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ORIGINAL ARTICLE

Ergonomics Study Among Operators in Water-Jet Production Area in the Aircraft Industry

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ABSTRACT – This paper conducts the ergonomics risks assessment (ERA) among the operators in water-jet production workstation area in the aircraft industry, working with aircraft panels' liners named Oriented Strand Board (OSB) and the aircraft panels which require forceful exertion, lifting and carrying task in order to complete the operation activity. The possibility of Work Musculoskeletal Disorders (WMSDs) among operators could occur due to their daily working activities. The objectives of this study are to conduct the initial ERA and advance ERA among the waterjet production operators. Twelve male operators had been participated in this study with age range of 20 to 40 years old. Nordic checklist, operational interviews, observations, Rapid Entire Body Assessment (REBA) tool and Manual Handling Assessment Chart (MAC) tool as part of advance ERA evaluation were applied in this study. The initial ERA results recommend for further investigation on awkward posture and forceful exertion among the operators in waterjet production. The results from REBA shows that all operators obtain high risk ergonomics score of 10 for load weight and high repetitive in lifting and carrying task. The results from MAC validate that gripping mechanism during lifting and carrying activity requires ergonomics intervention for reducing the forceful exertion and high repetitive risk. The results from ERA, REBA and MAC assessment in this study are novel contribution in the aircraft production since the similar data is not reported yet. The results can be translated into measurable design parameters for waterjet workstation improvement in future design workstation.

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ERA; REBA;
MAC; Water-jet;
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INTRODUCTION

Ergonomics is a study of combining scientific principles, methods, and tools from a variety of disciplines to develop a working system accounting human-in-loop in which people play an important role [1]. It also is the theoretical study of the interaction between humans and machines in the work environment. The basic goal of ergonomics is to match humans and machines together to maximise the worker's efficiency, minimise tension, and occupational exhaustion [2]. The main benefit of ergonomics investigation in the working environment is people can address the source of the working risks and eliminate the risk by implementing the engineering design, medical or organisational solutions for improvements [3].

Ergonomic risk assessment is part of the cycle of risk reduction and should be used in a comprehensive review of possible safety and injury risks. The aim of performing an ergonomic risk evaluation is to reduce safety hazards associated with the research by recognising actual or future hazards that could result in MSDS. When determining risk factors, efforts may be made to reduce or eliminate them. Risk assessments may also be beneficial when assessing an intervention performed at the workplace [4]. The assessment depends on the types of ergonomics risk factors identified [3]. The ergonomics assessment such as Initial Ergonomics Risk Assessment (ERA) and Advanced ERA was carried out in an aircraft industry's waterjet production unit to assess the ergonomics risk, musculoskeletal symptoms and their pain sources [5]. The Initial ERA conducted the Nordic assessment while the Advance ERA analyses by using the Rapid Entire Body Assessment (REBA) and Manual Handling Assessment Chart (MAC) that depend on the result of initial ERA [3].

It is difficult to find literature regarding ergonomics investigations in aircraft manufacturer. There are two almost similar studies conducted by Cichocki et al. [6] and, Jaafar and Rahman [7]. Cichocki et al. investigated cancer risk among aircraft manufacturer operators due to Trichloroethylene (TCE), Perchloroethylene (PCE), mixed solvents, and chromates exposure in the production department which produced insignificant correlation results between the chemical solvents and the cancer risk among the operators. In comparison, Jaafar and Rahman examined Cumulative Trauma Disorders (CTDs) among aircraft manufacturer employers to identify the correlation of work and other activities to an individual worker experiencing CTDs. The study suggested the posture training and exercise training for the group of the dominant hand, time spent in an awkward position, the number of standard rivets bucked, number of parts routed, number of parts ground, number of vibration-dampening rivets bucked, and newly hired individuals reduce the CTDs risk among employer.

It was found from literature study that the ergonomics issues in aircraft manufacturing are different all around the world due its product, workstation, working behaviour and the operation task conducted by the operators in the

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manufacturing unit. Therefore, it is important to assess the ergonomics risk among the operators in the waterjet production because the ergonomics risk could be different for operators in the waterjet unit due its multiple factors such as task, type of product, operators' demographic and working behavioural [8].

