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IDENTIFICATION AND EVALUATION OF ERGONOMIC INCONSISTENCIES IN THE MANNER OF PERFORMING CONTROL ACTIVITIES BY THE GLIDER PILOT

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Purpose: The reason for this publication was the opinions of pilots, incident investigation reports indicating problems with the ergonomics of the glider cabin, as well as the author's own experience.
Design/methodology/approach: The article attempts to assess the musculoskeletal load of a pilot. The research was carried out using the SWP method, with the help of which the load assessment was performed for selected positions adopted by the pilot in flight. The method allows the identification of the load on separate body segments.
Findings: The publication briefly characterizes the method and factors affecting the level of musculoskeletal load. During the study, the positions for which the greatest musculoskeletal load occurs were identified. The effect of incompatibility on operator unreliability was also considered. Based on the results, corrective measures were proposed, the implementation of which could increase pilot comfort, as well as flight safety.
Originality/value: The article identifies problems related to the ergonomics of the glider's cabin. A number of corrective measures have been proposed including non-invasive measures as well as minor interventions in the construction of the glider. The recipients of the publication can be pilots, operators and designers alike.

Keywords: risk management, ergonomics, flight safety, glider, cabin, pilot.

Category of the paper: Research paper.

1. Introduction

Examination of the level of product ergonomics may enable the identification of mismatch with the properties of the user. If application of a product may result in a hazardous or harmful situation, ergonomics becomes a decisive factor characterizing the product. The article presents an exemplary examination of forced positions imposed on a glider pilot by particularly shaped cabin space and the arrangement of control elements. During the analyses, the Work

Performance Audit (SWP) checklist developed at the Poznań University of Technology was used, based on international standards (PN EN 1005-4; ISO 11226).

2. Research Methodology

When analysing the recommendations for evaluation of the operator's position at work, many identification and evaluation methods for the risk resulting from ergonomics can be distinguished (Górny, 2017; Makarowski, 2010). Excessive load imposed on the organism due to the particular occupation causes the peripheral fatigue, including in the musculoskeletal system, as well as general changes in body functions and fatigue of central nervous system (Ewertowski, Berlik, Sławińska, 2019). Changes that contribute to fatigue of peripheral muscles and central nervous system lead to nuisances and even injuries of the musculoskeletal system, exhausted body energy and exhausted metabolic resources, impaired perceptual functions, impaired eye-hand coordination and reduced mental efficiency of employees (Dahlke, Sasim, Sasim, 2014; Sadłowska-Wrzesińska, Gabryelewicz, Krupa, 2017).

To identify non-recommended positions taken by the pilot, the following were used:

- observations of the prepared photographic material with the use of a goniometer and
- checklist for work performance audit (SWP Audit) developed with consideration to the PN-EN 1005-4 and ISO 11226 standards (Horst, 2004).

The purpose of SWP audit for workplace ergonomics is to identify the occurrence of non-recommended (unacceptable) body postures according to PN EN 1005-4 and ISO 11226 at time of operation. According to the authors of the standard, these body postures are characterized by an increased risk of pain, fatigue and musculoskeletal disorders. They can be identified both during the entire work and during individual activities consisting of basic movements.

This audit is a planned, periodic and comprehensive preventive review of threats occurring at a given workplace. The checklist included in the audit covers the identification of some of the ergonomic risk factors for MSDs (Horst, 2004):

- assuming unnatural positions of the whole body or its segments at time of work,
- the occurrence of unacceptable values of the applied forces and time of their impact,
- compression of soft tissue,
- movements of the body and its segments that do not correspond to natural trajectories and rhythms of human movements,
- movements near the extreme angular positions of the joints,
- chill,
- contact with vibration sources.

A series of checklists identifying the above criteria are included, i.e. in the Components of the Ergonomic Plan (Horst, 2004). If any of the above risks are identified, an analysis of the real exposure of the worker to MSDs should be performed. Exposure is determined by the size of the risk and exposure to the risk.

