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AN ANALYSIS OF THE ERGONOMIC DESIGN OF THE TACTICAL COMMANDER CONSOLE (TACCO) IN THE VIRTUAL ENVIRONMENT OF MEDIUM-RANGE TWIN-ENGINE MARITIME PATROL AIRCRAFT (MPA)

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ABSTRACT

This study was carried out to examine the ergonomic aspects of the design of the Tactical Commander Console (TACCO) in the virtual environment of medium-range twin-engine − Maritime Patrol Aircraft (MPA). The analysis was conducted using Jack 6.0 software. The evaluation method used in this study is the Posture Evaluation Index (PEI) method that integrates the results of analysis from three methods: Lower Back Analysis (LBA), Ovako Working Posture Analysis (OWAS), and Rapid Upper Limb Assessment (RULA). The purpose of this study is to evaluate the actual design of TACCO and to identify the most ergonomic design configuration, which is reviewed according to the distance and tilt angle of the control panel and the height of the chair. The results of this study show that the optimal ergonomic design for TACCO is as follows: panel at a distance of 10 cm, tilt angle of 60˚, and a chair height of 29.5 cm.

Keywords: Ergonomic; PEI; Tactical Commander Console (TACCO); Virtual Environment

1. INTRODUCTION

Indonesian aerospace technology is beginning to be considered by the world again due to its medium-range twin-engine turboprop aircraft, designed by the national aircraft industry. The aircraft design was generated through cooperation between Indonesia's national aircraft industry and Spain's aircraft industry.

During the development phase, the national aircraft industry introduced the Maritime Patrol Aircraft (MPA) variant that is equipped with navigation, communication, and mission systems. The advancement of the MPA configuration can be seen in the tools with which the aircraft is equipped, which are in a military configuration for maritime patrol.

The medium-range twin-engine MPA was designed by IPTN with a military configuration, with durability as a key consideration, alongside safety and comfort. The ergonomic aspect was the last thing to be considered in the development of this aircraft, especially with regard to the workstations inside the cabin. The cabin contains a workstation comprising both the control panels and a radar display for the systems of communication, environment, and mission control. This workstation is also known as the Tactical Commander Console (TACCO).

In designing the TACCO, neither ergonomic nor comfort aspects were fully considered. Ergonomic analysis was missing from the design process, caused mainly by an inability on the

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part of the national aircraft industry to undertake this form of analysis. One part of TACCO that was designed without considering the ergonomic aspect was the inter-console, which contains the panels for the communications, electrical, navigation, and mission control systems. These panels are used to control important aircraft systems, yet they were not designed to be at an optimal distance for humans (the operators) from their sitting position. This means that to access these panels, the human operators sometimes need to turn their back or waist or even get out of their sitting position. In this case, the concept of ergonomics should also serve as a basic framework for the design of the machine's control devices, so that the operator is able to operate the machine correctly and there are fewer workplace-related injuries. As explained, there are several types of control devices, such as a hand control, foot control, and data input devices (Sanders & McCormick, 1993).

The design process of the TACCO was conducted without the use of any specific ergonomic method. As a result, an ergonomic intervention must be conducted as part of a subsequent design improvement. Furthermore, the participatory ergonomics approach can be employed for this ergonomic intervention. The participatory ergonomics approach used in the ergonomic intervention was integrally merged with the concept of Appropriate Technology (AT). Its aim is to provide opportunities to workers for designing and controlling their work system alongside the contributions of the ergonomics experts working on the ergonomic intervention. It begins with the planning, design, and control of a number of activities and involves the input of knowledge from the user, a technician, or a maker as part of the process to achieve a goal (Batubara & Dharmastiti, 2017).

Meanwhile, to generate a good design in a design process a set of design plans and developments are needed in a "fit the job to the man" manner (Bridger, 2003). This begins with the process of idea generation and continues until the distribution step. Ergonomics is important to refine the design by considering humans in the implementation process. The traditional approach to ergonomics involves an evaluation of the existing design and prototype and sometimes also entails an in-depth adjustment trial by using samples from the users or operators of the system. This approach was needed to ensure that the design achieved certain ergonomic specifications, but it sometimes meant that many parts of the design were completed without proper consideration given to the operator. Therefore, the CAD function is now used as an alternative solution to develop an ergonomic evaluation system by modelling both the environments and the operators (Jung & Kee, 1996).