The operators in the waterjet unit working with OSB and the aircraft panels require forceful exertion, lifting and carrying task in order to complete the operation activity. The weight of each OSB was 25 kg while the weight for each panel was 1 kg on average. In average, two operators worked as partners lifting and carrying three OSBs and 175 pieces of panels in seven hours per working shift. The possibility of work musculoskeletal disorders (WMSDs) among operators could occur due to their daily working activities. Thus, the objective of this paper is to assess the initial ergonomics risk among operators of waterjet production in an aircraft industry which contributes to WMSDs.

State of the Art

Seven ergonomics risk factors contribute to musculoskeletal injury, and mental workload are awkward posture, forceful exertion, repetitive motions, static or sustained posture, whole-body vibration, contact stress and environmental factor [1]. Work musculoskeletal injury or working musculoskeletal disorders is increasing yearly based on work-related injury compensations increasing trend [3]. WMSDs occur among industry operators who are frequently operating their working tasks by doing repetitive motion or task in awkward or static work posture or exposed to the vibration or contact stress or under improper lighting or noise [3]. As a result, the operator experienced a variety of WMSDs symptoms such as pain related to the body parts, as illustrated in Figure 1.

Figure 1. Body parts exposed to WMSDs.

Awkward posture refers to the body positions during work, which differs significantly from the neutral position. The awkward posture examples are: operating task using hands over the head, body twisting, body bending, operating task with over-reaching hand, operating task with elbows over the shoulders, operating task with the neck or back bent more than 30 degrees without support, hand flexion and hand extension [3]. Forceful exertion occurs for the working activities that use of a high level of pulling or pushing force such as heavy lifting, lowering heavy load onto a rack, pushing a hard button, pulling heavy loads, stamping and drilling works. The forceful exertion also occurs in static and sustained postures, which put extra strength on the joints and overload the muscles and tendons, such as an army holding a rifle in lay down position over two hours per day [3]. Repetitive motions are referring to the frequent and repetitive body joints and muscle movement or very quick movement over a long period of time. A task is considered highly repetitive if the task, including 30 seconds of repetitive movement per minute in one cycle. The task with repetitive motions usually involves other risk factors such as the static or sustained position or forceful exertion or contact stress [3].

Static or sustained posture is defined as a minimal movement of the human body or the absence of movement in a specific position over a continuous and long time. Maintaining a static posture in one position, e.g. standing and sitting contributes to fatigue, pain and injury that can lead to different disorders [3]. Body vibration factor is classified by whole-body vibration (WBV) and hand-arm vibration (HAV). WBV is related to the task that uses kinetic energy to transmit mechanical motion via the seat or feet of the operator, such as buses and excavators or on rough and uneven surfaces, e.g. on mining rails. While HAV refers to hand and arm exposure to the kinetic energy from vibrating and percussive handheld power tools such as drilling activity.

Contact stress has two types. It can be internal or external. The internal contact stress involves a condition when tendon, nerve, or blood vessel is bent or stretched around a bone or tendon. Next, the external contact stress is a condition when a part of the body rejects a workstation component, such as a chair seat pan or a desk edge [3]. Environmental risk factor refers to environmental elements that affect human comfort, activity and health, e.g. thermal environments, lighting, noise and extreme atmospheric pressure [3].

METHODOLOGY

Participants

The ergonomics risk assessment was performed among 12 male operators who have an average age between 20 and 40 years old. They also have working experience average was one to seven years. The participants also free from a musculoskeletal-related medical background to obtain the findings that are affected by health factors. All participants were willingly basis.

Ergonomics Analysis

An ergonomics analysis was carried out at the waterjet area production unit in the aircraft industry. Figure 2 shows the oriented strand boards (OSB) as aircraft panels' liners, where the operators had used during working. Besides, Figure 3 shows the aircraft panels that produce in that industry such as aileron skin, fuel doors, ribs, skin, spar, hinge and fixed leads. Three OSBs were lifted by two operators that 25 kg of weight for each OSB. The number of panels produced per shift was 175 pieces, where the average weight of each panel was 1 kg. They need to work in seven-hour per shift.

