EFFECT OF WORKING POSTURES IN CONFINED AREAS

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Abstract

Aircraft inspection tasks are often performed under extreme conditions which may cause increased operator stress, fatigue, and workload. Several factors, particularly restrictive space which cause extreme postures, have been identified as possible contributors to stress and fatigue in the aviation maintenance environment. These factors are dictated by the design of the aircraft itself and the access equipment employed. Following development of a methodology for studying fatigue and restrictive spaces (Phase III), a set of four tasks from the C-check of a DC-9 were used to evaluate these effects. Inspectors were observed performing each task to collect postural data; and psychophysical scales were used to measure fatigue, postural discomfort, and workload. All scales showed that the same tasks have the greatest impact on the inspector. On the basis of those findings, improvements were generated, and are now being implemented at Northwest Airlines.

1.0 INTRODUCTION

Aircraft structures are designed as a compromise between aerodynamics, strength, weight, and access. In many instances, designers must concede optimum access in order to meet thee other requirements. This leaves many aircraft inspection and maintenance tasks to be performed in non-optimum conditions, which may lead to fatigue on the part of inspectors and maintenance personnel.

Task performance under extreme conditions can produce both physical and cognitive fatigue. *Physical fatigue* may be defined as a state of reduced physical capacity (Kroemer et al., 1990). Work can no longer be continued because the involved physical subsystems are not capable of performing the necessary functions. For example, a posture can no longer be maintained due to exceeding the endurance limit of the muscles (see Rohmert, 1973). *Cognitive fatigue* is a term normally associated with stress; it is a generalized response to stress over time where stress is the perceived inability to meet the task demands. The effects of fatigue may reside as a psychological state within the individual or extend to affect performance. Symptoms of fatigue include restricted field of attention, slowed or impaired perception, decreased motivation, subjective feelings of fatigue and task aversion, and decreased performance in the form of irregularities in timing, speed, and accuracy (Bartlett, 1953; Grandjean and Kogi, 1971).

An inspector's response to the environment is a function of the associated stress and fatigue effects. In most instances, this response cannot be described by one variable but is manifested in various physiological, psychophysical, and behavioral patterns. Inspectors attempt to respond to or cope with a stressful situation in order to lessen or eliminate the fatiguing or stressful situation's effect on them (Cox, 1985). They do so through one or more modes of response (Meister, 1981). For example, while performing maintenance or inspection in a cramped area of an aircraft, there may be an initial physiological response to the postural demands such as lack of blood flow to the leg muscles, which in turn causes a behavioral response (e.g., posture shifting) and/or subjective response (e.g., perceived discomfort). In addition, such a behavioral response may alleviate one component of the fatigue response, while causing another. Continuing the example, a change in posture may reduce the physiological response, but the new posture may make the task more difficult to perform and cause feelings of frustration.

In order to describe, and eventually predict, the effects of operator response on performance and workload, there is a need to understand the effects of stress and fatigue on the operator. During Phase III, ergonomic factors which may produce fatigue and ultimately affect performance and well-being were identified and are listed in **Table 1** (FAA/AAM & GSC, 1993). This compilation of factors is not an exhaustive list, and there are a number of other, lesser environmental, task, and operator characteristics which could contribute to fatigue effects (e.g., temperature, gender, age, etc.). However, the listed factors have been identified as the most salient and prominent factors as possible contributors to fatigue in the aviation inspection/maintenance environment and provide a starting point to focus investigation.

Table 1 Ergonomic Factors

ERGONOMIC FACTORS
Area/Volume of Workplace
Duration of Task
Equipment/Tooling Used
Lighting at the Workplace
Social Factors (e.g., resource availability)
Surface Condition of Adjacent Surfaces

2.0 BACKGROUND

2.1 Workplace Area/Volume

One of the most noticeable deviations from ergonomically optimum conditions is that tasks must be performed in restricted spaces, whether it be during access to, or inspection in, a given area. Confined spaces are normally associated with whole-body restrictions occurring when an inspector enters an intervening structure or works within an area confining the entire body to that specific area (e.g., cargo hold). Restrictive spaces are also created when the surrounding physical space is unlimited, but the immediate working area is restricted. These partial-body restrictions result in limited movement of a specific body part; for example, tasks aided by access devices (e.g., steps, cherrypickers) cause lower limb restriction because the feet must reside within a limited area. Other examples include reaching arms through access holes and positioning various body parts in and around fixed aircraft components (e.g., inside a small access panel). These partial-body restrictions may occur in addition to whole-body restrictions, as in interior inspection of the tail compartment which demands that the inspector climb into the area (whole-body restriction), as well as place their head and arms through narrow confines to check components (partial-body restriction).