Risk exposure is characterized by factors such as:

- duration,
- time profile of the exposure to risks from the group of ergonomic risk factors,
- frequency of occurrence,
- simultaneous occurrence of several risks.

The SWP audit is usually an audit for compliance with the standard and is a formal evaluation of the degree of compliance of i.e. body postures, that are adopted by an employee, with the requirements.

The audit should be carried out by a specialist in the field of ergonomics. During the audit, the employee should be observed at the workplace while performing the tasks. The body postures taken by the employee and the frequency of their changes are then recorded. First, the hazards are initially identified with means of the checklist. In the event of non-compliance, an exposure audit is carried out, in which the essence of exposure is characterised in details.

The basic tasks to be performed for the SWP Audit Checklist are:

- initial identification of risk factors for SWP-induced diseases in a given workplace,
- initial recognition by employers and designers of health hazards resulting from the existing or planned methods of performing the work,
- introducing the intervention plan for ergonomics covering the engineering, organizational and training areas at the tested workplace,
- shaping the awareness of ergonomics of the employee under study.

Positions that can cause musculoskeletal discomfort and disease of the musculoskeletal system are listed below.

Unacceptable positions for the torso are:

- bending sideways, leaning forward more than 20 degrees for more than 4 minutes, twisting and leaning backward without full support,
- keeping the torso leaning forward more than 60 degrees without support, leaning back without full back support, twisting, bending sideways, keeping the lumbar spine convex while sitting.

Unacceptable positions for the head and neck are:

- tilting the head to the side more than 10 degrees, twisting, looking less than 40 degrees from the horizontal plane of vision, and looking above the natural plane of vision,
- keeping the head tilted more than 25 degrees without support, leaning back, twisting, and bending to the side.

Unacceptable positions for the arms are:

- raising the arms without lifting the upper extremities,
- keeping the arms: visited to the side or lifted forward without full support over 60 degrees, lifted to the side or forward over 20 degrees without full support, bent back, twisted, brought in front of the trunk.

Unacceptable positions for forearms, wrists and hands are:

- bending/straightening or twisting the forearms and/or hands at the wrist at the limit of the joint range of motion,
- keeping forearms and hands twisted/bent at the limit of range of motion at the elbow or wrist joint.

Unacceptable positions for the lower extremities are:

- holding the lower extremities at the limit of range of motion at any joint,
- bending the legs at the knees while holding a standing position to the limit of the joint range of motion,
- keeping the legs extended at the knees while sitting at an angle of more than 135 degrees with no backward leaning support,
- keeping the leg bent at an angle less than 90 degrees while sitting,
- keeping knees elevated without support and leaning back backward of the torso.

3. Characteristics of the glider under research

The research was carried out on the SZD-30 “Pirat” glider with the marks SP-2741. The SZD-30 “Pirat” glider is a single-seat training glider. Originally, it was allowed to perform acrobatics. The cabin comfortably accommodates a pilot up to 2 m tall with a back parachute. Before taking a proper position in the cabin, the backrest of the seat should be adjusted according to your height and weight. The position of the pedals can be changed before and during the flight. The pilot fastened with belts should be able to make full deflections of the stick, fully press the pedals and have full reach to the panel with instruments by hand (Flight manual for the SZD-30 “Pirat” glider).

Figure 1. View of the SZD-30 “Pirat” glider in flight. Source: photo from the author's collection.

4. Research results

During the flight, a glider pilot performs many activities that have a very large impact on the safety of flight operations. Performing each activity changes the position of the pilot, and thus generates a change in the load on the musculoskeletal system. The tests carried out in the glider cockpit (Figure 1) included 15 activities performed by the pilot with the left and right upper limbs during the flight (Table 1). Example of analysis for description of activities – Elevator "to yourself", ailerons to the left was presented in Table 2.