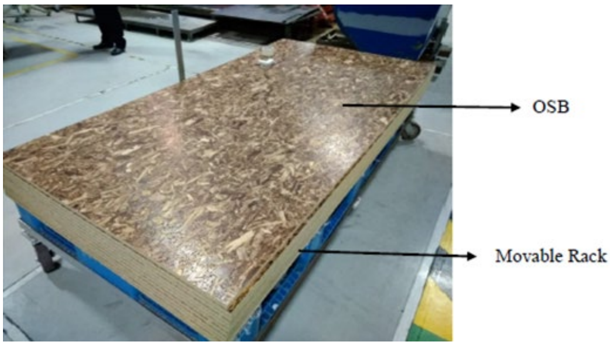


Figure 2. OSBs on the movable rack.

Figure 3. Types of aircraft panels in waterjet unit.

Operation Tasks

The operational activities in waterjet production unit basically operated in three work shifts with four operators per shift. Two operators worked with flow jet machine, and the other two operators worked with the ward jet machine for eight hours per work shift, including one hour break, as shown in Figure 4. The operation task started with the two operators lifted-up the OSB manually as from the movable rack and manual carry to the flow jet machine. The same task conducted by the other two operators that worked with the ward jet machine. The moving distance between the movable rack and the flow jet machine was approximately 5 m, and the ward jet machine was approximately 15 m. Next, the operators lifted-up the aircraft panels manually from the second movable rack and manual carry to the flow jet and ward jet machine each in 3 m distance. The machines trimmed and drilled the panel on OSB by operator's handling. In addition, the operators also need to bend down their body to lift-up the OSB and panels at a low height of the position on the moving rack, i.e. 15 cm from the floor. The operation cycle ended after the operator lowering the trimmed and drilled panel on the finished panels' rack. Figure 4 illustrates the operation flow in the waterjet unit.

Figure 4. Operation flow in waterjet unit.

Risk Factor Assessment

The ergonomics risk factor assessment determined by two types of assessment which the Initial Ergonomics Risk Assessment (ERA) and Advanced Ergonomics Risk Assessment (ERA). The Initial ERA was conducted using checklists of Nordic and ERA while the Advance ERA uses the REBA and MAC tool [7], [8] and [9] wherefrom Department of Occupational Safety and Health, Malaysia guideline [3].

The purpose of Rapid Entire Body Assessment (REBA) [9] is for assessing the specific body posture that exposed to the musculoskeletal symptoms based on Initial ERA results. This assessment enables the scoring of 144 possible posture combinations including the trunk, legs, neck, shoulders, arms and wrists. It also to determine the appropriateness or chosen position of the body, forceful exertion, form of movement or behaviour, repetition and coupling [10]. The overall score takes into consideration the same additional factor, such as load, coupling, and frequency accounted [11].

The Manual Handling Assessment Chart (MAC) is a tool to assess the common risk factors in manual lifting and lowering, carrying and handling [7]. The MAC tool helps the researcher to understand, interpret and categorise the level of risk of the various known risk factors associated with manual handling activities. The chart combines a numerical and colour-coding score system to highlight the level-risk of manual handling tasks. However, MAC is not appropriate for any manual handling operations, for example, the working activities that involve pushing and pulling motion. Also, MAC does not comprise a full risk assessment for individual and psychosocial risk factors were not considered when completing the score sheet. Besides, MAC is also not designed to assess risk for a workplace that using upper limb lifting, carrying and lowering.

Experiment

The risk factors among the participants were identified with some interview during working by using the Nordic checklist that obtains the demographic data and musculoskeletal [8]. The Initial ERA was conducted by interviewing among 12 operators based on the answers from the Nordic checklist and video recording and picture captions during their interaction with the OSBs and panels. The answers and feedback from interviews and the Nordic checklist were validated by analysing the video records and picture captions. The Advanced ERA was conducted by using the REBA and MAC assessments based on the results of Initial ERA. These assessments were identified the ergonomics risk by using the video recorder and picture captions that can verify in the Initial ERA results.

RESULTS AND DISCUSSION

The summary results of musculoskeletal symptoms among 12 operators in the waterjet production unit are shown in Figure 5. The highest feedback is 26% of shoulder pain complaints followed by the lower back pain from 23% response, and 15% responded regarding wrist or hand pain. It is also impossible to neglect the upper back pain and neck pain because almost half of the operators respond to both musculoskeletal pains with five and four feedback each.