Much research has addressed the effects of restricted space on access tasks. Access consists of physically reaching the area to be inspected. All of these activities involve controlling the movement of the body or body part(s) within a restrictive space. In aircraft maintenance/inspection this may be an unaided human task (e.g., area inspection of lower fuselage skin), aided by access devices (e.g., steps, scaffolding, cherrypickers), or require access through an intervening structure (e.g., inspection of wing fuel tank interiors through access holes). Normally aircraft are designed to the anthropometric boundary, i.e., the minimum allowable requirements based upon human body dimensions. However, designing to this boundary does not ensure performance is optimal. Mathematical models indicate that the amount of space defines the accuracy requirements of a task, which may dictate the speed of performance.

Numerous investigations have found a speed/accuracy tradeoff in human performance; as accuracy requirements are increased (i.e., decreased space), performance becomes slower (e.g., Bottoms, 1982; Drury, et al., 1987; Fitts in Wickens, 1992). For example, the speed with which a hand can be moved through an access hole is dependent upon the size of the hole. Further changes in performance may be found dependent upon the posture adopted while the body part is restricted. Wiker, Langolf, and Chaffin (1989) reviewed research indicating that there are only minimal differences in manual performance for work heights up to shoulder level. However, they found that position and movement performance decreases progressively when hands are used above shoulder level, due to the production of movement with pre-tensed muscles which may serve to increase tremor and decrease maximum muscle contraction speed. Restricted entries and exits affect whole-body ingress and egress times (Drury, 1985; Krenek and Purswell, 1972; Roebuck and Levedahl, 1961), as well as subjective assessments of accessibility (Bottoms et al., 1979).

These models indicate that the speed chosen by an inspector increases until reaching some limiting speed. The point at which increases in space no longer affect performance is the *performance boundary* (Drury, 1985). However, designing to this boundary does not ensure that increased operator stress, fatigue, or workload does not occur; it merely ensures that direct task performance is not affected.

Along with access, other aspects of the actual inspection task may be affected by a restricted space. Visual search requires the head to be at a certain location to control the eyes and the visual angle. Thus, restricted areas frequently force inspectors to adopt awkward head, neck, and back angles, inducing stress and fatigue. In many instances, inspectors are forced either to search an area at less-than-optimum viewing angles or to work indirectly using a mirror. Although both methods can produce acceptable performance, they increase inspector workload and stress. Hence, performance is less efficient than under unrestricted conditions.

Restricted areas may also prohibit easy access to any extraneous material in the immediate working area (e.g., workcards on the illustration). This forces inspectors to make decisions without their having comparison standards, increasing their memory load, or requires additional time for them to obtain information from the workcard, a manual, or a supervisor. Moreover, when viewing angles are less-than-optimum, this further decreases sensitivity and increases the difficulty of decisions. Thus, restricted spaces can make the decision-making more memory-intensive, lengthy, and difficult.

Conversely, pressures for cursory decision-making may motivate the operator can get out of the space quickly. Decision-making tasks exhibit a speed/accuracy tradeoff (SATO), with speeded performance associated with inaccurate decision-making. However, inspectors are highly motivated to perform accurately (Shepherd et al., 1991). Thus, it is predicted that accurate decision-making performance would not be compromised by even the most extreme space conditions, but that workload and stress may increase.

In addition, the inspection task requires that detected defects be marked and documented. As discussed above, restricted areas may not allow additional material such as non-routine repair forms in the workspace. Thus, the inspector must remember all defects within an area until they are later documented on the appropriate forms. This situation can add to the high memory load on inspectors and presents the potential for an inspector to forget to note a defect.

Finally, extreme space conditions only allow a limited number of inefficient postures to be adopted, thus physical working capacity may be reduced in restrictive spaces, as indicated by research in the area of manual material handling (Davis and Ridd, 1981; Mital, 1986; Ridd, 1985; Rubin and Thompson, 1981; Stalhammer, et al, 1986). Under unlimited space conditions, operators are able to adopt efficient postures or switch postures to use other muscle groups, enabling primary muscle groups to be rested (Drury, 1985). However, the frequent breaks from restrictive areas common during maintenance/inspection activities allow relief from sustained task performance and rest the primary muscle groups.

2.2 Task Duration

Some inspection tasks and many repair tasks require mechanics to be in a confined or restricted area for prolonged periods of time. Increased task duration forcing mechanics to spend longer periods of time in a restrictive area could psychologically affect their perception of space. Habitability literature concerned with the study of manned underwater vessels and space vehicles indicates that internal space requirements vary as a function of duration (Blair, 1969; Price and Parker, 1971). Furthermore, Cameron (1973) identifies duration as the primary variable associated with fatigue effects.

