COMPUTERIZED HUMAN MODEL FOR HELICOPTER CREW STATION DESIGN: THE APPLICATION OF THE DYNAMIC ANTHROPOMETRY DATA

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Abstract

The value of computer modelling of the pilot body in helicopter cockpit design permanently increases. Thanks to the application of these models the problem of the compatibility of the crew station geometry with anthropometric and biomechanical characteristics of pilots could be resolved at the early stages of designing. The survey of many publications reveals the inadequate understanding or ignorance of the problems related with the using these design support systems. As a rule, these human body models consist of a set of moveable links articulated by means of joints. Such models are termed the Multielement Link Model (MELM). Generally, these models are based on the following assumptions:

1) The links of the MELM are regarded as an absolutely rigid levers of the body's mechanical system (the spinal column as well);
2) The model links are connected through the ideal joints;
3) The geometric parametrs of the model are based on the static anthropometry data.

Static dimensions, which are taken with the body of the subjects in rigid standardized positions, are easily obtained and used in design. This kind of measurements are used in the development of the multielement human body models. The body dimensions, which change during angular or linear displacements of the measured link are the dynamic data. The dynamic dimensions, which are taken with the body in various working positions and functional arm and leg reaches, are usually more complex and difficult to measure.

The using of the MELM in the crew station design have one troublesome feature. It consists of the certain mis-match of the work space evaluation results obtained by means of the MELM and the measurements which were held with the real humans. This fact significantly reduces the value of such models. Therefore the US military standard MIL-STD 1333 B says: «Consideration shell be given to differences between link model data and classical anthropometric data». In fact, the question is about the main difference between two kinds of the anthropometric information. The designers try to use the MELM, the simple static model, for determination of the outer limits of the workplace or space reach envelopes for the placement of controls.

The link model data were compared with the dynamic anthropometric measurements, which were available to us. The comparison showed rather big discrepancy. It can lead to the mistakes in the control placement. We suspect this discrepancy is related with the simplifications in the human model design which take place due to the deficiency of the required anthropometric data. We set up the hypothesis that the spinal flexibility, the shoulder mobility, and the differences between the real and the ideal joints lead to the change of the center of the shoulder joint (CSJ) location as compare with the location of this point predicted by means of the MELM. The problem of development of the model which will take into consideration all these parameters and their quantitative variations for various humans seems quite challenging. We propose the other approach. As a result of the following quantitative analysis we found that these deviations could be mathematicaly described as a function of the arm height above the seat and the arm angle from the midplane of the body. The introduction into the algorithm of the special bloc of equations, which simulates a position change of the shoulder joint center, allows to obtain the acceptable accuracy of calculations.

Introduction

Today many big companies which deal with development in such areas as aviation, cars, and other complex man-machine systems use the computerized human body models in the design process. This fact is connected with a significant economic effect on the design process (reduction of the time of development, increase of the design quality, possibility of comparison of several alternative variants without building expensive full scale mockups and so on). One article written 7 years ago, Reference 1, informed about the existence of great number of vendors of such systems, most of whom produced software packages. In many science surveies such computerized tools as SAMMIE, COMBIMAN, ADAM etc. are mentioned (see, for example, the survey in the Reference 2). The SAMMIE is a success at Westland Helicopters LTD, Reference 3. We also know thanks to our collaboration with Eurocopter France that our French colleagues use similar system during the design process.

Some firms try to develop this kind of design support systems temselves, obviously due to economic considerations, taking into account the features of their products, the company's traditions of designing and the type of available 3-D modelling system. BOEMAN and CGE which were developed by Boeing, Reference 2, and MACMAN developed by McDonnell Douglas Helicopter Company, Reference 4, are the examples of specialized design tools for aviation area. We can safely say that this kind of activity exceeded the bounds of exotic.

It is possible to define three clusters of problems which are settled by means of this computerized design systems. First, is a problem of compliance of the work place geometry with anthropometric and biomechanical parametrs of flight personnel. The reach and the pilot comfortable working posture which is characterized by the joint angles are used as the criterions of the compliance. Besides that the clearences between human body's segments and the elements of structure are studied. Second, is a problem connected with the optimal design of external and iternal vision. «Dynamic» problems are concerned to the third cluster. It can be, for example, computer modelling of the motion of pilot's head during the crash impact.

Perhaps it should single out into a separate group a very interesting expericce of using of the computerized model of the maintainer (CREWCHIEF) which had been developed by the U.S. Air Force and was applied in the design of the RAH-66 Comanche helicopter, Reference 5. The problems of the first cluster and partly of the second one are solved by means of this program.

This paper is devoted to some particular but rather important questions which are connected with the problems of the 1-st cluster. It is necessary to say that the problem of compliance of the station geometry with the human geometry is very important in the area of helicopter design because just this kind of man-machine transport systems provokes a widely spread of back pain and back discomfort. This back pain has a considerable influence on the pilot's health, the period the flight service and the efficiency of flight missions. This problem is considered as a quite serious one, so that many reports of the special AGARD Conference, Reference 6, were devoted to the causes and the consequences of this helicopter pilot's back pain. Today it is possible to be sure that the specific work posture of most of helicopter pilots is the main reason generating this phenomenon. This poor work posture is closely connected with an inadequate compliance the station geometry (including geometric characteristics and mutual locations of all elements: flight controls, seats, cockpit controls panels, desks etc.) with the anthropometry and biomechanics. Besides that it is important to pay an attention to the significant differences between the same measurements within the crew member's population. The rather big experience of various helicopter operations (both military and civil) in Russia allows to say that this problem is inherent in all helicopters irrespective of country and company.

Our point of view

Obviously, the interactive computer graphics techniques and the mathimatical 3-D human body model are an up-to-date facilities which could allow to solve this problem effectively during the design stage. Of course, every company produces it's own point of view on this question. As it has been mentioned above some companies use the systems which were developed by specialized firms but the others develop this facilities themselves. The system designers face with two special tasks (among many others): the structure of human body model and the utilisation of an anthropometric database. We have already expounded our point of view earlier, References 7,8. Here it is in brief.

As a result of analysis of many publications related with the crew station design support we found that most of authors emphasize the problem of visualization and animation of the 3-D human body model on the display screen. Recognising the value of such visualisation we think that the maximum usage of the anthropometric and biomechanical information and the computer visualisation of the results of the workspace evaluation are more important. The results may be presented in different forms, for instance: the 2-D or 3-D reach zones or the recommended zones for control location which will provide an optimal pilot's work posture. The results are visualized wihtin the 3-D «electronic mockup» of helicopter crew station. Fig.1 shows the scheme of our crew station design support system.

