An Ergonomics Study for General Dynamics
Examining Work and Workspace Design for Potential Causes of Thoracic Outlet Syndrome

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Executive Summary

A key operator in the manufacture of missile casings for General Dynamics was diagnosed with thoracic outlet syndrome (TOS). The condition typically causes numbness or pain in the fingers, arms, and shoulder and can be caused by work-related activities, but also from myriad other sources. For this reason, the authors make no claim that the condition is a cumulative trauma disorder (CTD) caused by work or workspace issues. Instead, however, the authors used their training in ergonomics to help identify work and workspace issues that could cause TOS or agitate an existing TOS condition. To accomplish this, the work itself was first observed, both quantitatively and qualitatively, to identify issues. Then the workspace was inspected, again both quantitatively and qualitatively, to identify issues. The findings from these observations were compared to ergonomics principles and best practices to develop recommendations for General Dynamics. In general, things seemed to follow best practices; however, a few recommendations were developed. These recommendations include the elimination of overtime work, the addition of a handlebar to the operator’s cart, installation of floor mats near the vertical drill fixtures, as well as several more that are detailed in the report.
Introduction

General Dynamics (GD), a multibillion dollar company, is one of the ten largest defense contractors in the world. Since 1952, its engineers have been developing some of the most significant vehicles, aircraft, and weaponry used by the United States military. Some of their most successful products include the Ohio class submarine, the F-16 Fighting Falcon fighter jet, the M1 Abrams main battle tank, and the Patriot PAC-3 missile. The Patriot PAC-3 missile casing is produced by GD’s Armament and Technical Product business group at the Lincoln Operations in Lincoln, NE.

An Aerial Photograph of the North Lincoln Facility

A key operator in the manufacturing process of these casings developed numbness in the left shoulder area after working with larger workloads than normal for an extended period. As a result, the authors of the paper conducted an ergonomic study at the request of Lincoln Operations management. It was the hope of management that the authors would be able to identify potential causes of the shoulder numbness, if they exist, by examining work and workspace design. A small amount of medical research was conducted to help the authors better understand the issue at hand. The methods and results of these studies are summarized in this report. A few conclusions and recommendations are made. Additionally, a couple other potential issues noticed by the authors are described in the “Conclusions & Recommendations” section.
Defining the Condition & Medical Research

The authors conducted an interview with the operator to get a better understanding of the condition that was being experienced. The following questions were asked:

**Authors’ Questions**

1. How would you describe the sensations that you’ve experienced? Try to describe it as pain, numbness, etc.
2. Where precisely are the sensations located?
3. When do the sensations occur or what events trigger them? Do they seem to occur randomly?
4. How long do the sensations typically last?
5. Have you noticed any behaviors that seem to mitigate the onset of the sensations?

The operator’s responses to the preceding questions follow:

**Operator’s Responses**

1. “The sensation starts as numbness in the hand and work its way up the arm. There is also a pinch pain in the shoulder.”
2. “The sensation is located in my left arm. The numbness starts in the middle and ring fingers and works its way through my arm and into my armpit and shoulder area.”
3. “The sensations occur due to the positioning of my arm. One example is when I’m holding a bowl of cereal in the morning. This causes an onset of numbness in my hand. Another example is when I’m pushing a cart at work. Sometimes, the numbness just sets in when I’m letting my arm set at rest. However, since starting physical therapy sessions, the sensations have been less frequent and milder.”
4. “About 30 seconds after repositioning my arm they go away.”
5. “By keeping my arm in particular orientations, the onset of sensations can be avoided. Also the physical therapy seems to be helping.”