The pilot is usually equipped with a back parachute at time of the performed flight. The research was carried out with the use of the ATL 88 rescue parachute, which is currently the most commonly used rescue parachute for the flying crew in Poland.

Figure 2. View of the interior of the cabin of the SZD-30 “Pirat” glider, in which the research was carried out. Source: author's photo.

Table 1.
List of activities performed by the glider pilot SZD-30 “Pirat”

No.	Name of the activity carried out by the pilot
1.	Neutral position (flight controls in the neutral position, left hand resting on the knee – standby mode)
2.	Releasing the rope
3.	Elevator "away", ailerons in the neutral position
4.	Ailerons to the left, elevator in neutral position
5.	Ailerons to the right, elevator in neutral position
6.	Elevator "away", ailerons to the left
7.	Elevator "away", ailerons to the right
8.	Elevator “to yourself", ailerons to the left
9.	Elevator "to yourself", ailerons to the right
10.	Air brakes closed
11.	Air brakes opened
12.	Trimmer “nose heavy”
13.	Trimmer “tail heavy”
14.	Operating the radio
15.	Operating the ventilation

Source: own elaboration.

Activity 8 – Elevator “to yourself”, ailerons to the left

Table 2.
Description of activities – Elevator "to yourself", ailerons to the left

Locomotor system segments	Description of the position acc. to ISO 11226 and PN-EN 1005-4	
Torso	tilted backwards without support convex lumbar spine	
Shoulder(s)	front rise exceeding 60 degrees	
Forearm(s) with hand(s)	maximally extended elbow (angle approx. 150 degrees) Twisted inwards (angle approx. 60 degrees) bent up (to the limit of mobility)	
Head and neck	tilted forward up to 25 degrees Tilted forward exceeding 25 degrees	
Legs	while sitting, the leg is bent at an angle of 90-135 degrees	

Source: own elaboration.

