ARK, without banking and with maintenance of a specific pitch angle (AGB or AGD); in the second place, as he flies over the DPRM and BPRM, he must maintain quite accurately specific altitude and speed as shown by the KUS, VD and RV; for example, in the case of jet aircraft, speed of flying over DPRM should be 300-250 km/h at an altitude of about 200 m, and over BPRM--230-250 km/h at an altitude of 60-80 m, depending on its landing weight, position of center of gravity and other variable factors. In the third segment, there are fewer instructions from the DPSP and the pilot has the right not to respond to the controller's instructions..

The fourth and last segment of landing, from the BPRM overflight area to the start of the run on the runway, involves mandatory change to visual flying under the prevailing minimums at the present time (see No 2, p 13). In this brief segment, the elements of the sensory field include visual perception of distance to start of runway, lateral displacement of the runway, glide angle, speed of flashing of terrestrial landmarks, equalization point, kinesthetic and vestibulomotor sensations evoked, in particular, by the force applied to the controls, G forces, pressure to the hip region, etc. During this segment, there is discrete delivery of auditory information to the pilot from the navigator (about current speed) and flight engineer (about altitude, according to radioaltimeter readings).

The pilot's work in the motor field at the climb, level flight, descent and landing approach phases, with the exception of the last segment of the landing, cannot be submitted to the same analysis as was used for the take-off phase. This is attributable to the fact that the control actions of pilots at these phases are episodic (relatively rare movement of controls, seldom use of automatic pilot, use of actions unrelated to physical exertion--button-toggle-switch control of lowering landing gear, flaps, attenuation or elimination of exertion by means of trimming, etc.).

In the last, fourth segment of landing, when pilots cannot make full use of trimming (analogously to the situation during take-off) due to the limited time spent on the airborne segment of the route (10-15 s), their motor activity is of some interest from the standpoint of the parameters we have developed.

If we were to arbitrarily divide the last segment of landing into three parts, each of which is of approximately the same duration--5-10 s--(first part from the start of changing to visual flight to leveling out; second part is the period of leveling off and touching the runway and third part is the first segment of the run) and analyze typical curves of pilot exertions in all three parts of the fourth segment, we would detect several patterns.

Static force (F_r) applied to the rudder over the entire segment turns out to be about the same--15-35 kg/s, whereas the force applied to the elevator control (F_e) obviously reaches a maximum at the moment of leveling out and touchdown, constituting 5-24 kg/s for the segment; however, the static force applied to control the ailerons (F_a) is very small--0.2-2.2 kg/s. The frequency of dynamic force applied to all three controls (n_e, n_a and n_r) has a tendency toward increasing in the second part of this segment (to 2-10 imp/10 s). Mean amplitudes of dynamic force applied to rudder and aileron controls gradually diminish over the fourth segment (from 10-13 kg/imp to 3-5 kg/imp), but the same parameter for the elevator control (A_e) usually reaches a maximum during the second part of this segment.*

The curves reflecting typical changes in static and dynamic force applied by pilots to the control stick and pedals in the course of the fourth segment aboard An-10 and Il-18 aircraft are illustrated in Figure 3. The professiographic activity of pilots in the last segment of landing, including sources of perception, control action and objects determining them, is illustrated in Figure 6. The same figure illustrates the curves of changes in the three parameters of force used to move the rudder and ailerons.

We shall ultimately return to a more general analysis of these data, which characterize the psychomotor activity of pilots during take-offs and landings.

If we try to classify the activity of pilots in the sensorimotor field during an entire flight on the basis of the most general criteria, we could refer to three types of work operations.

Active visual flying ["visual monitoring"] is the first type of work operations. This type is used by the pilot during the take-off run and lift-off, as well as in the last segment of landing; in the third segment of take-off (climb to 150-200 m) and different segments of landing, with the exception of the last one, this type of work operations is used relatively seldom.