These sensations began after a prolonged period of higher-than-normal workloads for the operator. Upon visiting a physician, the operator was diagnosed with thoracic outlet syndrome (TOS). The rare condition actually encompasses a few different issues that may afflict the shoulder, arm, and
hand. These issues typically have the following symptoms: pain, numbness, and tingling in the fingers and forearm; pain and tingling in the neck and shoulders; poor circulation in the hand or forearm; and weakness of the hand muscles [1]. In general, the condition occurs when the vessels and nerves in the clavicle area are compressed [1]. The following figure illustrates this circumstance:

![Depiction of Thoracic Outlet Syndrome (TOS) [1]](image)

The vast majority of TOS cases are related to the nervous system [1]. And a few groups – such as women and overhead athletes (such as swimmers and volleyball players) – are more likely to develop the condition than the general population. Possessing any of the following traits is considered a risk factor for developing TOS: sagging muscles from aging; obesity; and large breasts [2]. Other behavioral and conditional traits that are considered risk factors for TOS include: sleeping disorders; imbalanced estrogen levels; imbalanced thyroid hormone levels; rheumatoid arthritis; fibromyalgia; poor nutrition; anemia; infections; upper torso tumors; enlarged upper torso lymph nodes; depression; and stress [2]. In some cases, work activities are the cause of TOS [2].

When swelling of muscles and tendons in the shoulder area occurs due to repetitive work activities, TOS may develop in susceptible persons. This makes TOS a cumulative trauma disorder (CTD) in these cases. A contemporary ergonomics textbook defines CTD's as follows [3]:

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“Cumulative trauma disorders (sometimes called repetitive motion injuries, or work-related musculoskeletal disorders) are injuries to the musculoskeletal system that develop gradually as a result of repeated microtrauma due to poor design and excessive use of hand tools and other equipment. Because of the slow onset and relatively mild nature of the trauma, the condition is often ignored until the symptoms become chronic and more severe injury occurs. These problems are a collection of a variety of problems, including repetitive motion disorders, carpal tunnel syndrome, tendinitis, ganglionitis, tenosynovitis, and bursitis, with these terms sometimes being used interchangeably.”

This definition is similar to the medical definition of TOS, except for its gradual onset quality. TOS can often have a more rapid onset resulting from repeated injuries (as opposed to repeated microtrauma) – perhaps from constant overhead lifting – to the shoulder area. For this reason, under the right circumstances, TOS can develop as a CTD. However, it is important to remember that TOS also has myriad other causes. In fact, the condition could be a CTD, but instead be caused by leisure activities that occur outside of the workplace.

The authors do not assume to understand the origin of the operator’s TOS. This is because it would be very difficult to determine conclusively whether or not the operator’s workload was the cause of the TOS. There could be a genetic predisposition to the condition or possibly it is due to poor nutrition or an imbalance of thyroid hormone levels. The TOS could have also originated from an extraprofessional activity – the operator is an avid bowler, though it was determined that the right hand (not the TOS hand) is used for this activity. For these reasons, the authors will use their training in ergonomics to help identify work and workspace issues that could cause TOS or agitate an existing TOS condition. Furthermore, recommendations are made to help correct the identified issues.
Work Observation

Authors’ Activities

- Qualitative observation of operator’s work – taking note of awkward positioning, lifting of excessive loads, etc.
- Quantitative observation of operator’s work – conducting a time study to determine the amount of time spent on each activity.

The primary duty of the afflicted operator in the manufacture of the PAC-3 casings is drill work. On average he drills holes for about one PAC-3 casing per day (five to six per week). On each casing there are approximately 190 holes drilled. Some of his other duties include operating an automated lathe, manually sanding casings, and manually applying a sealant to casings. In theory, the majority of the work is automated. However, some manual effort is put forth during the drilling to speed the process along. To provide some perspective to the reader, a simplified workspace diagram is provided:

![Simplified Diagram of the Operator’s Workspace](image)

The darkened areas in the diagram also represent lathes and drill fixtures. However, these are used for another missile casing – not the PAC-3 model – that is only manufactured sparingly, perhaps a
few times per year. For this reason, the authors exclusively analyzed the operator’s PAC-3 workload. Again, to provide some perspective to the reader, a simplified PAC-3 diagram is provided:

![Simplified Diagram of the PAC-3 Casing](image)

To better understand the process some initial observations were made. These observations provided some insight into which parts of the process might cause issues. It was noticed that the operator’s process essentially consists of four main sub-processes that essentially coincide with the four workstations (the lathe, horizontal drill fixture, vertical drill fixture, and staging area) and some transportation of casings – both between workstations and to other parts of the plant. During these initial observations, it was determined that the operator’s processing sequence and mannerisms were consistent. This point ensured that the author’s findings would remain relevant.