2.3 Equipment/Tooling

The equipment and tooling used during access and task performance can contribute to stress and fatigue effects. The tooling and equipment needed in an area may further physically restrict the area. Furthermore, the equipment may not be designed optimally for a given task. For example, ratchets used to loosen or tighten a bolt may not have attachments allowing inspectors to reach an area without placing their arms in an awkward position and creating torque in an inefficient posture. Similarly, eddy-current devices used to inspect rivets have no convenient resting place, leading to a less-than-optimal relationship among the inspector, the probe, and the eddy-current display.

2.4 Workplace Lighting

Studies in aircraft inspection have shown that poor illumination and other adverse lighting conditions could be important causes of eye strain or visual fatigue. Visual fatigue causes deterioration in efficiency of human performance during prolonged work. Thus, an adequate visual environment is crucial for ensuring acceptable performance in aircraft inspection. Poor lighting also demands that a certain posture be adopted for task performance by forcing a specific visual angle. Thus, restricted areas frequently force inspectors to adopt awkward head, neck, and back angles that induce stress and fatigue. Inadequate lighting requires inspectors always to hold their flashlight in one hand; likewise, awkward portable lighting forces them continually to struggle with and reposition the lighting (Reynolds and Drury, 1993).

2.5 Social Factors

Social aspects of the environment may also increase fatigue. As the number of people in a given area increases, the amount of space for each person decreases. If uncomfortably close spacing is required between individuals, their tolerance to the environment may be limited. If many individuals in the same area perform the same tasks, the available resources may become limited, and people may become frustrated (e.g., specialized/portable lighting not available).

2.6 Surface Condition

The surface condition of many areas in an aircraft hangar where work must be performed is poor: dirty, uneven, or rough. These surfaces force inspectors either to limit the postures they are willing to adopt or to adopt inefficient postures. For example, operators may stoop or crouch instead of sitting in a certain area to avoid oil-soaked clothing. These surfaces also present a safety hazard; at times they cause inspectors to slip or trip. Furthermore, continued kneeling or laying on rough or uneven surfaces can cause re-occurring aches and pains.

In summary, the effects of restricted space and the associated posture effects have been hypothesized to be the largest contributor of producing a fatigue response, and possibly affecting workload and performance. Thus, this evaluation focussed on this factor while simultaneously considering other factors in the aviation environment. On-site evaluation was undertaken in order to 1) measure and determine if increased stress and fatigue levels existed in the aviation maintenance and inspection environment; 2) determine if techniques and methods used successfully to measure fatigue and workload in non-aviation environments could be applied to this environment; and 3) if increased levels of stress, fatigue, and workload were found to exist, provide ergonomic interventions to improve this environment.

3.0 ON-SITE EVALUATION AND ANALYSIS

The maintenance facility where data was obtained possesses four bays and services only DC-9's on all three shifts (day, afternoon, night). On-site evaluation was two-pronged and included the analysis of 1) pre-existing conditions in terms of on-the-job injuries (OJI's) and 2) existing conditions in terms of direct and indirect data collection techniques.

3.1 Evaluation of Pre-Existing Conditions

This evaluation is important in that it can assist in determining if there is any need for ergonomic intervention, and if so, focus analysis towards the problem areas. In addition, it can guide the implementation process by emphasizing and prioritizing interventions. OJIs were reviewed because the data was already collected and thus easily accessible. The OJIs represent an extreme form of human/system mismatch, one which has led to an error severe enough to cause injury.

3.1.1 OJI Analysis

OJI reports from 1/1/92 to 6/30/93 were reviewed. The procedure outlined by Drury and Brill (1983) was employed to identify accident patterns. Accident/injury data were separated in order to identify OJI's which occurred in the hangar and OJI's which were specifically related to restricted space. The OJI's identified to be space-related were then grouped based upon age, job, years on the job, area, activity being performed, days out, type of injury, and body part injured. Thus, a small number of repetitive scenarios or patterns could be developed.

3.1.2 Results

The percentage of OJI's in the hangar which were space-related was 20.4% and is presented in **Figure 1**. This indicates that ergonomic interventions, particularly those related to space, should be addressed. **Figure 1** also shows other data that were meaningful in this analysis. Generally, a majority of injuries were sprains to the lower limbs or back/neck, and primarily occurred during repositioning, working, and access-type activities (i.e., climbing, slip/trips). **Table 2** presents a summary of the most predominant scenarios.