The base of the system is the mathematical model of pylot's body that was built on the principles which will be stated below. The fact that the human skeleton is governed by the mechanic rules allows to model it as a set of movable links which are connected each other via articulations. Such a model should: 1) correspond with the flight personnel anthropometric characteristics varied within the specified limits (+/-2 or +/-3 standard deviations); 2) take into account the statistical interrelations between the anthropometric measurements.

The individual combination of such measurements is a unique feature of every person as well as the fingerprints or the ear shape. It is known that the system of personal identification based on the combination of the anthropometric measurements was used in the crime detection from the end of XIX to the beginning of XX centuries. This method was invented by A.Bertillion, a French scientist. Most of this measurements are related each other not functionally but statistically, through the positive paired correlation. It is theoretically possible to model the complete variety of the combinaton of N anthropometric parameters by using an idea of a concentration ellipsoid (an ellipsoid of equal density of probability) within N-dimensional space. Particular parametric models which consist of not a great number of links are used for the designers needs. Main parameters are selected during the producing the model. One of this parameters is considered as an independent parameter. The joint distribution of this two or three main parameters are studied by modelling them by means of the concentration ellipse (2 parameters) or the concentration ellipsoid (3 parameters). The regression lines (if the rather strong correlation with the independent parameter exists) are used for the additional parameters. If the correlation is poor, the average value is used. Fig.2 shows the particular parametric model for the arm reach tasks. In our previous paper, Reference 7, were shown following characteristics for the human factor (HF) design problem connected with the evaluation of arm control reach should be selected as the main parameters:

H_{23} - the height of eyes above the seat (the independent parameter) and
H_{12} - the arm length.

The numerical values of the anthropometric parameters come from the computer database which stores 67 anthropometric properties of 560 pilots. These data are statistically processed by using the special software. The most essential feature of the computer database is calculation of a full correlation matrix of the anthropometric data. Only this kind of statistical information allows to deal with the joint distribution of relevant parameters.

Only such crew members who have shortest arm lengths among each group of people with the same «eyes-above-seat» height are interesting for the HF-analyst or the crew station designer during the solving the task of finding of the reach zones. The arm length is defined from the lower bound of the ellipse. This fact means that the statistical relation is replaced by the functional one in the given HF-design problem (Fig.3a). The values of the minor parameters using for determination of the link lengths which provide the location of the centers of hip joint and shoulder joint are defined from the regression lines (Fig.3b).

It is necessary to give a definition to the term «HF-design problem». Under this term we understand a particular task which is solved by HF-designer, or HF-analyst and is conneted with the process of concordance between any crew station element and the anthropometry and biomechanics of flight personnel. The particular human body model for the HF-design problem of the evaluation of yaw control pedals reach will consist of the different links and the main parameters should be different as well. The HF-design problem of the work posture quality evaluation by using the criterion of joint angles will require more complex particular model (3 main parametrs instead of 2), Ref.8. Therefore, the mathematical human body model, the algorithm and the form of evaluation are closely connected with the HF-design problem. In addition the HF-design problem determines the different characteristics of the model:

* the variation limits of the anthropometric characteristics and the form of their presentation: in main square deviations or in percentage number of pilots, (it depends on the Customer requirements);

* the type of control (button, switch, grip etc.) which determines the configuration of hand and fingers during the work and, therefore, the effective arm length;

* the type of functional reach: easy, full or maximum functional reach according to the terminology prescribed by the Russian standards, or Functional Reach (Restraint Harness Locked), Maximum Functional Reach (Restraint Harness Locked), Maximum Functional Reach (Restraint Harness Unlocked), according to the American standard MIL-STD-1333B.

It should be said that such an approach to the forming of the mathematical pilot body model make the concept of «the human body of such-and-such percentile» unnecessary because the percentile is suitable only to the distribution of the single random value and lose it's meaning in the multidimensional distributions. This means that the HF-designer deals with the «entire» population of flight personnel instead to limit himself to several particular cases. An insufficient attention to this question leads to situation described in the Reference 4. During the examination of the model validity using the mockup and several human subjects of the same size as those in the database the authors revealed that they couldn't select the appropriate human subjects. It was impossible because «most humans are not perfect 25th, 50th, or 95th percentile in size». Real humans have the anthropometric sizes which are described by means of more complex mathematical laws.

Main limitation of the conception of the multielement link model

As a rule, the mathematical human body model intended for the HF-analysis of the workspace consists of a set of moveable links articulated by means of joints. They are of two different types: hinge joints (elbow) and ball-and-socket joints (shoulder and hip). Such models are called the Multielement Link Models (MELM) of Human Body. First of all they differs from each other in the number of links. More often this fact is connected with the number of the spinal column segments. For example, the MACMAN has got the 3-segment spinal column (Reference 4) and the pilot body model of the Kamov helicopters company has got the 2-segment spinal column (Refeference 9). It is not necessary to be an expert in the anatomy to understand the approximateness of such a model.

Generally, these models are based on the following assumptions:
1) The links of the MELM are regarded as an absolutely rigid levers of the body's mechanical system (the spinal column as well);
2) The model links are connected each other via the ideal joints;
3) The geometric parametrs of the model are based on the static anthropometry data.

Two kinds of anthropometric dimensions, static and dynamic, are related to the practical problems of design engineering. Static dimensions, which are taken with the body of the subjects in rigid standardized positions, are easily obtained and used in design. For example, the lengths of the separate body segments are the static data. This kind of measurements are used in the development of the multielement human body models. The body dimensions, which change their value during angular or linear displacements of the measured link are the dynamic data. The dynamic dimensions, which are taken with the body in various working positions and functional arm and leg reaches, are usually more complex and difficult to measure. Our model was built with the using of the assumptions which have been mentioned above. The spinal link was considered as a rigid segment and the shoulder joint was modelled as an ideal joints. Besides that the measurements of the arm length (H_{12} in our database) were made by using the distance between the akromial point on the human body and the appropriate point on the hand. It is a static measurement.