A narrative of the operator’s process, broken down chronologically (and by workstation) follows:

- **Horizontal Lathe**
Afterwards, the part is vacuumed to remove lose material, light sanding occurs (if needed), and the workstation is wiped down with a cleaner.

**Horizontal Drill Fixture**

After processing at the lathe, the casing is carried, again across the chest, to the horizontal drill fixture. At this fixture two types of hole are drilled and two oval slots are routed out.

To secure the part in the fixture, the right side is placed into a drill ring. The drill ring is circular and fits on the outside of the part. It has a number of guide holes (to guide the drill gun), of which the quantity is specific to operations occurring at the station. Adjacent to the guide holes are lock holes (also small holes) that support the weight of the drill gun during drilling. These locks are engaged by rotating the drill gun approximately 90° after inserting the drill bit into the guide holes. These holes – the guide holes and the locks – make high repetition drilling more manageable by ensuring correct positioning of drill holes and by limiting operator fatigue.

A stand also supports the weight of the drill while it is drilling a hole. Cradles are set between the two ends to support the body of the part. The left side of the fixture also has a drill ring. However, there a hand crank is used to secure the part. The crank is located to the left side of the fixture and is small, with only a 4" outside diameter. The operator typically completes 92 revolutions with the left hand, taking 30 to 35 seconds, to secure the part.

With the part secure the operator starts by machining the right side. There 28 holes are drilled. The operator uses predominantly the right hand to hold and set the drill. Two different drill guns are used on the right side. The Quackenbush 15SC-1 is used to drill the first 24 holes. The Quackenbush 15SC-2 then completes 4 holes. On the left side of the part, 2 slots are routed and 68 holes are drilled. Using a Quackenbush 136SC-1 drill gun, 64 holes are drilled. While the setup of the left side matches that of the right, the drilling procedure is somewhat different. Some of the locks are not centered properly, which causes the drill to shift a small amount while activated. This requires the operator to steady the drill while activated. As opposed to activating the drill gun (by pressing the trigger) and letting it automatically drill holes from its locked position, the operator adds a manual component to this activity. After locking the drill gun in place and squeezing the trigger, the operator holds it steady by nesting it into the...
while applying a small amount of force by leaning forward. The drill's weight is supported mostly by the stand while in this position. It was noticed by the authors that this was a regular occurrence, on the horizontal drill fixture, as well as on the vertical one. When asked about this mannerism, the operator claimed that it not only steadies the drill but speeds up the drilling operation too.

While machining the left side, the operator defaults to the left hand for drill operation. After each hole is drilled the operator shakes the dust from the drill bit by rapidly tapping the trigger two times. All the drills are pneumatic and take very minimal force to squeeze the trigger. The final 4 holes on the left side are drilled with a Quackenbush 136SC-2. To route the 2 slots on the left side, a template in the shape of the slots must first be attached to the drill ring. The operator then guides the router with both hands over the outline, which takes approximately 90 seconds to complete. During this task the operator pushes his left arm against the fixture to gain some leverage. Part way into the cut the operator stops the operation to verify that the router is functioning properly by observing the machined area. Both routed slots are completed in this fashion. During the routing, heavy vibration is passed to the operator. The operator is also significantly vibrated during drilling, but not nearly so much.