Active instrument flying ["instrument monitoring"] is the second type of operations which, unlike the first type, is based on interpretation of symbolic, second-signal [signaling system?] information, rather than first-signal, graphic information. This type of work operations is used by pilots in the last segment of a take-off, when gaining altitude, in level flight in bumpy air (when the autopilot is turned off) and all segments of landing, with the exception of the last one.

*Description of changes in force applied to rudder and aileron control inherent in landings under calm conditions or in the case of head wind.

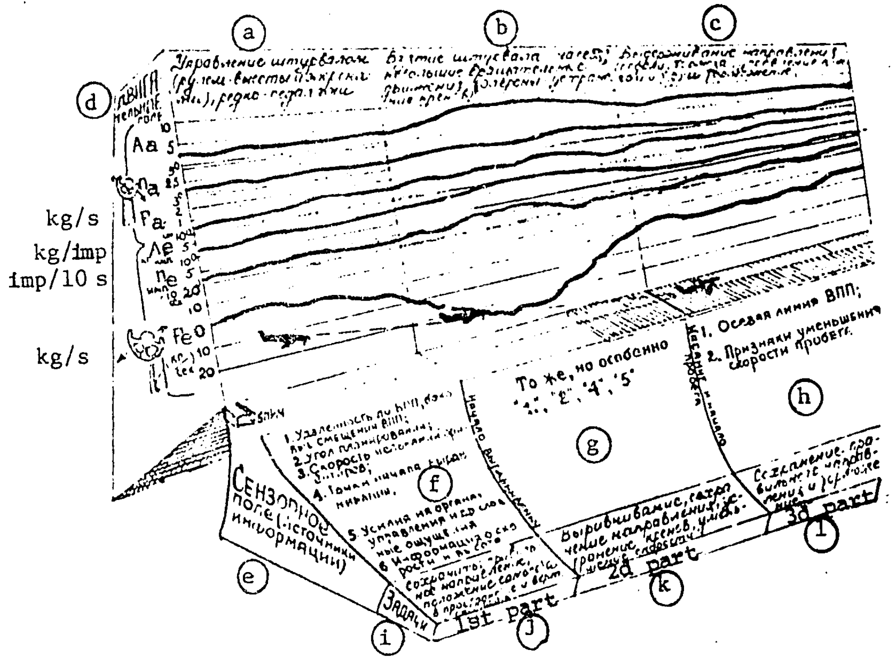

Figure 6. (Explained in the text)

Key:

a) control of stick (elevator and ailerons), seldom pedals
b) pulling stick toward pilot, minor turning movements (ailerons, elimination of bank)
c) holding bearing (pedals, brakes, ...)
d) motor field
e) sensory field (sources of information)
f) 1. distance from runway, lateral displacement of runway
   2. glide angle
   3. landmark flashing frequency
   4. points at which leveling out starts
   5. force applied to controls and other complex sensations
   6. information about speed and altitude
g) same as above, but particularly 1, 2, 4 and 5; vertical inscription: start of leveling out
h) 1. axial runway line
   2. signs of deceleration of run
   vertical inscription: touchdown and start of run
i) tasks
j) retain proper bearing, position of aircraft in space and vertical ...
k) leveling out, retaining bearing, eliminating banks and reducing speed
l) retaining proper bearing and braking

Passive visual and instrument flying is the third type of work operations used by pilots in level flight with satisfactory visibility; after turning on the autopilot, the pilots are able to monitor the flight visually (to detect oncoming aircraft and hazardous meteorological conditions) and with the use of instruments (to hold specified course, altitude, speed, etc.). Let us note that, with appearance of the slightest complication, such a flight changes into an active instrument flight (autopilot is turned off).

If one so desires, in addition to the above-mentioned three types of work operations, one could distinguish several other types, which are transitory, but there is no need to do this, since transitory types are not often encountered in real flights.