The using of the MELM in the crew station design have one troublesome feature. It consists of the certain mismatch of the work space evaluation results obtained by means of the MELM and the measuring which were held with the real humans («live dummies»). This fact is well known to the experts. For example, we can read the following sentence in the document MIL-STD-1333B («Aircrew Station Geometry For Military Aircraft»):

«Consideration shall be given to differences between link model data (e.g. shoulder pivot point) and classical anthropometric data (e.g. functional arm reach) specified by the acquering activity».

This sentence may be found in the Notes to five Figures which are included into into this standard:

Reach zones - minimum link percentile;
Propulsion control geometry;
Collective control geometry;
Yaw control pedals - forward range;
Yaw control pedals - aft range.

In fact, the question is about the main difference between two kinds of the anthropometric information. «Functional arm reach, a dynamic dimension, is not a simple derivative of anatomical arm length. Rather, it is a composite function of such factors as shoulder height, shoulder breadth, the length of the various segments of the arm and hand, and the range of motion at the shoulder, elbow, wrist and fingers», Reference 10.

In other words, we are trying to use the MELM, the simple static model, for the determination of the outer limits of the workplace or «space envelopes» for the placement of controls. However, this limits and envelopes are the results of dynamic anthropometry.

As far as we had known about this matter we compared the link model data with the dynamic anthropometric measurements, which were available to us. It is meant the functional arm reach data obtained in the study of the groupe of 100 Air Force pilots. This inestigation was held by the Air Force experts in area of anthropometry and biomechanics in the scope of the program of measurement of 2000 pilots for creation standards and guidances for the aircraft crew station design. Our computer anthropometric database (static human-body dimensions) is based on the results of this program, which were kindly given us by this experts. So it is possible to consider such a comparison as a correct one. The correctness was guaranteed by the unity of population, principles, tools, and methods of the measurements in both groups. The metodology of this program of the anthropometric measurements is stated in the Reference 11. The authors developed the special measurement device for carrying out of this dinamic measurements, to simulate pilot's workplace. The so-named coordinate method of the anthropometric measurements with the rectangular-spherical coordinate system (Seat Reference Point as a center) was used during the study. Fig. 4 shows the conditions of this measurements. Since the results were presented in the form of two groups of three reach envelopes (minimum, medium, and maximum reach envelopes for pilots both in light and in special clothing), the proposition to model this envelopes by means of computer graphic methods for the placement of controls appeared. Such an approach seems attractive due to it's simplicity and the presens of the requerement data. However, this approach will have one serious defect if the conditions on the pilot's workplace are different as comparedto those of the anthropometric device.
This differences are following:

* The arm reach measurements are related only to the seat with the back angle of 17 deg., whereas this seat back angle of modern helicopters may be rather different;
* Only one kind of the arm reach - the Easy Functional Reach (i.e. Restraint Harness Locked) was measured;
* The arm reach measurements are related only to the unadjustable seat. The requirement of the aligning of pilot's eyes with the horisontal vision line of the aircraft, prescribed by Russian standard, didn't carry out during the measurements. Therefore, the space locations of the centers of shoulder joints (CSJ) of the subjects with different anthropometric dimensions didn't correspond with the space locations of the CSJ in the real flight conditions.
* The arm reach measurements give the information related only to single type of the Functional Reach - the reach with the grasp of the switch by I, II, and III fingers. It is possible to define at least three types of arm and finger configurations (it depends on the control design) in the real cabin environment. This consideration gives the differences in the effective arm lengths.

If this measurement conditions are reproduced for the MELM, it is possible to obtain the comparable data concerning to the arm reach zones in the same coordinate system: the height above SRP and the azimuth. The dynamic measurements related to minimum, medium, and maximum arm reach zones were compared with the computation data, which were taken with the MELM. The particular model which link dimentions varied within the limits of +/-3 standard deviations (99.7 % of population for the single random value distribution, and 98.9 % for the joint distribution of two random values), was applied. This means that in every point of computation the program selected such a combination of the anthropometric parameters which lead to the minimum arm reach. The combination of the results of the dynamic anthropometric measurements and the results of the computation are presented in Fig.5. The average and maximum of the absolute values of the deviations as the function of the hight above SRP are given in Table 1 related to Fig.5.

TABLE 1

h height above SRP mm	average value of the discrepancy,mm	maximum value of the discrepancy,mm
0	171.00	325
200	26.00	148
400	45.25	81
600	43.17	76
800	36.00	74
1000	60.83	139

The comparison leads to unexpected conclusion about rather big discrepancies that take place between the computation data which were obtained from the MELM based on the static anthropometry and the dynamic anthropometric measurements. These discrepancies have larger values on the extreme vertical levels (above and espesially below) and smaller at the middle levels. Besides that, this discrepancies have larger values within the area of the negative azimuth angles. If take into account the fact that the average error of the anthropometric measurements was of 20 mm, these results cause the doubt concerning to the possibility of the using of our MELM for the design purposes.

The possible displacement of the center of shoulder joint

What is the reason of the revealed discrepancies ? We suppose that the reason is related with the assumptions which have been mentioned above. Of course, it will be nonsense to think that the anatomical lengths of the arm and hand segments changes with the motions. Therefore, the space location of the center of shoulder joint (CSJ) is changed. The question about the possible reasons of such a change of the CSJ location will be consider below. Now let us try to determine the possible displacement of the CSJ. Since we had in our disposal the set of the experimental space reach enelopes (Fig.5), we tried to restore the possible trajectories of the CSJ while the arm was moving horizontally by means of the geometric method. The space envelopes of minimum, medium and maximum easy functional reach were studied.

* The effective arm length was computed with taking into account the design of switch for every type of reach:
Hmed=H_{12}med - (L_1med - L_6med);
Hmin=H_{12}min - (L_1min - L_6min);
Hmax=H_{12}max - (L_1max - L_6max), where
H - effective arm length;
L_1med - medium value of the length of III-rd finger;
L_6med - medium value of the length of I-st finger;
L_1min, L_1max - extreme values of the length of III-rd finger, computed by using the regression equation;
L_6min, L_6max - extreme values of the length of I-st finger, computed by using the regression equation;

* Points were marked on each curve bounding the reach zone with the constant interval of 15 deg;

* The straight-line segment with the length of H*cosA, inward directed, and perpendicular to the tangent was drawn from each point. «A» is the angle between the horizontal line and the direction to the point belonged the reach zone bounding curve.

* The ends of the straight-line segments were joined by

means of the curve. This curves were considered as the horizontal projections of the possible trajectories of the CSJ corresponding to the arm movement.