**Vertical Drill Fixture**

To move the casing from the horizontal fixture to the vertical one the operator uses an automated hoist. The first vertical fixture (of two used) has a drill ring with guide holes and locks, which the operator utilizes. The part is secured via the same method as is used on the lathe (by using a wrench). On this first fixture, 80 identical holes are drilled using two drills, the Quackenbush 120SC and the Quackenbush 15SC-3, simultaneously. The only significant difference between the two drill guns is that the Quackenbush 120SC weights 12 oz more. Since the fixture is vertical, the operator follows a circular work path. Typically it is in a counter-clockwise direction. Loading the drill guns into locks takes an average of about 3 seconds. Actual drill time is about 19 seconds. While one drill is running the operator configures and starts the other drill. The method is orderly, but repetitive as the operator works between the two drills. It takes approximately 25 minutes to complete this task with the operator periodically stopping to check that the holes are accurately sized.
The second vertical fixture is configured the same way as the previous one. The casing is again moved to the fixture using the hoist and is secured by tightening the fixture with the same wrench. At this fixture only 4 holes are drilled using a Quackenbush 136SC-2. After loading the drill gun each hole takes 95 seconds to drill, which allows the operator to work on miscellaneous tasks during that time. When the drilling task is done the part is moved by the hoist to an empty handcart in the staging area.

Staging Area

While setting on the handcart, 3 holes are drilled with the Quackenbush 136SC-3. Following that the part is once again cleaned and prepped for a different process. This includes some more minor hand sanding. It also includes the application of another sealant. When the part is being transferred between different areas of the plant it rides on a small cart that the operator pushes by hand. When the operator is pushing the cart symptoms of TOS often occur. The design of the cart was analyzed and compared with the anthropometry of the operator to see if pushing the cart created awkward postures. When comparing the height of the cart with the part on it (39 in) to the knuckle (31.125 in) and elbow (45.125 in) height of the operator, it was determined that the reach does not create an awkward posture. That conclusion is also supported by casual observation of the task. One gets an understanding of what work is being done by measuring weights handled, postures, reaches, heights, and repetitiveness [5]. Many of these qualities are discussed in the next section. However, understanding the amount of time associated with each of these qualities is also relevant. As a result, time studies were conducted in addition to the qualitative observations made by the authors. These studies allowed the authors to better understand the process and gave them data to compare against ergonomic guidelines. The notes from the studies follow:
Authors’ Time Study Notes
Workspace Inspection

Authors’ Activities

- Qualitative observation of operator’s workspace – taking note of relative positioning of equipment, general environmental conditions, etc.
- Quantitative observation of operator’s workspace – anthropometry measurements, equipment weights, etc.

At present, only the afflicted operator is working the drilling process for the PAC-3. Therefore, it is important that the workspace is configured to fit this operator, considering both safety and comfort. Working heights and depths were measured at the four machining stations. Measuring from the ground to the middle of the lathe and drill rings on the horizontal fixtures, working height was measured at the same distance of 46 in. The maximum and minimum working heights only deviated by a quarter-inch from the two machines, with the shortest distance at 42 in, and with the highest height at 50 in. The depth of work is 4.5 in from the table’s edge. The first vertical fixture where the holes are drilled has a maximum working height of 44.75 in and a minimum height of 43.75 in. The second vertical fixture has a working height of 47 in. Both working depths on the vertical fixtures are 4 in from the edge of the work stand. The operator’s elbow height is 45 in from the ground, allowing possible extreme ranges of motion between the arm and body that can vary from 42° and 124°. However, upon observation, the operator’s true range of motion stayed in between 42° and 90° on the horizontal fixtures and between 64° and 110° on the vertical fixtures.

There are two working heights that are exceptions to these measurements. The first is on the horizontal fixture, as the routing occurs. The template attaches to the part with the cutout being at the top of the part. The operator uses both hands and stands at an angle to the part with the left hand positioned above the right hand. This creates an awkward reach and angle. Furthermore, this is the point of the process imparting the most vibration and requiring the most force.