2. General hypothetical scheme of psychophysiological activity of pilots in flight (during take-off and landing)

It is known that the process of sensorimotor coordination, which should be construed as organization of control actions that are corrected upon perception of their results, is the psychophysiological basis of piloting.

The concept of sensorimotor coordination is very broad per se, and if we were to try to classify it we could refer to visual and instrument sensorimotor coordination. There are some serious differences between the two, which consist of the fact that for visual flying the control actions are organized by a few acts of concentrated attention, mainly in the first signaling system, on the basis of continuous perception with all of its inherent specificity and clarity, with the use of well-fixed systems of conditioned associations as systems of afferent synthesis and action acceptor. In the case of instrument flying, control actions are organized by many acts of concentrated attention, mainly in the second signaling system, on the basis of discrete perceptions, with all of its inherent abstraction, with the use of less fixed systems of conditioned associations as afferent synthesis and action acceptor systems.

These differences explain why visual flying is much simpler than instrument flight, and why it is so complicated to switch rapidly from the former to the latter.

In spite of the above-mentioned differences between types of sensorimotor coordination, they can be disregarded in constructing a general scheme of pilot activity in the sensorimotor field.

It is obvious that pilots who control flights and particularly their most complex phases (take-off and landing) possess a sum of basic knowledge and automated skills that program pilot actions in a strict and stable fashion (in the sense of constancy). This program contains actions that are performed in the form of conditioned reflexes and stereotypes in the presence of certain triggering and situational stimuli (for example, pulling the control stick back during the take-off run or leveling out during a landing, start of turns, lowering the landing gear, flaps, etc.). All these actions are performed by pilots in the presence of specific situations and with appearance of specific triggering stimuli; actions of this type per se are largely automatic and take place on the basis of a number of mental ["thinking"] and motor stereotypes. Indeed, not to mention such basic control actions as making turns, lowering and retracting the landing gear, flaps, etc., even an insignificant change in flight course on the last line is an action that is strictly determined by a specific situation and specific signal. At the same time, any operation performed by the pilot under normal flight conditions, starting with slight turn corrections and ending with lowering or retraction of the landing gear and flaps, elicits more or less standard aerodynamic reactions of the aircraft, for the compensation of which the pilot has developed firm motor skills that effect a series of stereotypic control actions.

We propose the name of stable program for the program of such principal actions and principal [main] actions for the actions themselves (in Figure 7, where the overall scheme of pilot work is illustrated, the corresponding names and abbreviations thereof are shown in the rectangles and other figures).

Let us note that, since the stable program is carried out by means of mental and motor stereotypes, as well as automatic skills, in direct association with the afferent synthesis and action acceptor systems, all of these functional structures are united in a single system.

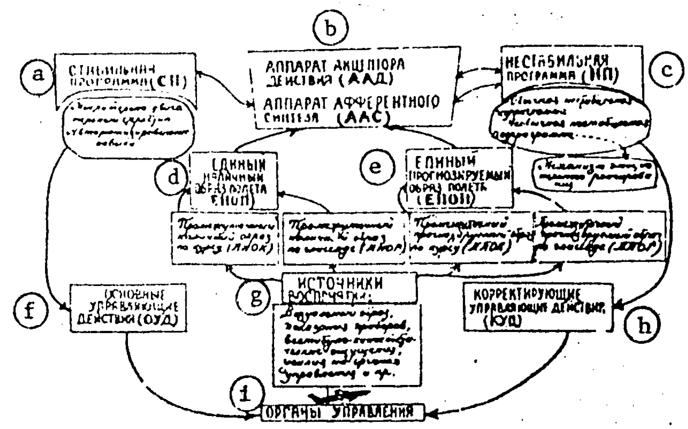

Figure 7. General hypothetical scheme of pilot work in flight (take-off and landing) [several inscriptions are illegible]

Key:
- a) stable program (SP)
- b) action acceptor system (AAD) [top], afferent synthesis system (AAS) [bottom]
- c) unstable program (NP)
- d) single on-hand image of flight (ENOP)
- e) single predicted image of flight (EPOP)
- f) main control actions (OUD)
- g) sources of perception
- h) corrective control actions (KUD)
- i) controls

The availability to pilots of only these rigidly programmed and stereotype elements, which are merely the basis of their strategy or general outline for their work, is utterly inadequate to perform a specific flight and, in particular, a take-off or landing. This is attributable to the fact that the stable program of the main control actions virtually never takes into consideration specific flight conditions that are unlike prior conditions.