Of course, we didn't hope to recieve an exact information with the aid of such geometrical constructions using the averaged experimental data. But we were able to obtain some qualitative pattern. Fig.6a shows the horizontal projection of the typical trajectory. It is possible to divide this curve into three parts. The part from point 1 to point 2 - displacement of the CSJ along the arc; the part from point 2 to point 3 - displacement of the CSJ along the arc which has the larger curvature; and the part from point 3 to point 4 - an abrupt change of the trajectory shape («tail» or «loop»). The same geometrical constructions were carried out for the vertical section slices of the arm reach space envelopes. The curves of vertical relocation of the CSJ were obtained through the same analysis (Fig.6b). It is interesting to note that the some increase of the heigth of the CSJ which take place in the zone from 0 deg from the midplane of the body to -45 deg corresponds with the part of the horizontal projection which was called «tail» or «loop». It will be interesting to follow the CSJ displacement during the arm movement of a number of human subjects. It will provide more precise quantitative data. Hovewer, we suppose that our results reflect the reality quite correctly.

So than, during the movement of the stretched arm along any horizontal plane for the dynamic anthropometry measurements the CSJ didn't stay fixed, but moved along complex tragectory. This fact leds to the discrepancy between the measurements and the results obtained with the aid of the MELM based on the 3 assumptions which have been mentioned above.

The probable biomechanical causes of the CSJ displacement

We suspect this discrepancy is related with the simplifications in the human model design which take place because of the deficiency in the required anthropometric data. In the ideal case we will need the database of a big number of the measurements which are taken with the human subjects of a rather big population. In actual fact there are 148 movablebones, 29 joints with three degree of freedom, 33 joints with two degrees of freedom, and 85 joints with one degree of freedom in the human body. The mechanism which is called «Human body» has 244 degrees of freedom ! Fig.7 which is taken from the Reference 12 shows the structural scheme of such a mechanism. Hovewer, one can say that in accordance with the Russian standards and design guidances the easy functional reach is related to the posture of crew member fixed by shoulder belts so his shoulder-blades are retained against the seat back. Therefore, it is possible to consider the spinal column as a rigid link. In practice this kind of reach «in the pure state» is possible, perhaps, only in one case:in the conditions of using of the additional forced restraint system of the energy attenuating seat during the crash of helicopter. This system retains the pilot's body against the seat in five points with the force 50 of KG applied in every point. The CSJ is practically motionless and the results of computation with the aid of the MELM are correct for this case. Hovewer, during the functional reach measurements which have been discussed above the harness system didn't exclude some limited mobility of the spinal column.

Becides the flexible spinal column, the movable shoulder does it's bit to the CSJ displacement. The shoulder is a rather complex «mechanism» which links are articulated by means of 5 joints (see Fig.8 which is taken from the Reference 13).

One more simplification should be considered. The ideal joints are meant. As a matter of fact, real joints are very complex «designs». First, the surface of the joint is not a surface of sphere or cylinder. The location of instant rotation axises may change constantly because of the imperfect congruence of the joint surfaces. Second, the surfaces of two bones come into the contact with each other and are kept in the state of the contact through the attached muscles, tendons, and ligaments. Hovewer, the muscles, tendons, and igaments are «transforming designs», and it may be such conditions of motion when the two joint surfaces stop to contact. But even if the contact is not lost, the conjuction allows tree types of motion: rolling, sliding, and combination of rolling and sliding, Reference 14, 15.

Let us to return to the Fig.6 with taking into account this considerations. It is possible to propose the idea that the three sections of the horizontal projection of the trajectory of the CSJ are explained by the successive influences of the different biomechanic causes. For example, the section 1-2 may be explained by the motion of the CSJ along the arc because of the spinal twisting; the section 2-3 is the motion of the CSJ because of the shoulder «mechanism»; and the section 3-4 is the motion of the CSJ which is caused by the simultaneous functioning of the shoulder «mechanism» and the spinal twisting (becides that, the involuntary arm bend in the elbow joint is also possible).

It is possible that the future progress in the area of the computer modelling of human body will be connected with the full account and usage of all this properties. But it should be noted that in addition to the computer technologies it will require a considerably more detailed and, therefore, more expensive anthropometric studies. Mathematically, it means the necessity of the consideration of the variations and statistical regularities of the all quantitative anthropometric characteristics.

The alternative path

It is clear that the path of the direct modelling of the flexible spinal column, which consists of a number of segments, the shoulder mechanism, and real joints will lead to the such a situation when the using of the complex model will be postponed for an indefinite time. Deeming it as a necessary path we propose the alternative which allows, we hope, to use the today's simple link model with an additional block.

We set up the hypothesis that the spinal flexibility, the shoulder mobility, and the differences between the real and the ideal joints lead to the change of the CSJ location as compare with that predicted by means of the MELM. Finally, all this sophistications are just needed for more accuracy prediction of the CSJ location. The comparison of the dynamic anthropometry measurements with the results of computation leads to the disclosure of some mathematical regularity which considerably facilitates the problems. We computed the field of displacements of the CSJ in the direction determined by the arm angle from the midplane of the body (azimuth) and the hight above the SRP. The fixed CSJ of the MELM was considered as a center of the displacements. This computations were carried out for the medium and minimum arm reach groups. Fig.9a and Fig.9b show the results of this computations. It is clear that the curves look like sinusoids. It is possible to approximate this regularities by means of the sinusoid equation in general form:

$PP = A + B*\cos[C*(W + D)]$, where

PP is the displacement of the CSJ, mm;
W is the arm angle from the midplane of the body;
A,B,C,D are the coefficients which depend on h;
h is the height above the Seat Reference Point.

The curves representing the changes of the coefficicts A,B,C,D versus height above the SRP are shown in the Fig.10. The next stage is the approximation of the obtained relationships with the aid of 2-D curve equation.

$Y = +/- (f_1*h^2 + f_2*h + f_3)^{1/2} + f_4*h + f_5$, where

Y is one of the coefficients A,B,C,D;
h is the height above the SRP;
$f_1,\ldots,f_5$ are the coefficients of the 2-D curve.

Therefore, the sinusoid expressed the relationship between the CSJ displacement and the height above the SRP is the aided block of the MELM for the more exact prediction of the CSJ location. We term it «the Block of matching with the dynamic anthropometry data». We suppose that the relative simplicity of this approximation is the indirect evidence for the correctness of our presumption concerned to the causes of the mismatch. Fig. The improved MELM is provided with the additional parametrical link PP (the CSJ displacement). The validation of the improved MELM (i.e. comparison of the results of computation with the measurements) shows the satisfactory coincidence (see Tabl.2). Maximum discrepancy doesn't exceed the error of the measurements (15 mm).