The other work height that is the exception is when the part is on the cart and the operator countersinks holes. The working height at that point is 39 in, which does not cause an awkward position for the operator whose knuckle height is 31.25 in from the ground. This particular work area is adequately designed to fit the operator using general principals. It would also accommodate any worker whose dimensional size is within the 50 percentile of the population.
<table>
<thead>
<tr>
<th>DESCRIPTION:</th>
<th>TRIAL 1</th>
<th>TRIAL 2</th>
<th>AVERAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Forward functional reach</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Includes Body Depth at Shoulder</td>
<td>34.50</td>
<td>35.00</td>
<td>34.75</td>
</tr>
<tr>
<td>b. Acromial Process to Functional Pinch</td>
<td>30.25</td>
<td>31.00</td>
<td>30.63</td>
</tr>
<tr>
<td>c. Abdominal Extension to Functional Pinch</td>
<td>27.50</td>
<td>27.75</td>
<td>27.63</td>
</tr>
<tr>
<td>2. Abdominal Extension Depth</td>
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<td>7.50</td>
<td>7.25</td>
</tr>
<tr>
<td>3. Waist Height</td>
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<td>40.00</td>
<td>40.50</td>
</tr>
<tr>
<td>4. Tibial Height</td>
<td>20.00</td>
<td>21.00</td>
<td>20.50</td>
</tr>
<tr>
<td>5. Knuckle Height</td>
<td>31.25</td>
<td>31.00</td>
<td>31.13</td>
</tr>
<tr>
<td>6. Elbow Height</td>
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<td>45.25</td>
<td>45.13</td>
</tr>
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<td>7. Shoulder Height</td>
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<td>57.00</td>
<td>57.13</td>
</tr>
<tr>
<td>8. Eye Height</td>
<td>64.00</td>
<td>64.00</td>
<td>64.00</td>
</tr>
<tr>
<td>9. Stature</td>
<td>68.50</td>
<td>68.50</td>
<td>68.50</td>
</tr>
<tr>
<td>10. Functional Overhead Reach</td>
<td>83.00</td>
<td>84.00</td>
<td>83.50</td>
</tr>
<tr>
<td>28. Hand Thickness Metacarpal 3</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
</tr>
<tr>
<td>29. Hand Length</td>
<td>7.88</td>
<td>7.88</td>
<td>7.88</td>
</tr>
<tr>
<td>30. Two Digit Length</td>
<td>3.63</td>
<td>2.75</td>
<td>3.19</td>
</tr>
<tr>
<td>31. Hand Breadth</td>
<td>3.75</td>
<td>3.75</td>
<td>3.75</td>
</tr>
<tr>
<td>32. Digit One Length</td>
<td>4.88</td>
<td>4.75</td>
<td>4.81</td>
</tr>
<tr>
<td>33. Breadth of Digit One Interphalangeal Joint</td>
<td>0.57</td>
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<td>0.57</td>
</tr>
<tr>
<td>34. Breadth of Digit Three Interphalangeal Joint</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
</tbody>
</table>

**Authors' Anthropometry Notes (Distances in Inches)**

The authors measured critical distances on the operator's body. This anthropometry data (shown above) was useful in determining whether or not particular workspace elements (as well as specific work activities) were appropriately custom-sized for the operator. In general, the measurements of the operator do not deviate much from averages. Thus, a workspace designed for the average operator should accommodate the operator comfortably and, as a result, many of the most general ergonomics principles can be directly applied to this scenario. The weights, usage times, and usage frequencies of the drills were also measured so that the authors could make inferences about the work's adherence to best practices. This data follows:
Authors’ Tool Measurement Data (Weights in Pounds, Time in Minutes)