Ergonomic analysis achieved by modelling the environments and operators could be carried out using digital human modelling and simulation software as part of a Virtual Environment (VE) simulation. This type of VE is a representation of the physical system generated by the computer and allows its users to interact with the synthetic environment in accordance with real environmental circumstances (Kalawsky, 1993). In addition, Siemens Jack version 6.1 software is commonly used for ergonomic analysis. In the analysis process, this study will use the Posture Evaluation Index (PEI) method. This method aims to calculate the human posture comfort level, which is modelled in Jack 6.1 based on the calculation of a Task Analysis Toolkit. Thus, it is expected in this study to generate a design for TACCO on the ergonomic medium-range twin-engine MPA.

Some of the other methods that are recognized for use in ergonomic posture analysis include the Weaving Postures Analyzing System (WEPAS) method, Photographic Posture Analysis, Rapid Upper Limb Assessment (RULA), Occupational Repetitive Action (OCRA) Checklist, Rapid Entire Body Assessment (REBA), and Ovako Working Posture Analysis (OWAS). The primary aim of these methods is to reduce the impact of work-related musculoskeletal disorders and to design working postures that are both comfortable and appropriate for workers. This research constitutes an initial study for redesign of the MPA to be a human-friendly, human-centered design. In this initial research, ergonomics analysis is constrained solely to the physical attributes of users. No consideration was given to the environmental stimuli (such as vibration, movement, stress, and strain) that affected users.

2. METHODOLOGY

2.1. The Nature of Operator Postures in TACCO

In an MPA, the operator will sit observing a display monitor for the total length of an operation or mission. Regarding the MPA specification, this whole operation will take about three to five hours. In the sitting position, the TACCO operator will perform surveillance work that comprises interaction between the TACCO workstation and the operator. They will operate different buttons, toggles, switches, and a joystick with both hands and will tend to alter their body angle, leaning in different positions every few minutes to perform a monitoring task on the TACCO interface display. They will also tend to move their head around to observe this TACCO interface display.

This particular job is similar to any repetitive observing role that people carry out on the ground, such as ATC or working at a nuclear power plant workstation or drone control center. One thing that distinguishes the TACCO operator job from similar operator jobs on the ground, however, is that this job is performed in the air. Aircraft as places of work contain many safety and health-related issues, such as vibration, an unbalanced workspace, pressurization, altitude, and many more. As such, all work-related tools that are used on board an aircraft must be well designed in order to withstand the demands of the environmental and work-related circumstances placed upon them. For instance, a semi-well-designed chair would probably be permitted for groundwork because the operator would be able to take a mini-rest or straighten their back at almost any time. But the TACCO operator is unable to do the same as they are not in a position to leave their post (as a safety issue) and their working environment does not allow them to do so.

2.2. Posture Evaluation Methodology

Ergonomics evaluation for working posture has a broad selection of tools. But in this particular case, the tools or method must be easy to use and the result must be relatively easy to apply and also be reliable. Different tools, methods, or approaches to analyzing the sitting posture characteristics of the TACCO operator can be utilized. To study which of these methods is suitable for the research requires an understanding of the operator’s sitting position and the nature of the task characteristics.

For three to five hours, the operator’s sitting posture is similar to that of a weaver. This kind of posture can be analyzed using WEPAS, which can also be used for posture analysis in other sedentary activities (Choobineh et al., 2004), not only for weaving activities. However, the WEPAS method is not considered to be the most practical method for assessing workers’ postures. It requires a staged room and particular software, in addition to any other tools for probing the operator’s posture through markers on their body joints, using a camera and display as a posture-monitoring device. After such a device has captured the operator’s posture, there are still many more adjustments to make until the data can be used for design purposes.

WEPAS employs a method similar to that of Photographic Analysis of Human Postures. The WEPAS version is a basic method of human posture analysis. Basically, Photography Analysis of Human Postures is performed by applying photographs of a body posture to a frontal and sagittal plane (Rosario, 2014). A significant problem that may occur during analysis is inaccuracy caused by the markers. As explained before, there is a chance that the markers that act as a reference point and that are placed on a human’s joints to calculate the distance and angles of the human postures on the photograph will miss the exact location of the anatomical region. This will not lead to serious errors with regard to large measurements such as shoulder distance, sitting height, etc., but it will alter the outcome of smaller or angular measurements if the markers are completely misplaced (Rosario, 2014).