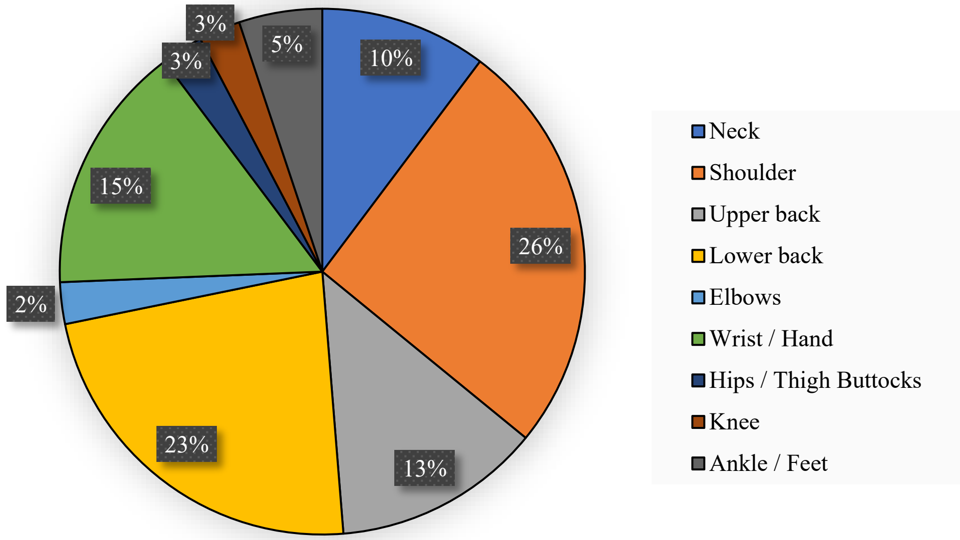


Figure 5. The summary results of musculoskeletal symptoms among operators in waterjet unit.

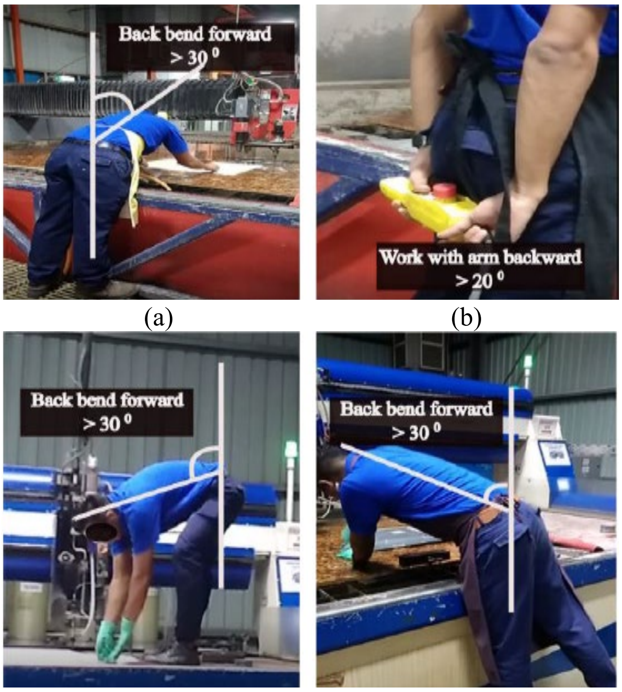
The summary result of Initial ERA among operators in waterjet unit is shown in Table 1. Forceful exertion is the main ergonomics risk among operators which is seven out of 12 operators experienced the excessive use of body strength during work tasks. All operators were identified working in awkward postures, but the score shows below than the minimum requirement for Advanced ERA. However, based on the video observations, awkward postures factor cannot be ignored because it becomes a domino effect to the forceful exertion as shown in Figure 6(a) to 6(d). As an example, the operator positioning the panel on the OSB, pin and putting a load on the panel in 30° back bend forward posture as shown in Figure 6(a) and 6(d). Also, the operators bend their upper body during lifting the OSB and panels from a low height, as shown in Figure 6(c). Both activities were conducted by operators in 30° back bend forward posture for two hours accumulated in every eight hours working shift. In addition, the operators were also handling the pendant controller to control the drilling and trimming tool in awkward posture as illustrated in Figure 6(b) due to safety requirement, i.e. Avoiding the pendant controller cable twisting around the body. Besides, the musculoskeletal symptom results in Figure 5 shows high responses on lower back pain that lead to awkward posture as the risk factor. Consequently, it suggested in this study to investigate further the forceful exertion together with the awkward postures factor using Advanced ERA.