TABLE 2

h height above SRP mm	average value of the discrepancy, mm	maximum value of the discrepancy, mm
0	1.33	4
200	4.00	9
400	4.50	14
600	4.08	12
800	6.00	14
1000	2.75	7

Conclusions

The work on the such a complex tool as the computerized human body model is continuing. Hovewer, we still use the described version of the MELM in the design of helicopter crew stations. Fig.11 shows the possibilities which the program gives to the HF-engineers for the analysis or design of the «pilot-friendly» workspace. The concrete example of the reach analysis of the variant of the control panel carried out during the development of the crew station of the MI-38 is presented in the Fig.12.

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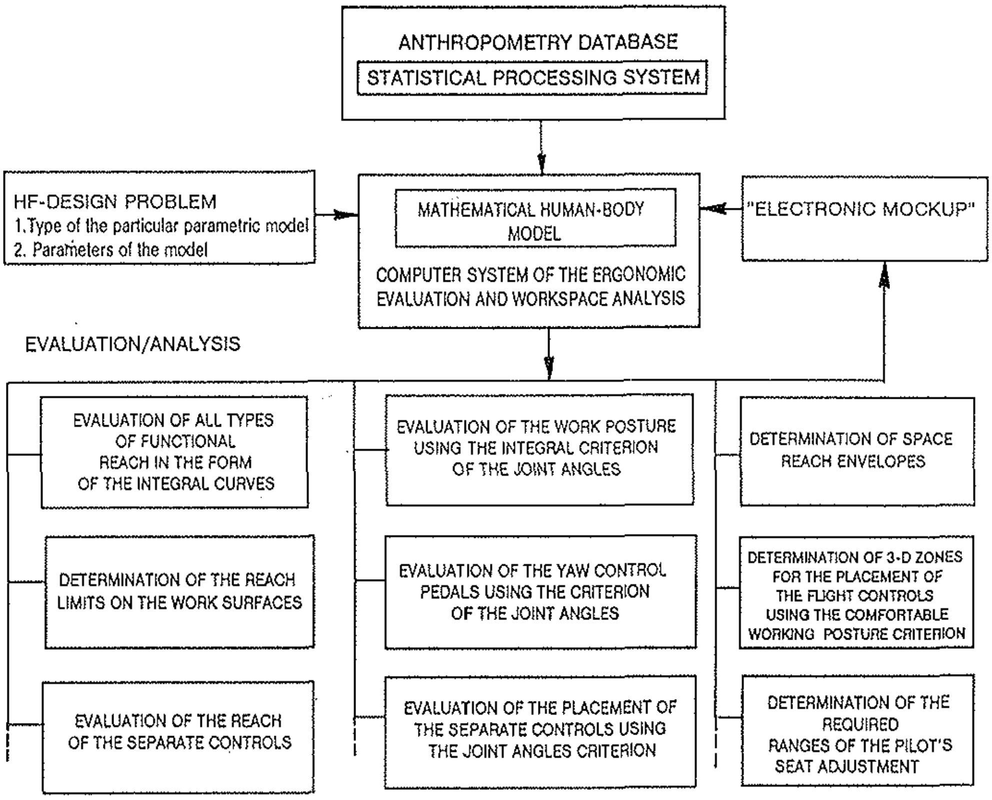
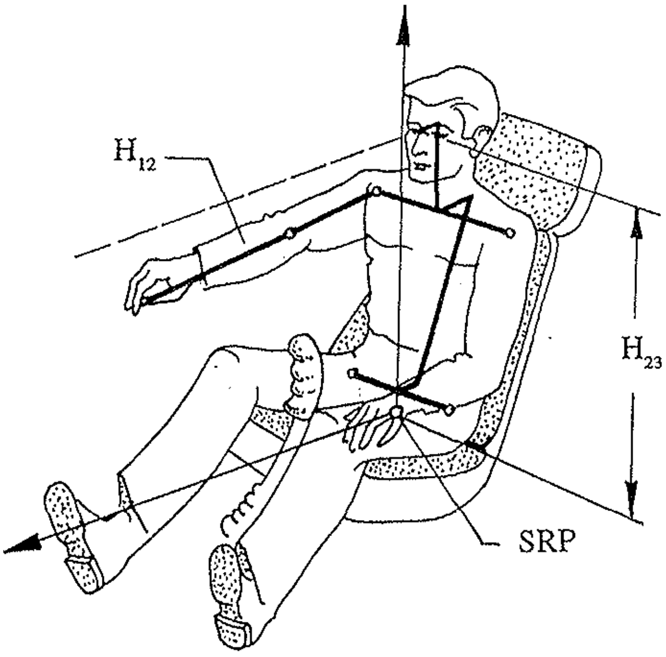


Fig.1 Structure of the crewstation design support system



H_{23} - the height of eyes above the seat (the independent parameter) and
H_{12} - the arm length.

Fig.2. The parametric model for the arm reach tasks.

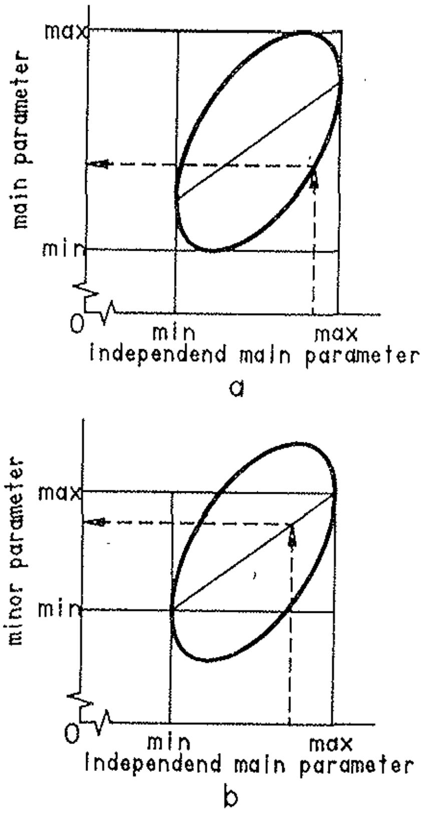
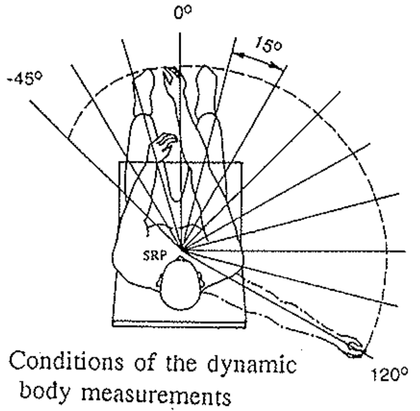