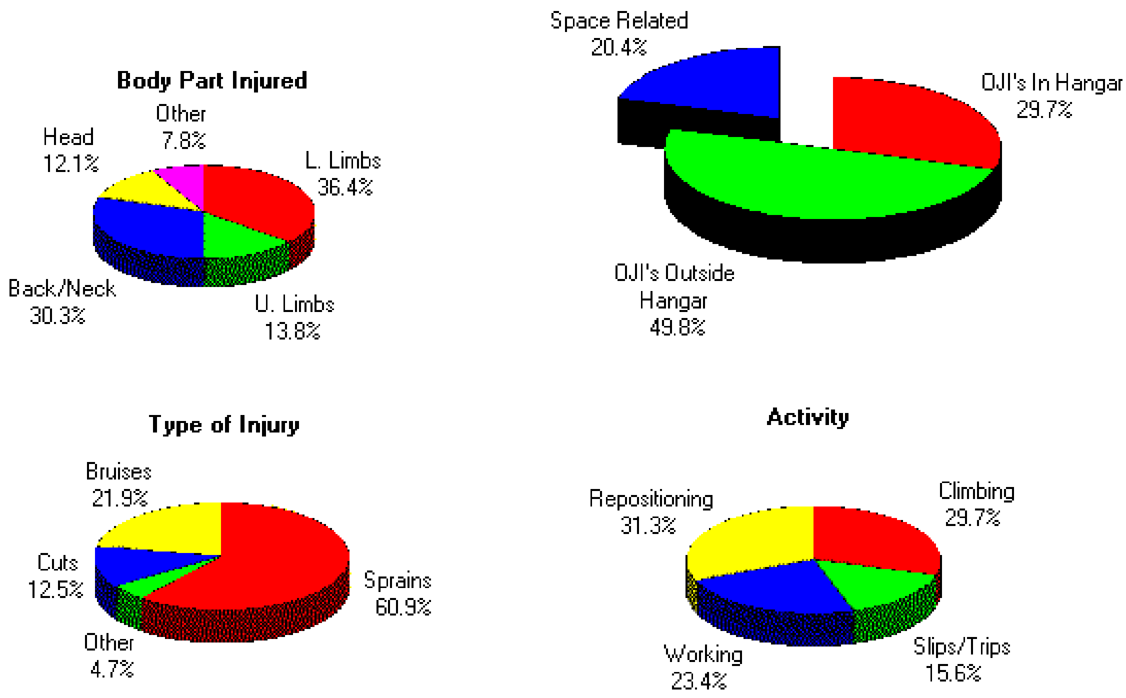


Figure 1 OJI Report Summary

Table 2 Summary of Space Related Hangar OJI's

- Repositioning in cramped or dirty places (e.g., fuel tank, tail interior and bag bin) often causes sprains or strains.
- Head lacerations are associated with walking in the cabin or around the fuselage exterior.
- Kneeling causes bruises or strains in the knee.
- Lifting in confined spaces can result in straining the back.
- Falls on stairs and access stands are common.
- Most injuries occur during access or maintenance subtasks.

3.2 Evaluation of Existing Conditions

Four inspection tasks were selected for analysis: aft cargo compartment, horizontal/vertical stabilizers, tail interior, and wheelwell/main landing gear. These tasks provided a representative sample of tasks with regard to varying environmental conditions (i.e., amount of space, lighting, etc.). Both behavioral (direct recording) and psychophysical (indirect recording) data were collected to assess the effect of the aviation maintenance and inspection environment on inspector fatigue, discomfort, and workload.

3.2.1 Behavioral Measures

Whole-body postures were recorded throughout task performance. In addition, detailed descriptions of each task were obtained. This step included having human factors analysts work with inspectors during the completion of workcards. While obtaining task descriptions, emphasis was placed on documenting ergonomic factors identified in Section 2 which create, or exacerbate, stress and fatigue effects.

3.2.2 Psychophysical Measures

Psychophysical techniques were used to measure fatigue, physical discomfort, and workload. These techniques are particularly attractive for field use because they are unrestrictive, require minimal instrumentation, are easy to use/administer, and provide valid and reliable results.

The *Feeling Tone Checklist (FTC)* was utilized to measure fatigue effects over time. It is an interval scale that has been found to be a valid and reliable measure of subjective feelings of fatigue (Pearson, 1957). The *Body Part Discomfort Chart (BPD)* is the most noted technique utilized to obtain postural discomfort data (Corlett and Bishop, 1976). This chart categorizes the body into a number of functional areas to allow the assessment of individual body areas. A 5-point ordinal scale was utilized to solicit operators' BPD ratings. The *NASA - Task Load Index (TLX)* is a multi-dimensional rating scale that measures six workload-related factors (e.g., mental demand, physical demand, temporal demand, performance, effort, and frustration) and their associated magnitudes to form a sensitive and diagnostic workload measure (Hart and Staveland, 1988).