<table>
<thead>
<tr>
<th>Name</th>
<th>Weight</th>
<th># of Holes Drilled</th>
<th>Time Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>QB 136SC-2</td>
<td>8.3</td>
<td>4</td>
<td>1:40</td>
</tr>
<tr>
<td>Router</td>
<td>8.7</td>
<td>2</td>
<td>3:00</td>
</tr>
<tr>
<td>10QNPD</td>
<td>6.1</td>
<td>8</td>
<td>2:30</td>
</tr>
<tr>
<td>QB 136SC-1</td>
<td>8.3</td>
<td>64</td>
<td>16:45</td>
</tr>
<tr>
<td>QB 15SC-3</td>
<td>12.4</td>
<td>40</td>
<td>25:45</td>
</tr>
<tr>
<td>QB 120SC</td>
<td>13.0</td>
<td>40</td>
<td>25:45</td>
</tr>
<tr>
<td>QB 136SC-3</td>
<td>8.2</td>
<td>3</td>
<td>1:00</td>
</tr>
<tr>
<td>QB 15SC-2</td>
<td>12.1</td>
<td>4</td>
<td>1:20</td>
</tr>
<tr>
<td>QB 15SC-1</td>
<td>11.9</td>
<td>24</td>
<td>13:30</td>
</tr>
</tbody>
</table>
Comparison of Observations to Ergonomics Principles & Best Practices

Of the 21 risk factors associated with CTD’s as per the Eastman Kodak Company Ergonomics Group, at least 5 are present in the process being studied [5]. These factors follow:

- Inefficient work methods requiring excess force application
- Work postures including elevated shoulders or deviated wrists
- High-frequency work (repetitive cycles of 30 seconds or less)
- Overtime work
- Vibration from tools

Some of these issues cannot be corrected because they are simply too inherent to the operator’s work. However, others can be eliminated, or at the very least mitigated. The authors discuss all of the issues in this section, but their recommendations in the following section (“Conclusions & Recommendations”) reflect only those issues that are correctable. To gain a deeper understanding of the issues related to the PAC-3 drilling and related activities, the authors systematically compare the existing process to lists of design guidelines prescribed by the Kodak Ergonomics Group for repetitive work. A comparison to a few select principles from Niebel’s *Methods, Standards, and Work Design* is also included. The first list used for comparison follows:

General Guidelines for Repetitive Work as per the Eastman Kodak Company Ergonomics Group [5]

- Engineer products to allow machinery to do highly repetitive tasks; leave more variable tasks to human operators. ✗
- Spread the load over as many muscle groups as possible to avoid overloading of smaller muscle groups. ✓
- Design of tasks to permit gripping with the fingers and palm instead of pinching. ✓
- Avoid extreme flexion or extension of wrist. Design work surface heights, orientations, and reach length to permit the joints to remain as close as possible to their neutral positions for maximum muscle strength. ✗
• Keep forces low during rotation or flexion of the joint. Use power assists if forces are high. Avoid repetitive gripping actions. ☑

• Provide fixtures to hold parts during assembly so that awkward holding postures can be minimized. ☑

• Minimize time or pace pressures. ☑

• Give people time to break into a new repetitive task. ☑

For the listed principles that do not have corresponding issues in the existing PAC-3 work, a checkmark is to be found (☑). Those with corresponding issues have a negative mark (☒) and include some further elaboration. In the case of engineering products to allow for automation of highly repetitive actions, this may be appropriate at some point for the process, but is well beyond the scope of this report. The second negative mark is for design of work surface heights and the presence of wrists in extension. These topics are covered more thoroughly in the more specific lists that follow.

Specific Guidelines for Repetitive Work as per the Eastman Kodak Company Ergonomics Group [5]

• Keep the work surface height low enough to permit the operator to work with elbows to the side and wrists near their neutral position. ☒

• Avoid sharp edges on workplace parts bins that may irritate the wrists when the parts are procured. ☑

• Keep reaches within 20 inches of the front of the work surface so the elbow in not fully extended when the forces are applied. ☑

• Keep motions within 20 to 30 degrees of the wrist’s neutral point. ☒

• Avoid operations that require more than 90 degrees of rotation around the wrist. ☑

• Avoid gripping requirements in repetitive operations that spread the fingers and thumb apart more than 2.5 inches. Cylindrical grips should not exceed 2 inches in diameter, with
1.5 inches as the preferable size. Hand tools that produce vibrations, require wide grip spans, or repetitively abrade the wrist area during use are of particular concern.