Fig. 3. Determination of the value of the model parameters by using the concentration ellipse



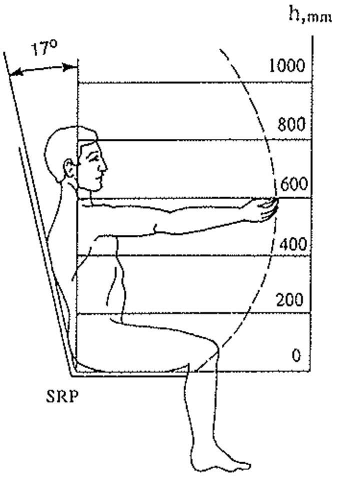
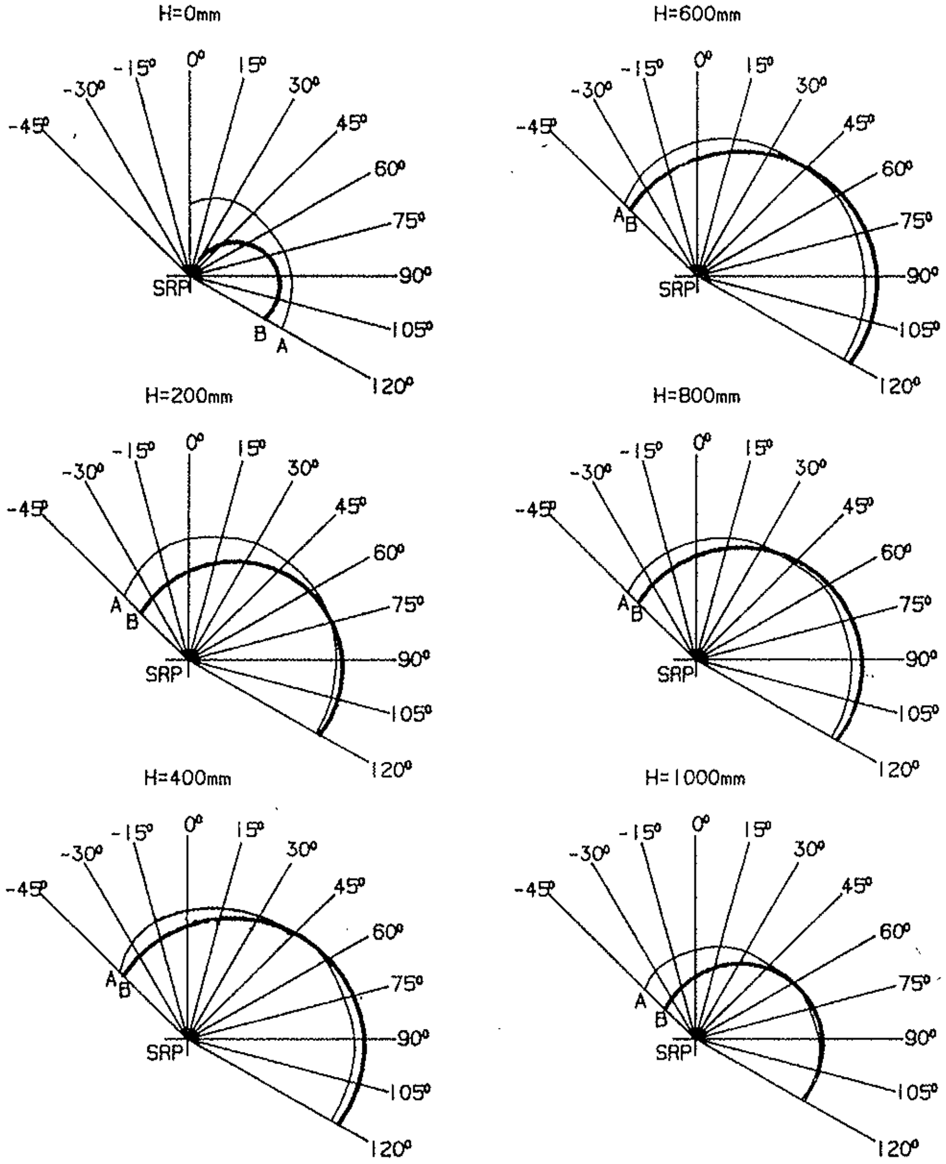


Fig. 4. Conditions of the dynamic body measurements



A - measurements
B - computation

Fig.5. Combination of the anthropometric measurements and the results of the computation