3.2.3 Experimental Protocol

Postures were sampled every 30 seconds throughout each task. Data was obtained on two inspectors performing each task. The FTC and BPD was administered before and after task performance. In addition, the TLX was administered after task performance. The FTC, BPD, and TLX data were obtained on five experienced inspectors per task.

3.2.4 Results

An adapted version of the Ovako Working Posture Analyzing System (Louhevaara and Suurnakki, 1992) postural recording scheme was utilized to classify whole-body postures during task performance. This system has been found to be valid and reliable (Karhu, et al., 1977, 1981). It categorizes whole-body postures into action categories based upon the severity of different postures, thus making it useful as a step in determining which postures need to be addressed by workplace changes. Table 3 lists the categorization scheme and corresponding action categories. The postural data were categorized by action categories and averaged across inspectors for each task with the results presented in Figure 2. These data indicate that inspectors adopted the largest percentage of extreme postures (i.e., AC2, AC3, and AC4) in the aft cargo and tail interior areas; although there was still a large percentage of extreme postures in the other areas.

Table 3 OWAS Classification Table

Trunk	Upper Limbs	Lower Limbs								
		2 S	1 S	2B	1 B	K	W	S	L	C
Straight	2 Below	\\\\\\	\\\\\\	\\\\\\			\\\\\\	\\\\\\		
	1 Above	\\\\\\	\\\\\\	\\\\\\			\\\\\\	\\\\\\		
	2 Above	\\\\\\	\\\\\\	\\\\\\			\\\\\\	\\\\\\		
Bent	2 Below				^^^^^	^^^^^			^^^^^	^^^^^
	1 Above				^^^^^	^^^^^	^^^^^		^^^^^	^^^^^
	2 Above	^^^^^		^^^^^	^^^^^	[shaded]	[shaded]		[shaded]	[shaded]
Twisted	2 Below	\\\\\\	\\\\\\	\\\\\\	^^^^^	[shaded]	\\\\\\	\\\\\\	[shaded]	[shaded]
	1 Above		\\\\\\	\\\\\\	[shaded]	[shaded]	^^^^^	\\\\\\	[shaded]	[shaded]
	2 Above		\\\\\\		[shaded]	[shaded]	[shaded]	\\\\\\	[shaded]	[shaded]
Bent & Twisted	2 Below				[shaded]	[shaded]	[shaded]		[shaded]	[shaded]
	1 Above	^^^^^		^^^^^	[shaded]	[shaded]	[shaded]		[shaded]	[shaded]
	2 Above	[shaded]		^^^^^	[shaded]	[shaded]	[shaded]		[shaded]	[shaded]