However, the Photographic Analysis of Human Postures method is considered to be an easy and cheap approach to postural analysis. The benefit of this approach is that it can be employed as part of a particular method or tools that contain similar characteristics. Furthermore, this postural analysis requires a method that breaks down and analyzes the anatomical region of the body. Different approaches are needed for different goals, and selection of the appropriate tool can be challenging. Some popular examples of assessment methods are: (1) RULA; (2) OCRA checklist; (3) REBA; and (4) OWAS (Savino et al., 2016). For the nature of this task and the aim of this research, RULA and OWAS are likely to be used.

2.3. Posture Evaluation Index (PEI)

The PEI method provides the same benefit as Photographic Analysis of Human Postures, i.e., anatomical analysis is split into a few sections of the body. The PEI method also includes a Lower Back Analysis (LBA) score alongside RULA and OWAS to enhance the accuracy of the calculation. Using Siemens Jack 6.1 to recreate a VE that is more immersive than mere photographic analysis, combined with the ability to use its calculation engine for LBA, RULA, and OWAS, creates an enhanced version of the benefit from the previous version.

First, the interactions between the operator and the TACCO workstation were modelled using the Jack 6.1 software, which were then analyzed using the PEI method. PEI is a method that integrates the LBA score and two body posture assessment methods, OWAS and RULA. The result of the integration generates a comprehensive assessment of the working process in the work environment. The PEI method is used to determine the optimization of an operation in a work environment as seen from the perspective of ergonomics (Caputo et al., 2006). Figure 1 is a flowchart of the PEI method. Although the PEI method is not considered to be a state-of-the-art method for calculating and analyzing an ergonomic design, it is easy to use and has the considerable advantage of yielding an instant result, meaning there is no need to use any special tools or the latest technology. Regarding its nature, this method is considered suitable for use in Indonesia. The novelty of this research lies in its object (MPA) because the aircraft is a national product, and for the first time the design process involves integration of the human factors principle into its process.

2.4. The Digital Mock-Up

This study was carried out on the TACCO operator with the aim of acquiring data related to the operator when using the console. To calculate the data acquired from the workstation, indirect observation was employed using a digital mock-up, with the anthropometry data of the operators based on the journal titled "*Anthropometry of the Singaporean and Indonesian populations*" (Chuan et al., 2010). The next step involved construction of the VE for the actual design. The made VE represented the actual real-life condition of the work station.

Once the VE of the actual condition had been made, both the mannequin and VE were imported to the Jack software. The making of the human model was carried out using data from Indonesian Anthropometry. The human models studied were the 5 and 95 percentiles because the workstation would be mass-produced. The human model that had already been imported into the VE on the Jack software would be formed to model the motion of the operator that would be analyzed.