- For repetitive operations that require finger pinches, keep the forces below 2.2 ft-lb. This represents 20 percent of the weaker operators' maximum pinch strength. For gripping actions, keep the required forces to 4.8 ft-lb. This represents 20 percent of the isometric grip strength of the average woman when the hand is at its optimum span for force exertion.

- For continuous, highly repetitive operations, design a five-minute break for another activity into each hour.

- Select a glove with the least interference for gripping if the hand protection is needed for a repetitive task. Provide a range of glove sizes to permit people to get the best fit for both large and small hands.

Perhaps the biggest two issues associated with the preceding list are related to work surface height and wrist positioning. As noted, the work surface height often exceeds the operator's elbow height of 45.25 in. In fact, the work surface height varies from about 39 in to 47 in for various activities, but is commonly above 45 in. A quarter-inch margin is not nearly enough to ensure that the elbows will remain in a neutral position. It is actually more than likely that such a small distance will require the operator's elbows to extend outwards, resulting in potentially agitating shoulder abduction. It is recommended that work be placed at or below elbow level so that upper arm abduction need not occur [5]. However, in the case of this operation, it seems infeasible, at least in the short-term to make any recommendations associated with work surface height because they all exist on capital-intensive machinery that would need significant alteration to ideally accommodate the operator. However, this may be something to consider for the long-term.

The wrist issue is more minor, especially since it is not likely to be related to the operator's TOS and it has not yet caused a complaint of another CTD such as carpal tunnel syndrome. However, best practices call for keeping a straight wrist and avoidance of tissue compression, which can both contribute to CTD’s and numbness, respectively [3]. Both of these are occurring when the operator holds the drill gun and leans into it to steady it and to speed it along. It would be wise to educate the operator about the potential risks associated with this non-essential activity (called such
because the drill locks should hold the drill gun in place to operate albeit slower), so that the behavior may be immediately altered and medical attention sought if necessary.

Finally, considering the highly repetitive nature of the work, it is recommended that a five minute break be allotted every hour. With both repetitive static work and dynamic activities, work recovery should be scattered into short, frequent cycles [3]. This is due to the fact that recovery occurs fast initially, but then tapers off with time. As a result, the greatest relative benefit occurs with short breaks. This is not currently the practice for the afflicted operator, as scheduled breaks of longer duration occur less frequently. However, the operator has some freedom to operate at an individual pace and should be encouraged to take a brief break whenever symptoms of TOS act up.

Going along with this issue of recovery, is the related issue of overtime. As mentioned earlier, overtime work is considered a risk factor in repetitive work for developing CTD’s. It is said that, “If the total number of repetitions per work shift is very high, the wear and tear on the joint may be a significant factor...,” in the potential for CTD development [5]. Likewise, “With overtime work or extended work weeks, there may be inadequate time for repair of the traumatized joints and muscles, and muscle and joint soreness may progress to more severe cumulative trauma disorders, such as...’frozen’ shoulder,” which is pain, stiffness, and decreased motion in the shoulder [5]. Obviously, this type of work activity is going to contribute to the development of TOS as a CTD or agitate an existing TOS condition.

Tool Design for Repetitive Work as per the Eastman Kodak Company Ergonomics Group [5]

- Design handles that make use of the maximum strength capability of the hand by featuring power or oblique grip involving the palm. Avoid pinch grip requirements. Make the handle diameters as close as possible to 1.5 inches and the span on the double-handled tools from 2 to 2.5 inches. ✓
- Make handles long enough (about 4 inches) to avoid applying repeated pressure to the base of the thumb, as when using a putty knife or a paint scraper. ✓
- Orient the tool handle so it does not have to be used with the wrist deviated markedly in either the ulnar or radial directions. ✓
• Design tools to reduce the need to exert a sustained force on a cold and hard surface. Properly textured handles increase the feeling of control on a powered tool; handle material with low thermal conductivity may also be desirable for some tasks.