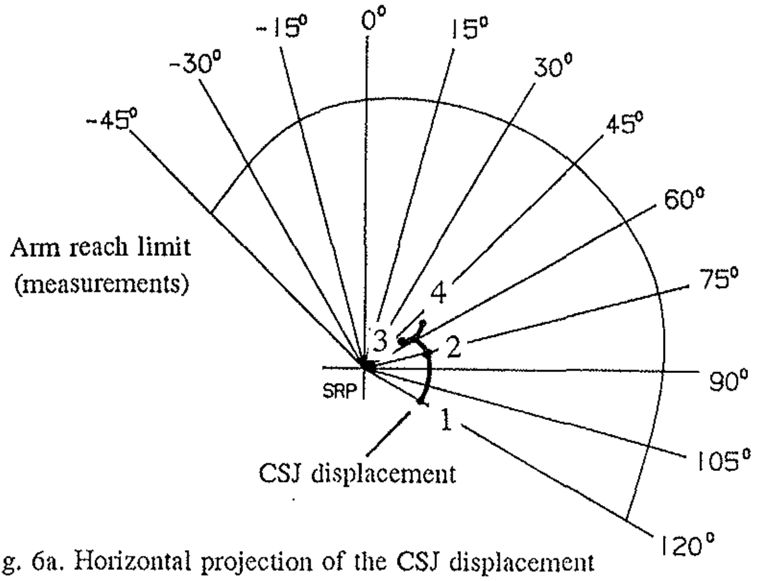


Fig. 6a. Horizontal projection of the CSJ displacement

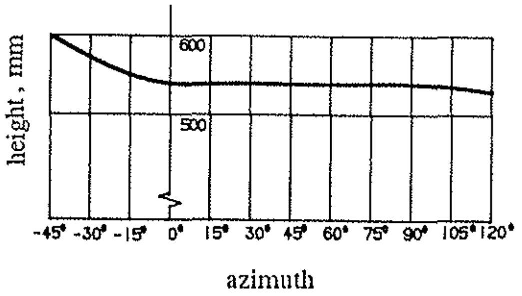


Fig. 6b. Vertical relocation of the CSJ

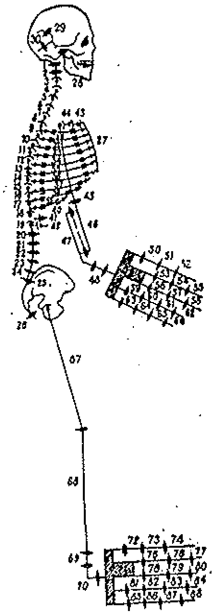


Fig. 7. Structural scheme of the mechanical human body model

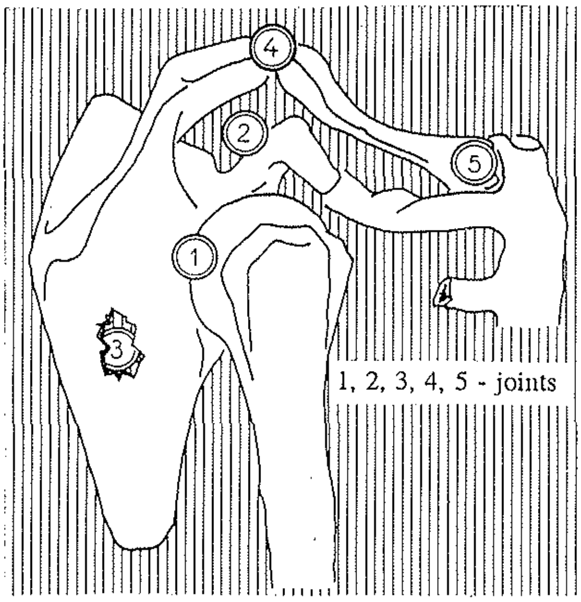
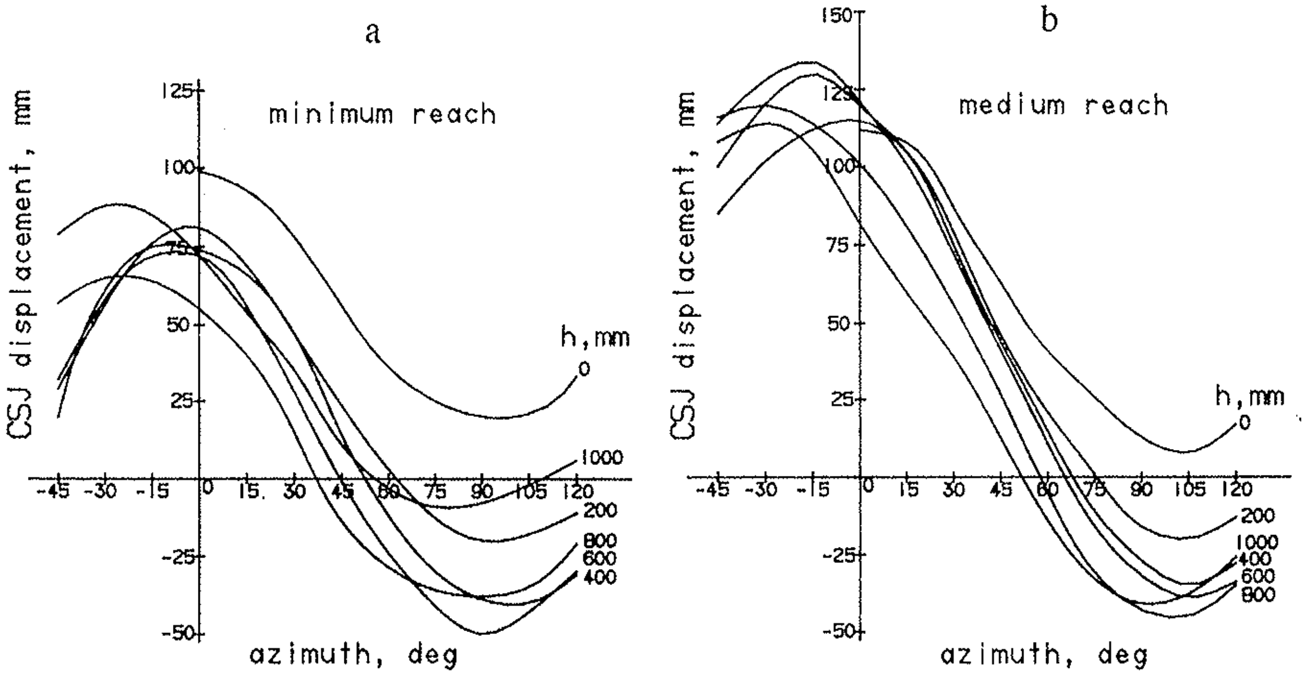


Fig. 8. Links and joints of the shoulder "mechanism"



h is the height above the SPR (arm elevation)

Fig. 9. The CSJ displacement VS the angle from the midplane of the body (azimuth)