These conditions, which refer to the entire sum of perceptions of pilots, for example, during one of the periods of a landing, include the following: force applied to controls, glide angle, movement in horizontal plane in relation to the axial line of the runway, readings of certain instruments, estimation of speed-accelerations, etc.

Regardless of how the flight is being performed--visually or by instruments--the perceptions or conceptions the pilot gains from the above sources apparently form two solitary [single] images of the flight in relation to three measurements of space, the runway and terrestrial landmarks--topography of the region: a single on-hand image of the flight (ENOP) and single predicted image of flight (EPOP).

Each of them apparently arises as a result of synthesis of two intermediate images characterizing flight of the aircraft in the horizontal and vertical planes. Of course, this synthetic process acquires special importance when making a landing approach, when the image of the flight in the horizontal plane signifies estimation of the aircraft's course, while the image of the flight in the vertical plane enables the pilot to assess the precision of maintainig the glide path.

Thus, the single, for example, on-hand image of flight at the landing stage is the product [derivative] of two intermediate on-hand images of flight with regard to course and glide path (PNOK and PNOG), while the single predicted image (EPOP) is the result of synthesis of intermediate forecast images with regard to course and glide path (PPOK and PPOG).

The synthesized single images of flight (ENOP and EPOP), entering into the hypothetical system of afferent synthesis and system of acceptor of action, serve as the basis for constructing precise, corrective control actions in functional structures containing an unstable program. The unstable program, like the stable program and action acceptor, is probably governed essentially by the laws of dynamic stereotypy and conditioned reflex switching over; however, the unstable program, particularly its unique [unusual] subprogram, is characterized by immediate construction of new and frequently disrupted dynamic stereotypes and active involvement of mechanisms of emotional reaction (L. S. Isaakyan, 1963), which apparently does not occur in the functional structure of the stable program.

We can make a distinction between usual and unusual subprograms in the unstable program; apparently, the probability of prior use of the latter subprogram is immeasurably lower than the probability of having used the former subprogram and, consequently, use of the unusual subprogram is characterized by the need to process large flows of information and necessity of a high throughput, in addition to the above-mentioned distinctions. Thanks to the usual subprogram, which has a set of tactical decisions-actions, the pilot performs a broad range of fine control actions, which are called corrective actions (KUD) on the general diagram [scheme]. Under ordinary take-off or landing conditions, expressly these corrective actions, which are of a compensatory, tracking and anticipating nature, meet all of the pilot's needs for piloting. Expressly they are the delicate [fine] pattern that is applied to the general canvas [outline] of pilot actions and constitutes the most complex and creative part of his activities in flight, and primarily landing. It may be assumed that under such simple take-off or landing conditions, the entire scheme of pilot activities (Figure 7) is functioning, with the exception of the unusual unstable subprogram. As we have already indicated, the latter, unlike the usual unstable subprogram, has considerably fewer tactical decisions, ready elements for rapid construction of new and complex dynamic stereotypes and tonic conditioned reflexes, as well as much greater activation of the mechanism of emotional reaction. Evidently, under more complicated and difficult take-off or landing conditions, when the pilot encounters a situation unlike all that he encountered heretofore, the most intensive element of the activity scheme is the unstable program with its unusual subprogram. Probably, under such take-off or landing conditions, the corrective control actions (KUD) are determined, to a significant degree, by the unusual unstable subprogram contained in the unstable program.