Table 2 presents the summary results on the REBA assessment among operators in the waterjet unit. The results show that the average REBA score among all operators is 9 which is a high level of ergonomics risk relating to the upper body part, e.g. trunk, neck, and coupling arm area. 50% of operators obtained the highest REBA score of 10, 42% of operators obtained score nine, and only 8.3% operator obtained score 7. A total of 92% of operators belong to score 4 which indicating medium risk for the trunk area. In comparison, all operators obtained score 3, which indicating medium risk for coupling area and 58.3% of operators also score 3 for the neck area. These results verify the awkward posture risk that had been identified in Initial ERA results as shown in Table 1 and confirms the feedback from the operators regarding the shoulder pain and back pain as illustrated in Figure 5 is related to the trunk and neck area. While the shoulder pain occurs among operators, as resulted in Figure 5 is associated with the forceful exertion, risk result in Table 1, which referred to the coupling arm area in Table 2.

Table 3 shows the summary results of the score of MAC scores among operators in the waterjet unit. All operators obtain high-risk scores in total MAC score with 16.6% of operators obtained score 20, 41.7% of operators obtain score 19 and other 41.7% obtain score 8. All operators belong to the purple indicator colour, which defined as high ergonomics risk in an activity that relates to load weight and lifting frequency. Next, a high score of 10 is relating to grip on the load task, which all operators obtain red colour or high risk. Also, the musculoskeletal symptom results show that shoulder pain among operators occurs due to the forceful exertion risk identified in the initial ERA and verified by REBA assessment. This relates to the coupling arm area due to load weight and lifting frequency according to MAC assessment results. The evidence of the coupling arm area and its correlation to the shoulder pain, the forceful exertion risk, and the load weight and lifting frequency is illustrated by Figure 7 which the operators moving the OSB and the panel without using aid tool during operation.

Table 1. The summary results of Initial ERA among operators in waterjet unit.

OPERATOR	SUMMARY RISK FACTOR: Awkward posture	Advance ERA?	Static and sustained work posture	Advance ERA?	Repetition	Advance ERA?	Forceful exertion	Advance ERA?	Vibration	Advance ERA?	Lighting	Advance ERA?	Temperature	Advance ERA?	Ventilation	Advance ERA?	Noise	Advance ERA?
	Min. requirement for advance ERA (≥6)		Min. requirement for advance ERA (≥1)		Min. requirement for advance ERA (1)		Min. requirement for advance ERA (≥1)		Min. requirement for advance ERA (≥1)		Min. requirement for advance ERA (1)		Min. requirement for advance ERA (1)		Min. requirement for advance ERA (1)		Min. requirement for advance ERA (≥1)	
1	1		0		0		0		0		0		0		0		0	
2	1		0		0		0		0		0		0		0		0	
3	1		0		0		0		0		0		0		0		0	
4	1		0		0		0		0		0		0		0		0	
5	1		0		0		2	Yes	0		0		0		0		0	
6	1		0		0		2	Yes	0		0		0		0		0	
7	2		0		0		2	Yes	0		0		0		0		0	
8	2		0		0		2	Yes	0		0		0		0		0	
9	2		0		0		0		0		0		0		0		0	
10	2		0		0		0		0		0		0		0		0	
11	2		0		0		2	Yes	0		0		0		0		0	
12	1		0		0		2	Yes	0		0		0		0		0	



(a) (b) (c) (d)

Figure 6. Awkward postures among operators in waterjet unit: (a), (c), (d) back bend forward, (b) work with arm backward.

Table 2. Summary of results on REBA among operators in waterjet unit.