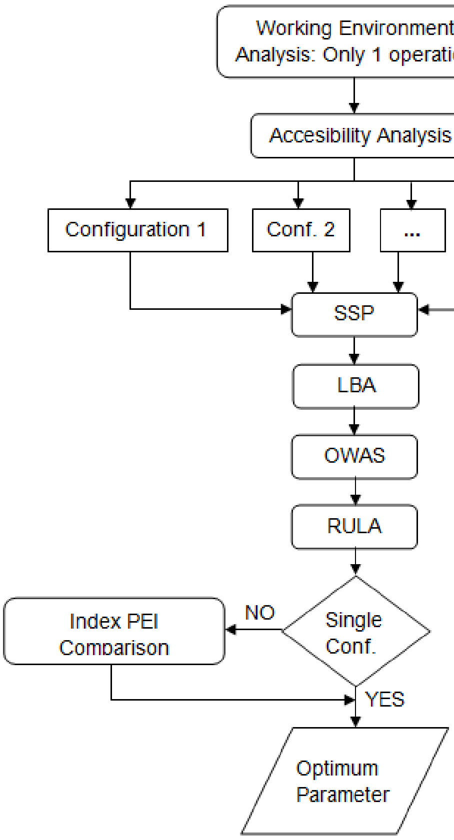


Figure 1 PEI method flowchart

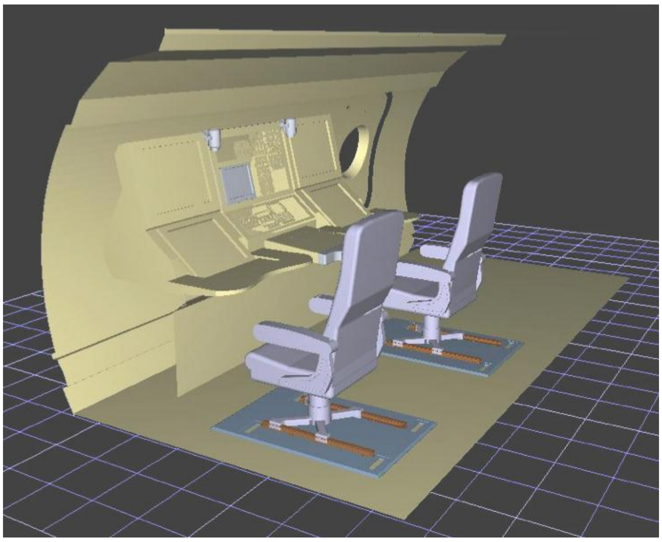


Figure 2 Visualization of the workstation design of the *Tactical Commander Console* (TACCO) in Jack 6.1

The next step involved analyzing the PEI using the Jack 6.1 software with a tool in the Jack: Task Analysis Toolkit. The first analysis carried out within the PEI was the Static Strength Prediction (SSP) analysis. This analysis was conducted to validate the working posture that was made, so that the same could be replicated in the other population. On carrying out the PEI method, it is suggested to use the upper limit (above 90%) of the capability to analyze the SSP.

The second step involved the use of LBA to observe the force exerted on the lower part of the back, which comprises the L4 and L5 parts. This analysis evaluates the real-time load exerted on the back of the mannequin when carrying out the given task. The generated value of the pressure is then compared to the limit of the pressure stipulated in the National *Institute for Occupational Safety and Health* (NIOSH) standard, which is approximately 3400 N. After the LBA analysis, the study continued by carrying out an OWAS analysis. OWAS is an ergonomic evaluation method to examine working postures that observe the standard postures for the trunk, arms, lower body, and neck. The final analysis to be carried out was the RULA analysis. RULA is a tool used to evaluate the posture risk factors, static muscle contraction, repetitive motion, and the force used in a particular task. The final RULA score shows the degree to which workers are exposed to the above risks and allows corrective actions to be suggested based on the score.

The last step is to calculate the PEI value. PEI is a posture assessment method that combines the assessments obtained using LBA, OWAS, and RULA and is summarized into three variables: I_1, I_2, and I_3. The I_1 variable shows an evaluation of the LBA score with the compression strength limit from the NIOSH standard (3400 N). The The I_2 and I_3 variables both show the OWAS index divided by its critical value (“4”) and the RULA index divided by its critical value (“7”). The equation for the PEI method is given below:

$$PEI = I_1 + I_2 + mr.I_3 \tag{1}$$

where I_1 = LBA/3400 N, I_2 = OWAS, I_3 = RULA/7, and *mr* is the amplification factor = 1.42

Thus, the PEI value of the actual design was generated from analysis of the anthropometry of the 5 and 95 percentiles. In the next step, which is making the configuration design, the first consideration is to determine the critical parts of the TACCO and the body part dimensions that are to be used. The variable determining is carried out on the variables, which relates directly to the operator’s working posture forming.

The configuration variables include the distance of the communications panel on the inter-console from the operator, the tilt angle of the communications panel on the inter-console, and the height of the operator’s seat. The determined variables were selected as they are related directly to the forming of the recommended seating posture. Each configuration was tested to both the 5 and 95 percentiles.

Once the configuration design had been made, the human model in percentiles 5 and 95 was imported into the VE along with the configuration design. The next step was to conduct the PEI analysis using Jack 6.1 for every TACCO design configuration. These had already been constructed and would be compared to generate the most ergonomic design from the comparison between the actual design and the realized configuration.