From the physiological point of view, the proposed scheme does not have sufficient functional and structural grounds for most of its elements. There are no precise physiological data concerning organization of images, let alone images of flight; the views that are being developed in recent years by I. S. Beritashvili concerning the image-related activity of animals as an independent form of nervous activity of animals (along with conditioned reflex and unconditioned reflex activity) cannot, of course, serve as serious grounds for the detailed elements of our scheme. There are even less concrete physiological grounds for the hypothetical system of afferent synthesis proposed by P. K. Anokhin, although it is unquestionable that such a system must exist. The action acceptor system (P. K. Anokhin), stable program and usual subprogram of the unstable program probably contain some complex conditioned reflex associations, dynamic stereotypes and tonic conditioned reflexes (in the interpretation of E. A. Asratyan, 1962) that occur on the level of the two signaling systems. It is more difficult to conceive of the physiological mechanism of the unusual unstable subprogram, which functions mainly under complicated flying conditions. Probably, here too the same mechanisms are in effect to some extent as in the structure of the usual subprogram, but their expression is complicated by several circumstances: in the first place, there are too few conditioned reflex elements, on the basis of which new and complicated dynamic stereotypes and tonic conditioned reflexes should be constructed; in the second place, the motor components of these elements are notable for being very little conditioned and fixed; and in the third place, we cannot rule out the negative induction effect on performance of the entire unusual subprogram and corresponding corrective actions on the part of a markedly stimulated [excited] mechanism of emotional reaction. Since adequate pilot performance under complicated conditions is often instantaneous and, so to speak, subconscious, it may be assumed that some of the elements of the unusual subprogram function on the order of "first second reaction" (P. K. Anokhin, 1949; R. G. Zeval'd, 1963), which occurs with the shortest latency period (Forbes and Morisson, 1939; Moruzzi and Magoun, 1949, and others).

The hypothetical general scheme of pilot work that we propose has something in common with the psychophysiological scheme of information processing and decision making, the conceptions of which have been developed in recent years by engineering psychologists (D. Yu. Panov, V. P. Zinchenko, 1964; V. P. Zinchenko, N. I. Mayzel' and L. V. Fatkin, 1965; D. N. Zavalishina, 1965; V. V. Davydov, 1960; A. Newell, J. C. Shaw and Simon, 1958, and others).

According to these conceptions, which are based on the results of psychophysiological studies, the first steps of information processing consist of singling out the adequate signals among numerous others, transforming them by means of comparison to standards-engrams into primary images of signal identification, which can ultimately be used via two channels or two types of conversions. The automatic type of converting information implies comparison, in the presence of a triggering signal, of primary images or models-images, first into a model-goal (or program) and then to the set of decisions-instructions [commands] present in memory, among which one decision-instruction is readily selected. The retrieval [search] type of converting information consists of induction of secondary models-images as a result of interaction between the model-goal (program) and primary images or models.

The secondary models-goals in the form of associations, concepts and judgments are compared to one another to obtian a mental model of a decision (deductive route) or, in a more complicated situation, to form models of a future decision (hypotheses). In the latter case, the model of a future decision forms several tertiary models, comparison of which yields the decision model. It is believed that the automatic ["automated"] type of conversion occurs entirely, not counting the triggering signal, without reflection in consciousness; the searching type of conversion is usually realized, although in some cases we cannot rule out the possibility of unconscious execution thereof (V. N. Pushkin, 1960, 1965; M. S. Bernshteyn, 1961, and others).

If we compare the above-described engineering psychology interpretation of information processing to our hypothetical scheme of pilot activity, we shall see similar elements: the unstable program in the scheme resembles the information processing channel of the search type, whereas the stable program corresponds well to the channel of automatic information processing. We cannot fail to mention that our scheme makes fuller use of the physiological, experimentally proven facts, which are generally recognized as the basis of higher nervous activity and mental phenomena. In the future, we shall demonstrate that the general scheme of pilot activity in the sensorimotor field is a useful tool for analyzing errors made by pilots in the course of a landing.