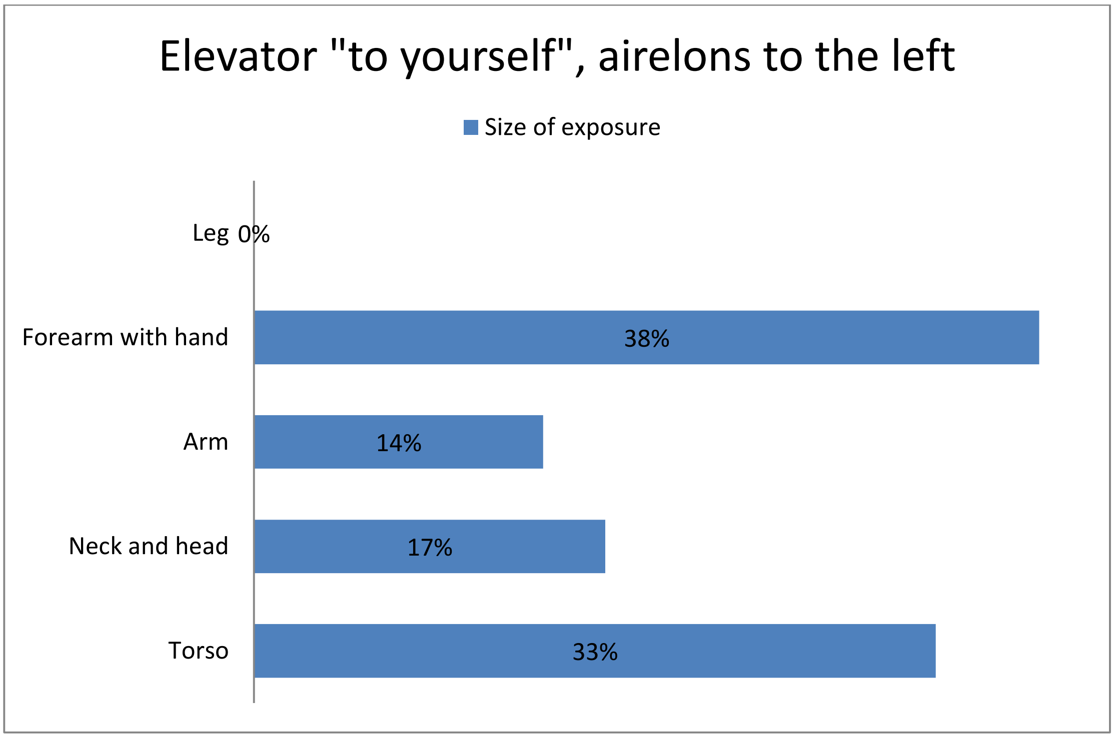

Figure 3. Results of the study of the percentage of exposure to ailments of individual segments of the locomotor system for the “Pirat” glider pilot. Activity - elevator "to yourself", ailerons to the left. Source: own study based on research.

The diagram shows the percentage exposure levels to individual segments of the locomotor system in relation to static positions analysed with means of the questionnaire method. The following is included in the detailed evaluation: torso, neck with head, arm, forearm with hand, and legs.

In this position, the greatest exposure (up to 38%) concerns the forearm with hand of the pilot. Whereas, for the torso, similarly to most other cases, exposure value is 33%. The neck with head are exposed in 17%. The arm is subject to a lower exposure, constituting approx. 14%. The legs are not exposed, which may be due to the neutral position of the rudder.

The analysed position is very unfavourable for the pilot. The total value of exposures is the second largest among all the analysed positions taken by the pilot during the flight with the “Pirate” glider.

5. Analysis of research results

The table below (Table 3) presents the percentage results of the occurrence of non-recommended positions according to the SWP Audit Checklist for individual positions from Table 1. In order to facilitate the comparison of results for individual activities, a cumulative value was introduced, the maximum value of which was set at 500%. It includes the individual activities performed by the pilot in flight, including the quantification of exposure expressed as a percentage in relation to static positions. The exposures for torso, neck and head, arm, forearm with hand, and legs are specified in the table below. The sum of the exposures is also presented.

Table 3.
Presentation of final grades according to the SWP questionnaire method for the activities under research

The amount of exposure	Torso	Neck and head	Arm	Forearm with hand	Leg	Cumulative value of exposures
Neutral position	33%	17%	14%	13%	0%	77%
Release the rope	33%	17%	14%	13%	0%	77%
Elevator "away", ailerons in the neutral position	33%	17%	29%	13%	0%	91%
Ailerons to the left, elevator in neutral position	33%	17%	29%	13%	0%	91%
Ailerons to the right, elevator in neutral position	33%	17%	14%	0%	0%	64%
Elevator "away", ailerons to the left	33%	17%	29%	13%	0%	91%
Elevator "away", ailerons to the right	33%	17%	14%	13%	0%	77%
Elevator “to yourself", ailerons to the left	33%	17%	14%	38%	0%	102%
Elevator "to yourself", ailerons to the right	33%	17%	14%	13%	0%	77%
Air brakes closed	33%	17%	14%	13%	0%	77%

Cont. table 3.

Air brakes opened	33%	17%	14%	13%	0%	77%
Trimmer “nose heavy”	33%	17%	14%	25%	0%	89%
Trimmer “tail heavy”	33%	17%	14%	13%	0%	77%
Operating the radio	33%	17%	14%	13%	0%	77%
Operating the ventilation	33%	17%	29%	38%	0%	116%

Source: own elaboration.

The lowest sum of loads occurs for the activity "Ailerons to the right, elevator in the neutral position" and amounts to 64%, the highest for the activity "Operating the ventilation" and amounts to 116%.

During all activities, the same exposure is recorded for torso and neck with head (33% and 17%, respectively). This proves that the pilot does not need to change the position of the torso, head or neck when doing the activities, so it is relatively easy to introduce corrective actions. At the same time, the pilot is constantly exposed to separate exposures throughout the flight, without the possibility of changing the position, which is particularly problematic during long-term flights, often lasting more than 5 hours.