S = Straight B = Bent K = Knee W = Walk S = Sitting L = Laying C = Crawl

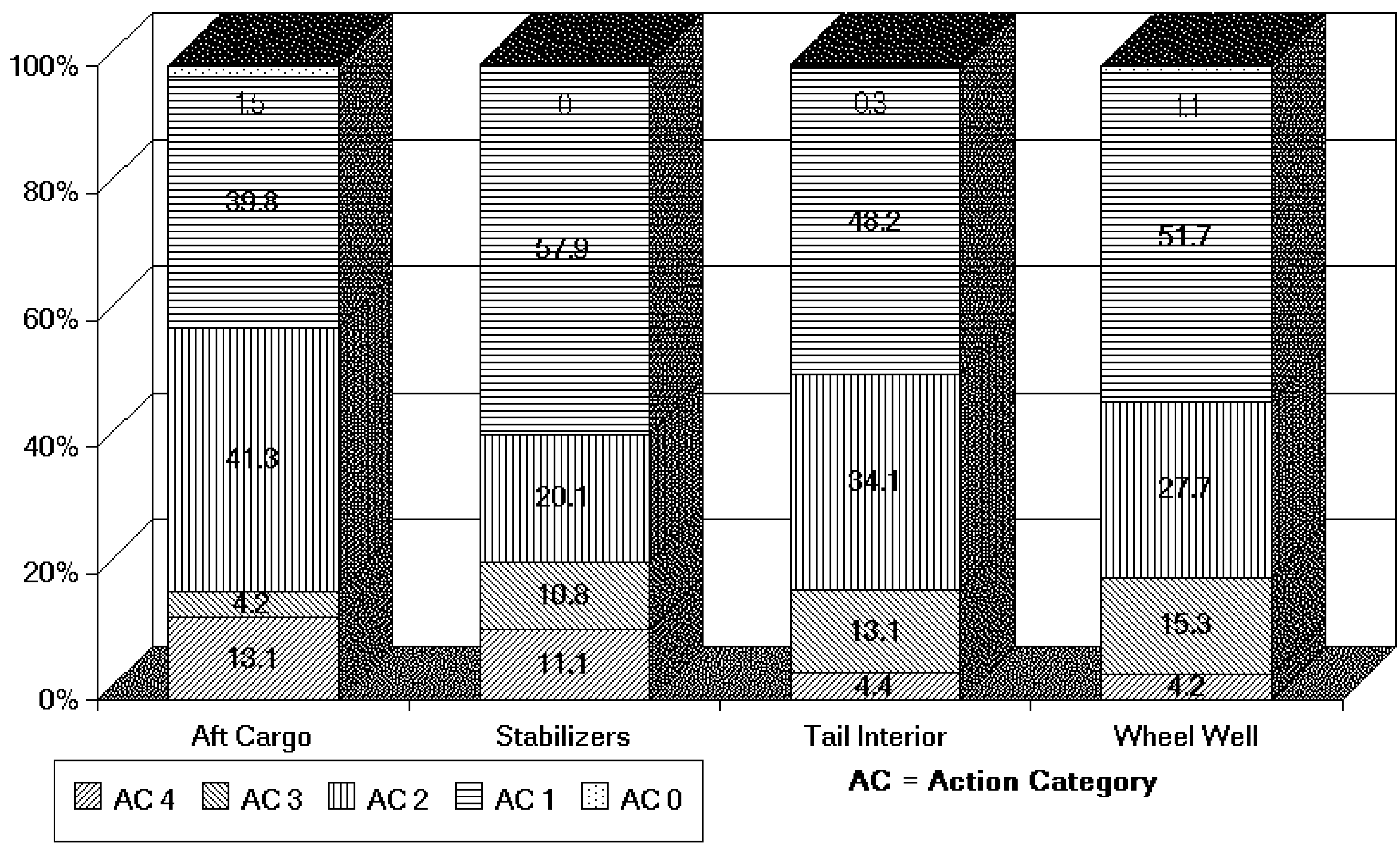
Action Category 1. The overall posture is ordinary. Normal posture. No action is necessary. These postures are marked with ****.

Action Category 2. The load imposed by the overall posture is of some significance. The load of the posture is slightly harmful. A better working posture should be sought in the near future. These postures are shown with a **blank square**.

Action Category 3. The strain imposed by the overall posture is significant. The load of the posture is distinctly harmful. A better working posture should be sought as soon as possible. These postures are marked with **********.

Action Category 4. The strain imposed by the overall posture is of great significance. The load of the posture is extremely harmful. A better working posture should be sought immediately. These postures are shown with **shading**.

By Task



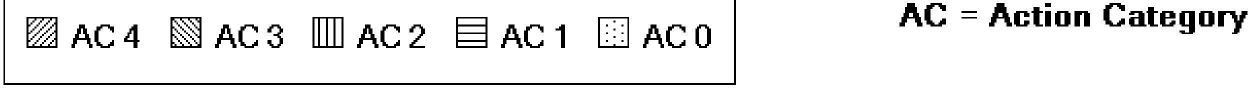


Figure 2 Posture Ananlysis

The BPD and FTC difference values (i.e., end of task - beginning of task) were averaged across inspectors and are presented in **Figures 3** and **5**. **Figure 3** indicates that inspectors experienced the greatest body part discomfort in the aft cargo and tail interior areas. Likewise, inspectors indicated the most fatigue after inspecting the tail interior. Fatigue was also judged to be high in the aft cargo area; although, the average value was skewed by the judgement of one inspector who rated his fatigue to be less (**Figure 4**). The TLX data was averaged across inspectors and is presented in **Figure 5**. Workload was rated to be highest in the aft cargo and tail interior areas, with the primary contributors being physical demand and effort.