3. RESULTS AND DISCUSSION

3.1. Actual Design Analysis

Analysis using the PEI method was carried out after the human model had been positioned, with the operator accessing the communications panel on the inter-console part. The human model was analyzed using data from percentiles 5 and 95.

Based on the LBA score, the task carried out by the operator on the actual design was below the NIOSH standards, which are 1119 N (for percentile 5) and 1469 N (for percentile 95). Thus, it can be concluded that for the actual condition of the operator with data for percentiles 5 and 95, there is a relatively low risk of injury to the backbone or the spine. This is because the Lower

Back Compression Force score remains below the Compression Action Limit based on the NIOSH standard (3400 N).

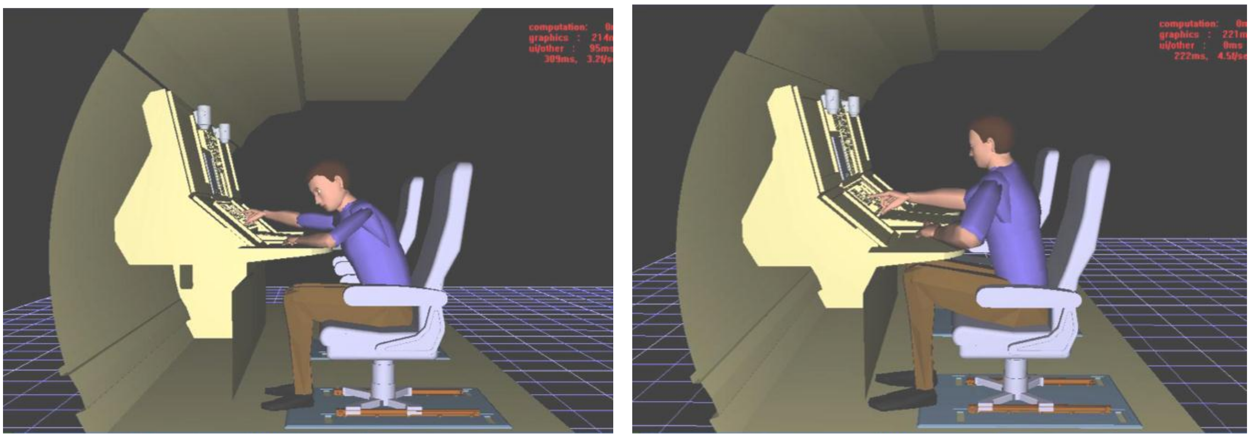


Figure 3 The actual condition of the operator’s working posture for the human model; Percentile 5 and Percentile 95

From the results of the analysis, different OWAS scores are generated between percentiles 5 and 95. From the result of the analysis of the OWAS module for the actual condition of percentile 5, the generated OWAS codes were 4211 for percentile 5 and 4111 for percentile 95. The OWAS code was then calculated and the OWAS score generated; 3 points (denoting immediate improvement is needed) for percentile 5, and 2 points (denoting improvement is needed in the future) for percentile 95.

The assessment of the RULA score shows that the actual design of the TACCO is relatively lacking in terms of its ergonomic aspect. The 6 points on the RULA assessment for percentile 5 and the 5 points for percentile 95 indicate that the risks should be investigated further and should be improved immediately.

Overall, the actual design of the TACCO has a relatively high PEI value. This indicates that the actual design of the workstation needs to be improved to generate a low PEI value. The results of the analysis using the PEI method, which are carried to the human model percentiles 5 and 95, can be seen in Table 1.

Table 1 Recapitulation of the LBA, OWAS, RULA, and PEI values for actual design

Configuration	Percentile	LBA	OWAS	RULA	PEI
Actual Design	5	1119	3	6	2296
	95	1469	2	5	1946

It can be seen from the actual design that the three analyses carried out still do not show an ergonomic value. These are based on the fact that the PEI calculations for the actual design still do not show the comfort level to the extent of 2296 points for percentile 5 and 1946 points for percentile 95. The next step is to design and analyze the configuration design of the TACCO. Studied variables, determined on variables that are directly related to the formation of the operator work posture. The configuration variables that were designed comprise the distance of the communications panel on the inter-console, the tilt angle of the communications panel on the inter-console, and the height of the seat. Table 2 comprises a list of the design configurations of TACCO.