The exposure of the arms remains at the level of 14%. Only at time of 4 tasks this value increases to 29%. The increase in exposure is related to the requirement for large reach of the upper limbs. To perform these activities, it is necessary to achieve an extreme rudder positions (front and left, while the pilot holds the stick in his right hand). An additional element increasing the exposure is the adduction of the arms while deflecting the stick to the left.

Also for the forearm and hand, the increase in exposure results from the need to increase the work zone, whereas twists occur.

According to the results of studies conducted with means of the questionnaire method, legs are not exposed to the exposure. However, it should be noted that during the implementation of the research emphasis was made on activities performed with the upper limbs. The exposure to the legs may be increased if rudder deflections were included in the performed activities.

While the activity for which exposure is the highest (operating the ventilator – 116%) does not have direct impact on the safety of the flight, the remaining activities for which the exposure is very high, and their precise and repeated performance is necessary to maintain the safety of flight operations, should be the area of concern. In the author's opinion, the greatest emphasis should be made on activities for which exposure is high, and at the same time their performance requires large forces from the pilot (very large forces to control the ailerons and the aerodynamic brake lever). It should be noted that the position with high exposure are largely the positions in which ailerons are deflected to the left.

In each examined pilot's activity there is exceeding of norms for torso – bent back without support and convex lumbar spine, and for neck – neck: bent forward more than 25 degrees.

This indicates the possibility of introducing corrective measures to improve the pilot's working conditions during the entire flight. In the author's opinion, the most effective method is to modify the seat bowl so that the back is supported along its entire length and the spine in the lumbar region is not convex. This change could also help to reduce forward neck flexion. According to author's observations, many pilots try to optimize their position in the cabin by using additional pillows (e.g. narrow, elongated pillows placed between the parachute and the lumbar spine), and back on the lumbar spine to reduce its protrusion), or folding the seat cushion several times to provide better cushioning.

Also, the upper limb positions (arm – raised above 60 degrees and forearm – stretched above 150 degrees) are repeated for 13 and 10 activities, respectively. This is primarily due to the placement of the controls (handles) at a relatively large distance from the pilot and at a high altitude. It may be helpful to place the controls and handles as close as possible to the pilot and lower. At the same time, it should be remembered that aircraft cabin design is always a compromise between pilot comfort and matching the cabin space to the aircraft structure. An additional complication when rearranging the controls can be the high position of the knees, making it impossible to move individual components.

Exposures such as twisting and/or bending of the arm, adduction of the arm, and twisting of the forearm occur especially when reaching full stick deflection. One solution may be to reduce the swing envelope of the stick. This can be done, for example, by shortening the rod. However, it requires the reduction of forces on the stick by using appropriate gears in the rudder and aileron drives. The second cause of bending and twisting is the handling of the aero-brake and trimmer levers. In both cases the rudder handles are spherical in shape. Changing the shape of the handle to an elongated one, placed in the vertical axis (in case of a full-handed airbrake) seems to be an adequate, simple and cheap solution.

Below the author decided to propose other corrective actions, the implementation of which could increase comfort and reduce risk associated with the use of glider.

The load can also be caused by placing the left hand on the knee in the neutral position, which does not result from the pilot's comfort, but is instilled from the beginning of the training process. This is done for quick and easy access to all controls and to prevent accidental shifting of any of the controls in case of acceleration acting on the glider in any direction, which happens during common but incorrect practice of resting the hand on the airbrake lever.

In case of trimmer operation, the higher exposure value for the "head-heavy" position results primarily from the need to bend and twist the wrist at the same time. In this case, a simple solution may be to modify the handle, e.g., with an elongated shape leading downwards in the vertical axis, so as to make it easier to grasp and not to make it more difficult to get in and out of the glider, especially the emergency dropping of the cabin. It is also caused by twisting and bending of the wrist, which results in the radio station manipulator and air vent not being located in the axis of the pilot's extended arm (especially air vent operation, where the lever must be moved in the axis located at an angle of about 45 degrees to the axis of the arm).