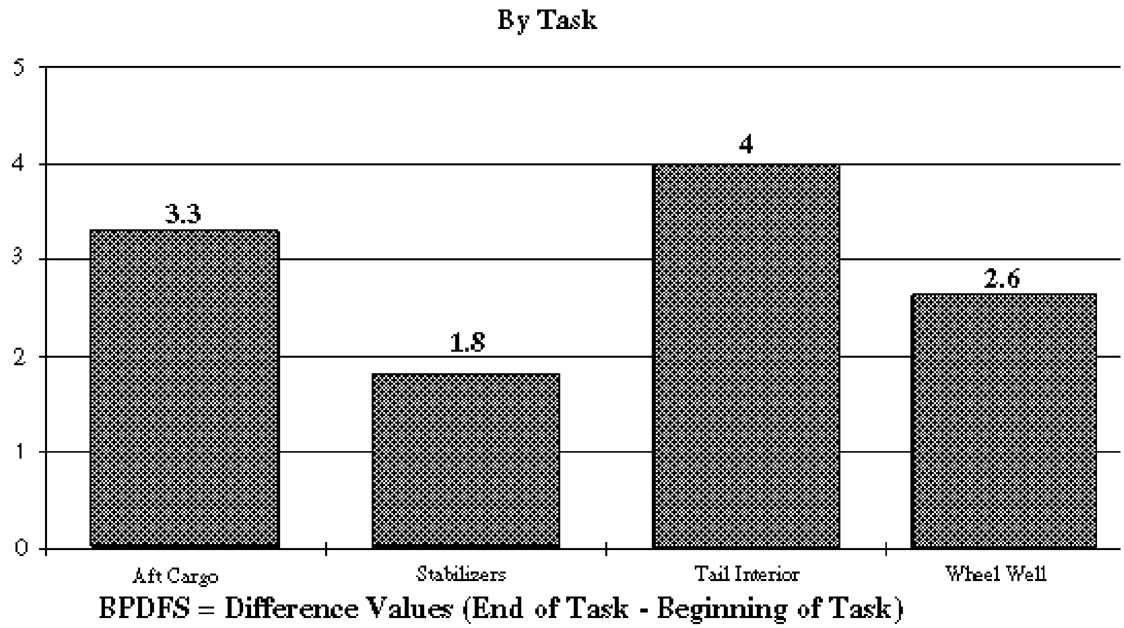


Figure 3 Body Part Discomfort Over Time

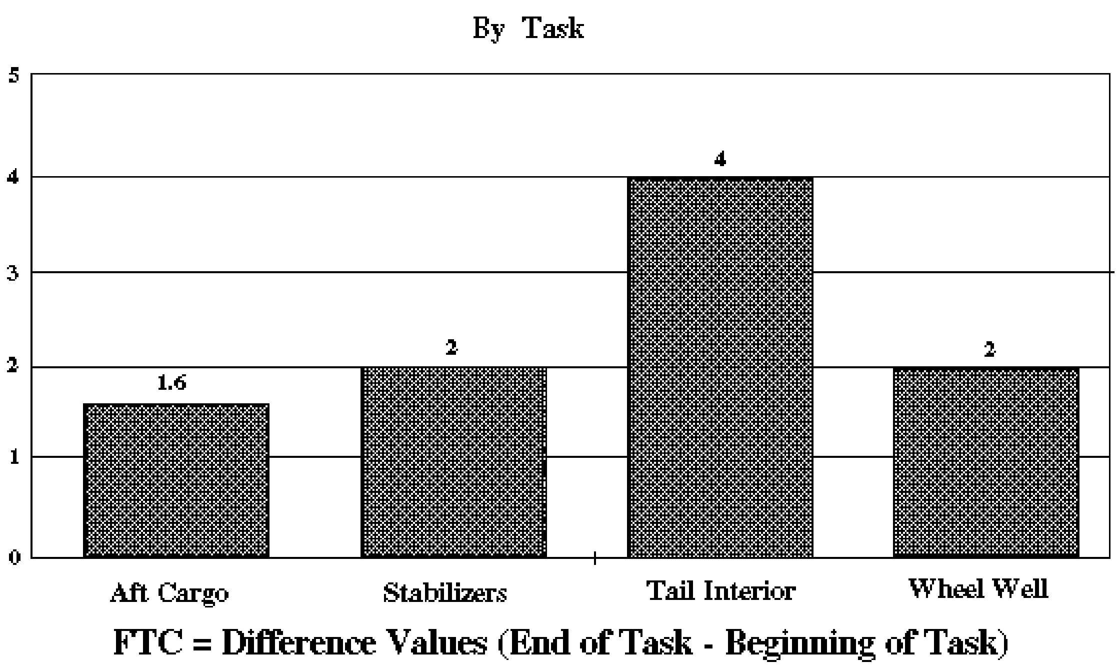


Figure 4 Fatigue Over Time

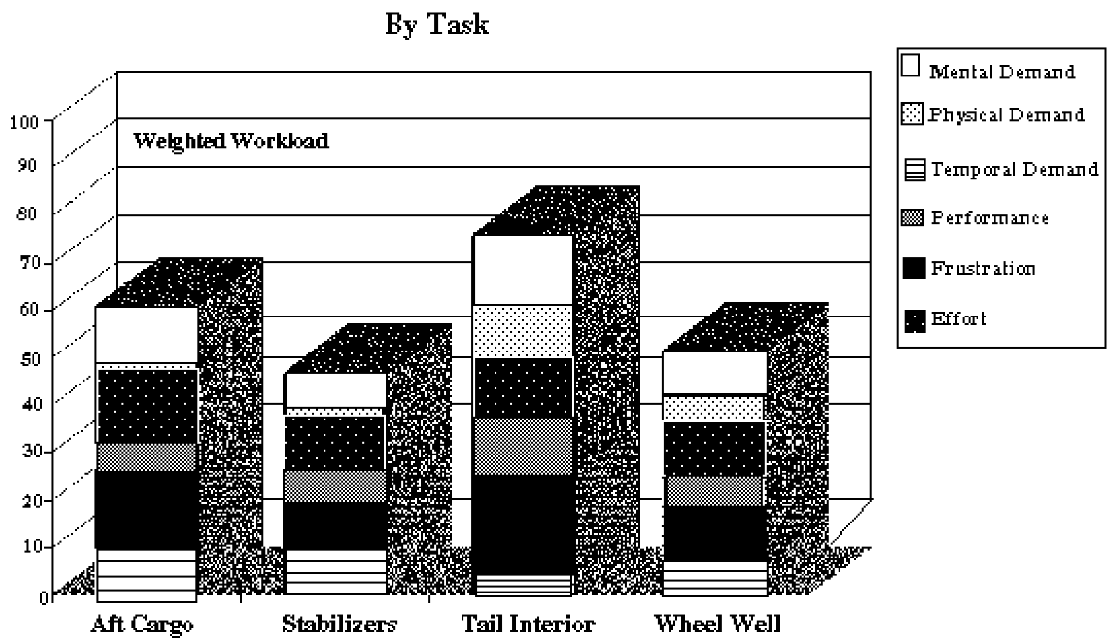


Figure 5 TLX Workload Data

4.0 FINDINGS

The above analysis and results indicate that inspectors often experience increased stress, fatigue, and workload levels. The psychophysical data provides a consistent pattern of stress being experienced during task performance in different areas. Generally, fatigue, body discomfort, and workload were judged to be higher in the aft cargo and tail interior areas than in the other areas. There was some disassociation between the postural and psychophysical data. The stabilizers and wheelwell/MLG were not rated to be extremely fatiguing, although there were many extreme postures (i.e., AC3 and AC4) noted while inspectors worked in these areas. This indicates that posture may be just one factor which contributes to fatigue, and that other factors (e.g., space, lighting), in combination with extreme postures, play a role in eliciting fatigue, as expected from the discussion in Section 2.

5.0 PRACTICAL INTERVENTIONS

Based upon the above evaluation, specific ergonomic interventions were provided for each task analyzed. These were generated from a logical analysis of the factors contributing to fatigue in each area, and the possible steps which could impact upon these factors. In addition, the techniques and tools used for this analysis can be applied and used to develop and guide a comprehensive ergonomics program.

5.1 Design Requirements/Interventions