Table 2 The design configurations of TACCO

No.	Configuration	Percentile	Panel Angle (degree)	Panel Distance (cm)	Seat Height
1.	1A	5	50	5	24.5
	1B		60		
	1C	95	50		
	1D		60		
2.	2A	5	50	10	
	2B		60		
	2C	95	50		
	2D		60		
3.	3A	5	50	5	29.5
	3B		60		
	3C	95	50		
	3D		60		
4.	4A	5	50	10	
	4B		60		
	4C	95	50		
	4D		60		

3.2. Comparison Analysis of the Design Configuration

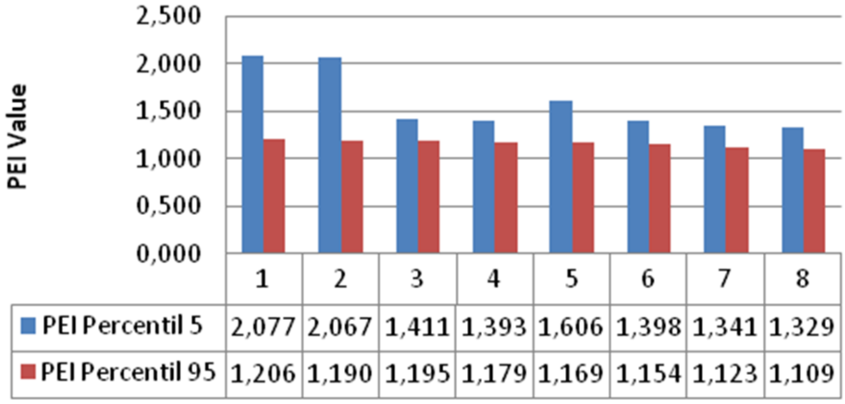
A comparison analysis of the design configuration was carried out after the design configurations had been completed and the human model was positioned, ready to be analyzed using the data from percentiles 5 and 95.

Table 3 Recapitulation of the LBA, OWAS, RULA, and PEI values on design configuration

No	Configuration	LBA	RULA	OWAS	PEI
	Actual Design	1119	3	6	2296
		1469	2	5	1946
1.	1A	1063	3	5	2077
	1B	1029	3	5	2067
	1C	1180	1	3	1206
	1D	1128	1	3	1190
2.	2A	1027	2	3	1411
	2B	966	2	3	1393
	2C	1145	1	3	1195
	2D	1089	1	3	1179
3.	3A	1002	2	4	1606
	3B	984	2	3	1398
	3C	1054	1	3	1169
	3D	1004	1	3	1154
4.	4A	791	2	3	1341
	4B	750	2	3	1329
	4C	900	1	3	1123
	4D	852	1	3	1109

Based on the three analyses used to generate the PEI value for each design configuration, it can be seen that the tested postures affect the OWAS score. The OWAS score for each design configuration is affected by the operator’s anthropometry data, with 2 points for the OWAS score for the percentile 5 anthropometry data and 1 point for the percentile 95 data. The changes could be seen in the LBA score that is below the actual design configuration score.

This is because of the change in body posture that affects the LBA score in such a way that the LBA score is lower than the actual configuration score.



	1	2	3	4	5	6	7	8
🟦 PEI Percentil 5	2,077	2,067	1,411	1,393	1,606	1,398	1,341	1,329
🟥 PEI Percentil 95	1,206	1,190	1,195	1,179	1,169	1,154	1,123	1,109

Figure 4 Chart of PEI value comparison of the whole configuration

The RULA scores show that the design configuration of TACCO is already better than the RULA score of the actual design. The RULA score of 3 points for percentile 5 and percentile 95 indicates that the risks should be investigated further. The low RULA score, which means a low risk of injury, is affected by the hand position.