3. Results

1. Professiographic analysis of pilot performance in flight enabled us to describe three types of work operations of pilots: active visual flying, active instrument flying and passive visual-instrument [monitored] flight.

In the course of the analysis we described pilot activity in the motor field by means of the quantitative parameters of force applied to the controls, which we developed.

2. Professiographic analysis of pilot activity in flight enabled us to construct a general hypothetical scheme of their activities, which is applicable primarily to take-off and landing conditions. This scheme is based on the idea that pilots form single on-hand and predictable images of flight, by means of sensations, perceptions and conceptions, each of which is the derivative of two intermediate images of flight (for course and glide path). The single images of flight activate systems of afferent synthesis (search for an answer to the question of "What to do?") and action acceptor (monitoring the progress of performance of planned actions). Under simple take-off and landing conditions, the single images of flight and both of these systems activate the stable program and unstable program with its usual unstable subprogram, the stable program forming the main control actions (OUD), while the usual unstable subprogram forms corrective control actions (KUD) and, to some extent, activates the mechanism of emotional reaction. Under complicated and difficult take-off and landing conditions, in addition to these functional structures, there is vigorous activation of the unusual unstable subprogram as well. From the physiological point of view, its activation is characterized by the following features: limited number of conditioned reflex elements, on the basis of which there must be immediate organization of new and complex dynamic stereotypes and tonic conditioned reflexes; insignificant conditioning and consolidation of motor components of the above-mentioned conditioned reflex elements; negative inductive influence on functional structures of the subprogram exerted by the strongly stimulated central nervous mechanism of emotional reaction; existence of complicated (chain, complex and others) conditioned reflex reactions with a short latency period and without direct reflection in consciousness.

From the standpoint of engineering psychology, activation of these structures is characterized by the following: drastic increase in flow of information related to the effect of a situation, the probability of occurrence of which is infinitesimally low; need for maximum expansion of throughput (amount of information processed per unit time); presence of only some tactical decisions that are actually made very seldom; extremely intense mental and emotional stress (or nervous-emotional stress).

On the whole, activation of these functional structures, which are responsible for the unusual and unstable subprogram, is manifested by various autonomic, somatic, behavioral and other reactions, which are perhaps governed by certain patterns that depend on the stressfulness of external conditions (at take-off or landing).

We shall discuss in our next chapter [pamphlet], in detail, these pilot reactions during take-offs and landings under simple, complicated and difficult conditions.

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Abbreviations

ADP	airport control center
AGB	bomber aircraft gyro horizon
AGD	azimuth gyro sensor [?]
ARK	radio compass
BPRM	inner marker beacon
BSUZP	onboard landing approach system [also encountered as BSU ZP]
DAK	remote reading astrocompass
DGMK	distant-reading gyromagnetic compass
DPP	approach control center [control tower]
DPRM	outer marker beacon
DPSP	landing system control center
EUP	electric turn indicator
GIK	gyro induction compass
GMK	gyromagnetic compass
GPK	directional gyroscope

GRM	glide-path beacon
IP	starting point
KDP	command control center
KP	check point
KPP	command flight instrument
KRM	radio-range beacon
KUS	combined speed indicator
M	machmeter
NKP, NPP	navigation system instruments
OSP	instrument landing equipment
PSP	instrument landing system indicator
RDP	area control points
RSP	landing approach radar system
RUD	engine controls
RV	radioaltimeter
SDP	take-off system control center
SKP	flight command post [?]
SP	instrument landing system
UK	course indicator
UKV	ultrashort wave [station, radio]
US	speed indicator
UVD	air traffic control service
VAR	rate-of-climb indicator, variometer
VD	barometric altimeter

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