Participant	Neck	Trunk	Leg	Posture Score A	Force	Score A	Upper arm	Lower arm	Wrist	Posture Score B	Coupling	Score B	Score C	Activity	REBA
1	2	4	2	6	2	8	2	1	2	2	3	5	10	0	10
2	3	4	2	6	2	8	2	1	1	1	3	4	9	0	9
3	3	4	1	6	2	8	2	1	1	1	3	4	9	0	9
4	2	4	2	6	2	8	2	1	1	1	3	4	10	0	10
5	3	4	1	6	2	8	2	1	1	1	3	4	9	0	9
6	3	4	2	7	2	9	2	1	1	1	3	4	10	0	10
7	3	4	1	6	2	8	2	1	2	2	3	5	10	0	10
8	2	4	1	5	2	7	2	1	3	3	3	6	9	0	9
9	3	4	3	7	2	9	2	1	2	2	3	5	10	0	10
10	3	4	1	6	2	8	2	1	1	1	3	4	9	0	9
11	2	4	2	6	2	8	2	1	2	2	3	5	10	0	10
12	2	3	1	4	2	6	2	1	1	1	3	4	7	0	7
Avg	3	4	2	6	2	8	2	1	2	2	3	5	9	0	9

*Score	Level of MSD risk
1	Negligible risk, no action required
2-3	Low risk, change may be needed
4-7	Medium risk, further investigation, change soon
8-10	High risk, investigate and implement change
11+	Very high risk, implement change

Table 3. Summary results of MAC tool among operators in waterjet unit.

Risk factors / operator	Lifting Operation											
	Load weight and lift / carry frequency	Hand distance from lower back	Vertical lift region	Torso twisting / sideways bending Asymmetrical Torso / load (carrying)	Postural constraints	Grip on the load	Floor surface	Other environment factors	Carry distance	Obstacles en route (carrying only)	Communication and co-ordination (team handling only)	Total MAC score
1												19
2												19
3												18
4												18
5												18
6												19
7												18
8												19
9												20
10												20
11												18
12												19

*Colour score	Handling risk
	Low level of risk. Although the risk is low, this level accounted for disable people such as pregnant women, disabled, recently injured, young or inexperienced workers.
	Medium level of risk. Examine tasks further.
	High level of risk. Quick action needed. This may expose a significant proportion of the working population to risk of injury.
	Unacceptable level of risk. The handling task may represent a serious risk of injury and must be improved.
Blank	Not related

Figure 7. Observation evidence shows unused of handgrip aid tool.

Therefore, the most affected body part of operators is the upper body like shoulder, wrist, neck, and trunk. Besides, the lower back also another one of the affected body parts. From a biomechanical viewpoint for the lower back, the fact that broad moments are produced as heavy loads are raised at the lumbar spine raises the issue of the existence of the internal forces that must be present to support the spine when these high load moments arise [12]. Repetitive flexion of the spinal segments decreases the passive spinal tissue stiffness and enhances the intervertebral motion. This leads to the reduction of the intradiscal fluid amount. Considerable intradiscal fluid loss lessens the nucleus load-bearing capacity. This fact results in the loading transfer towards the sensitive fibres of the annulus, thus causing higher stresses. As a consequence, given that support during fully trunk bending is given from passive tissues, even small decrease of the stiffness of passive tissues, owing to sustained loading, can substantially diminish the stability of the spine and escalate the vulnerability to injury [3]. The ergonomics intervention that would recommend attenuating these musculoskeletal disorders by using engineering control where applied to solve the lifting and carrying issue in this study.

CONCLUSION

The objective of this study is to assess the ergonomics risks factors among the operators in the waterjet unit in the aircraft manufacturing industry, where 12 male operators had participated voluntarily. Initial ERA was conducted by using the Nordic checklist, demographic interview, video observations, and picture captions. The Advanced ERA was conducted based on the results from Initial ERA by using REBA, MAC tool with task analysis, and time analysis. The results from Initial ERA show that the main ergonomics risks are due to forceful exertion and awkward factor relating to musculoskeletal pain at shoulder, lower back and upper back, while detail results from REBA show that the main body area that exposed to awkward posture and forceful exertion is the neck, trunk, and coupling arm area, were correlated with MAC results that the shoulder pain and back pain occur due to load weight lifting and moving activities. It can be concluded that most affected body part of the operators is their upper body, i.e. shoulder, wrist, neck, and trunk. The ergonomics intervention is strongly suggested in the future study to reduce the ergonomics risks among the operators in the waterjet unit.

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