A problem encountered by a large group of pilots is the inability to achieve full overhead and side swing, not only due to the capabilities of the upper limbs, but by blocking the stick through the thighs. The above problems indicate that the stick is placed too close to the pilot. At the same time, it is necessary in the present situation to ensure full lateral and forward deflections. The solution to the problem may be the previously mentioned shortening of the stick (requiring at the same time reduction of forces on it by redesigning the gears in aileron and elevator drives).

Another problem is the position of the airbrake lever. In this case, the high force required to operate the airbrake is a factor contributing to the high score. Except for positions where the brake is locked, it takes a lot of force to hold the brake in the desired position. This is due to the effect of "sucking" the aerodynamic brake plates from the airfoil, which is transmitted by the brake drive to the steering wheel located in the cabin. In the author's opinion, the most important corrective action is to reduce the force on the steering wheel by modifying the airbrake drive gear. A measure that might not reduce the rating, but would certainly affect the pilot's comfort is to change the handlebar grip. The pilot is forced to apply a lot of force to change it from a slippery ball to an elongated handle that accommodates the whole pilot's hand, pointed upwards so as not to impede lowering the cabin. Modernization in this area is necessary because it threatens primarily in the critical phases of flight, which are takeoff and landing. During take-off behind the aircraft, when the glider is towed at a speed of about 120 km/h (which cannot be abruptly reduced without disengagement) at the same time, under the influence of the "pigtail" of the towing vessel, the airbrake plates are often sucked out. Due to high forces on the control stick and uncomfortable grip, it becomes almost impossible for physically weaker pilots to close the brake under such conditions. Also during landing, the pilot is often unable to close the brakes due to excessive forces (especially less experienced, experienced pilots usually help themselves by reducing speed). These situations related to the inability to apply the brakes have often resulted in aviation accidents or incidents. Another aspect is the control of the airbrakes during the approach to landing. The need to apply large forces makes it difficult to perform smooth, controlled, precise movements with both the brakes and other controls (stick, pedals). This affects the construction of a proper landing profile, which also translates into its safety. It is worth mentioning that there are large differences in values of forces occurring on particular glider units. Correct operation has some influence on it. Often the forces can be reduced by proper lubrication of the power transmission elements.

Some of the corrective action suggestions listed above may be difficult to implement. This is due to the age of the design and the declining number of users. However, it is possible to implement a number of inexpensive actions that would significantly increase pilot comfort in the cabin. These actions include, but are not limited to, replacing some handles or installing new ones, or redesigning the seat (Berlik, Dahlke, Sławińska, 2018).

6. Summary

During the research, operational positions are identified, which are not recommended and are unacceptable according to the standardization. According to this, the design works can be implemented, in order to eliminate ergonomic inconsistencies. When carrying out such operations, other risk factors should be taken into account, for example the forces applied at time of the performed task. Therefore, it is recommended to continue the research work, because without it the introduced beneficial changes will be incomplete.

Issues related to aircraft cabin design are difficult because on one hand ergonomics and pilot's comfort are important issues and have great influence on safety. On the other hand, the possibilities of proper cabin design from the ergonomic point of view are limited by the structural features. This is particularly evident in the case of gliders, whose performance is particularly important from the user's point of view. Usually such parameters as rate of sink, maximum glide ratio, or speed ranges at which the glider operates are a priority when choosing the appropriate design. It is important to consider ergonomic factors in the design, but also in the further operation of aircraft. Often, the implementation of small corrective actions can result in a significant improvement in the ergonomic quality of the cabin. Pilots themselves are an irreplaceable source of information, so it is important for the entire aviation community to be aware of and collectively strive to improve designs, not only from the standpoint of performance, but also from the standpoint of crew comfort. The growing proportion of pilots flying for recreation rather than competition may cause ergonomics and safety to become increasingly important to potential users.

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