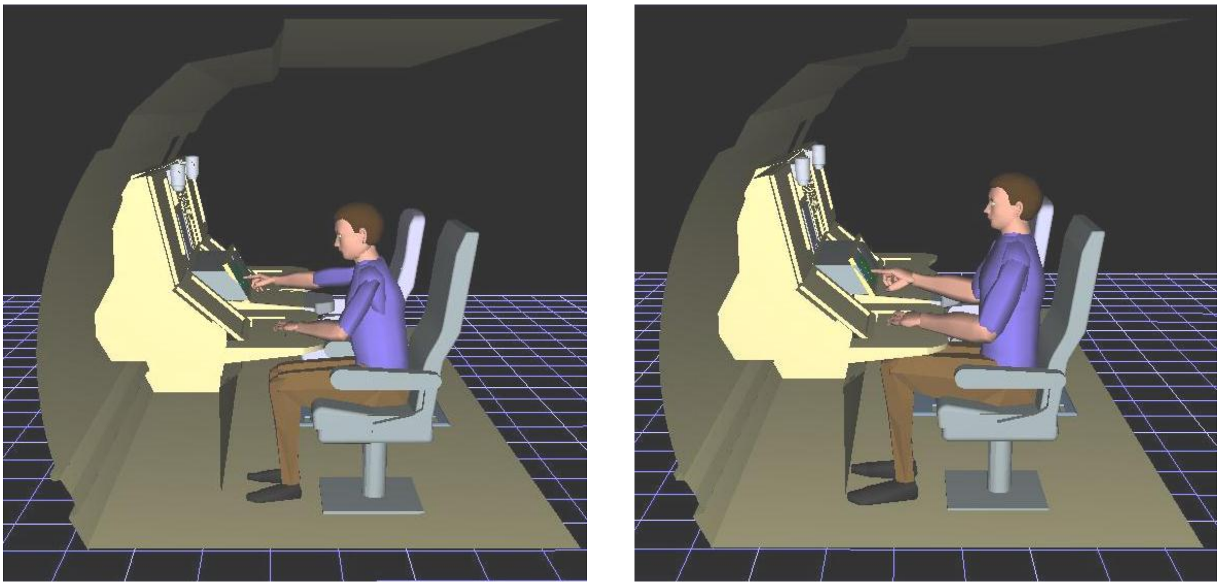


Figure 5 Recommended design configuration of the *Tactical Commander Console* (TACCO)

From the chart of the PEI calculation result, it can be seen that recommended design configuration 4 has the lowest PEI value. This configuration is the design configuration 4B for the operator with percentile 5 and 4D configuration for percentile 95. It can be concluded that an improvement to the design of TACCO in consideration of the distance of the communications panel (10 cm), the tilt angle of the communications panel (60° incline), and the height of the seat (29.5 cm) will generate the lowest PEI value. This configuration is the most ergonomic design for the operators who use it. The generated PEI scores for the configuration are 1329 points for percentile 5 and 1109 points for percentile 95.

4. CONCLUSION

From the study of "An analysis of the ergonomic design of the Tactical Commander Console (TACCO) in the virtual environment of medium-range twin-engine Maritime Patrol Aircraft (MPA)", it can be concluded that: (1) The operator's working posture at the TACCO workstation is not in an ergonomic position to enable access to the panels on the inter-console; (2) The generated PEI scores for the operator's working posture in the actual condition are 2296 points for percentile 5 and 1946 points for percentile 95; (3) The lowest PEI score was generated in configuration 4, which had a PEI score of 1341 points to 1109 points; (4) The PEI score for configuration 4 was 1341 points with a tilt angle of 50^o for the communications panel and 1329 points for a panel tilt angle of 60^o for percentile 5, and 1123 points with a panel tilt angle of 50^o and 1109 points with a tilt angle of 60^o for percentile 95; and (5) The most ergonomically optimal TACCO configuration design for the operator involves bringing the communications panel 10 cm closer than in the actual condition, setting the tilt angle of the communications panel to 60^o, and using a seat height of 29.5 cm.

This result, however, is not expected to be a best result or best practice for this kind of analysis. This is because the PEI method, by its nature, is a fast-analysis approach to calculation as opposed to a thorough and comprehensive method for design-proofing. In Indonesia, this kind of method (a practical, fast, and easy-to-use method) is preferred by industries for use as a design guide. This is largely reflective of the lack of available cutting-edge technology to apply comprehensive research and the lack of awareness and knowledge of human factors/human-centered design methods, even within for aircraft industries.

5. ACKNOWLEDGEMENT

All data were provided by PT. Dirgantara Indonesia under the Non-Disclosure Agreement (NDA) Act. Some of the data have been hidden in order to comply with this agreement, and some of the narration of the text that contains specific information has been altered. Overall, however, the technical value of this research has not been diminished in any way.

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