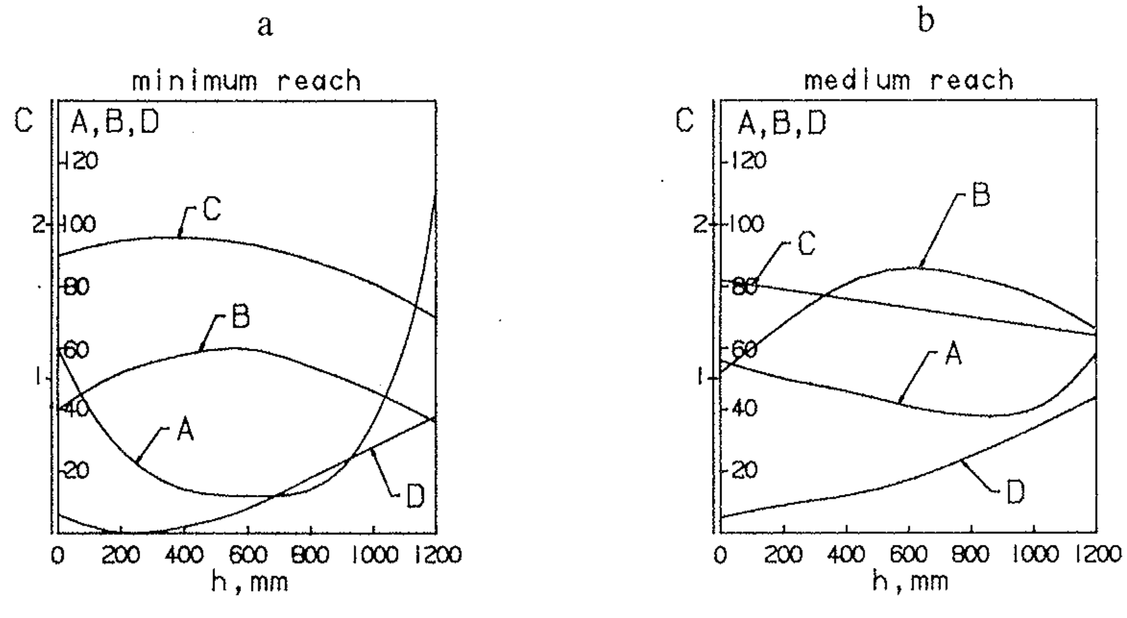


Fig. 10. The coefficients of the sinusoid VS height above the SRP (arm elevation)

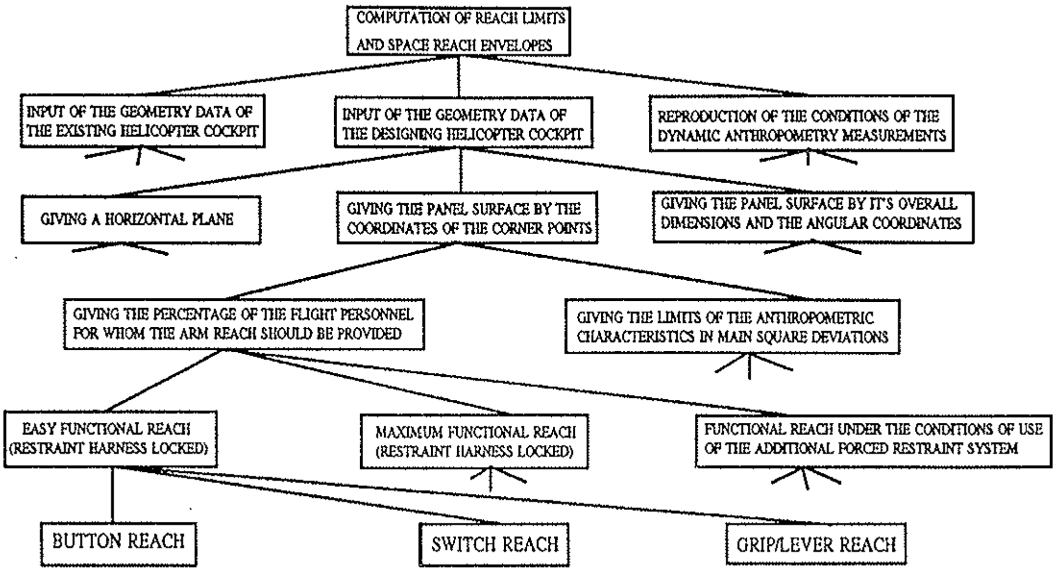


Fig.11. The "tree" of possible variants of workspace evaluation/analysis

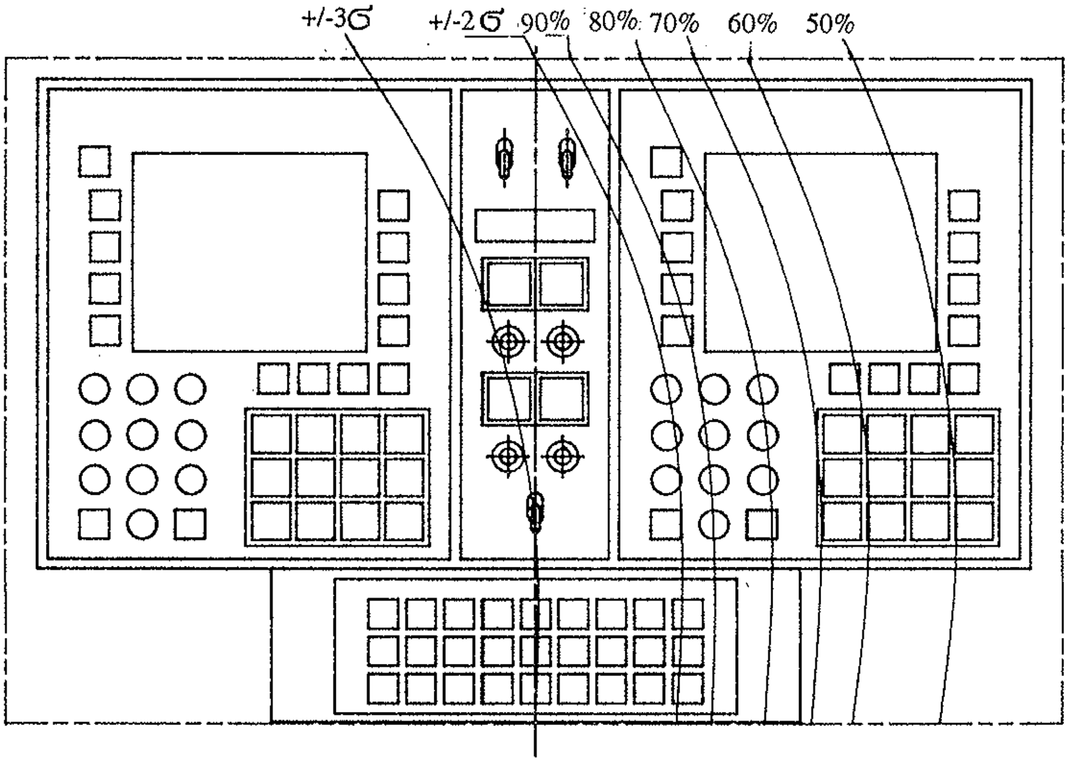


Fig. 12. The example of the reach analysis of the control panel