For each task, design requirements were stated and are presented in Table 4. Design requirements are positive statements about what needs to be accomplished during redesign. Notice that these are not solutions, but requirements, and that there may be several alternative solutions which address each requirement. Formally stating these requirements can assist in the generation of solutions and reduce the probability of overlooking potential solutions (Drury, 1987). For each design requirement, alternative solutions are advanced in an attempt to address each design requirement. In addition, these requirements were prioritized according to the OJI's which occurred in each area. This assists in selecting interventions which will maximize the reduction in injury for a given budget.

5.2 Ergonomic Program

This evaluation has only addressed a small subset of ergonomic problems which exist in the aviation maintenance environment, particularly those related to restricted space and posture, although other factors were considered during the evaluation and recommendation phases. This work has revealed the need for a comprehensive ergonomic program which could address all components of the aviation maintenance environment. There were many issues which were not addressed (e.g., safety concerns), which could be evaluated and improved using tested ergonomic techniques and tools.

The techniques applied in this project were found to be sensitive and could be adapted and utilized to further investigate other areas of the aviation maintenance environment.

Ergonomic programs have been developed for manufacturing environments with great success (e.g., Reynolds and Drury, *in press*). These programs are based upon the idea of continuous evaluation and intervention using the tools and techniques applied above to improve the fit between human and system, and hence reduce error-causing mismatches.

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