• Reduce the vibration from the powered hand tool, such as an electric drill, as far as this is practical.

Vibration from power tools is known to affect circulation and nerves and can potentially cause what is called white fingers syndrome or finger numbness [3]. It is also known that vibrating tools contribute to the development of CTD’s by causing spasms of small blood vessels in the hand, wrists, and arms, which degrades circulation [5]. For this reason, it may be wise to consider better padding for the drill gun handle. Wrapping it might effectively mitigate vibration risks. A look at better dampening gloves might also be appropriate.

Other miscellaneous ergonomics principles recommended by the Kodak group (primarily those developed to reduce various forms of fatigue) follow [4] [5]:

• Avoid forward reaches of more than 20 inches in front of the body for standing work.

• Avoid reaches or lifts above 50 inches.

• Provide handles or handholds for objects to be handled (lifted, carried, or pushed).

• Provide seating for people who work on their feet for most of the day.

• Reach should not exceed 14 inches to either side of the body’s centerline, otherwise bending will be required.

A few reaches exceeding 50 inches do occur when operating the hoist. However, these instances are so rare and brief that they do not constitute a significant issue for the operator. The larger issue is that the transportation cart used to move the casings to other parts of the plant does not have appropriate handles.
Current use of hearing protection seems appropriate and satisfactory. However, lighting is non-optimal and makes it difficult to perform some inspection activities without the assistance of a flashlight. It might be worthwhile to further illuminate the workspace if ever economically feasible.
Conclusions & Recommendations

Clearly, to address the immediate problem of the operator’s TOS the authors defer to medical practitioners. The treatment mainstay for TOS is physical therapy and stretching. Physical therapy helps posture, strengthens the afflicted areas, and improves flexibility [1]. The operator is already engaged in this activity and should continue to be until a medical practitioner deems termination appropriate. Furthermore, a wellness program has existed at GD for some time now that requires employees to gather together and stretch before and after shifts. For the afflicted operator additional stretch time after lunch or at the end of the shift may be beneficial.

If the operator is not currently taking an anti-inflammatory pain reliever such as ibuprofen, a doctor may recommend it as being beneficial. If swollen tissues are the cause of the operator’s TOS, this medication could reduce compression in the shoulder area and help to relieve some of the pain. Also, if the medical practitioner deems it necessary, surgery may eventually be used to correct a lingering case of TOS. The goal of the surgery would be to alleviate compression of nerves or vessels in the operator’s clavicle area.

Following a few general guidelines can reduce the severity and frequency of suffering due to TOS. These guidelines follow [2]:

- Do not carry such heavy weights that repeated injuries occur to the shoulder area.
- Do not lift objects overhead.
- Reach overhead as scarcely as possible.

Following these guidelines may not eliminate the symptoms of TOS, but they can help to minimize them. With this knowledge in hand the operator will be able to better adapt to his workload, eliminating troubling motions when feasible.

Specifically related to work and workspace design, the authors make the following practical recommendations:

- Install a T-bar handle for the transportation cart used by the operator.
Install anti-fatigue floor mats at the workstations currently lacking them – the vertical drill fixtures.
Investigate vibration-limiting gloves and grips for the drill guns.
Do not schedule overtime work for the operator.
Encourage the operator to take frequent short breaks when he needs them.
Allow extra time for the operator to stretch.

It is possible that the posture that the operator assumes to push the cart is agitating his TOS condition. This is thought possible because the symptoms oftentimes onset during that activity. To give the operator more postural flexibility when moving the cart, and thus alleviate TOS symptoms, it is recommended that handles be added. Handles should straddle the load's center of gravity and be at a height that permits comfortable posture and mechanical advantages (typically 36 to 44 inches) [5]. Furthermore, consideration of a handlebar arrangement that allows pulling might have some value. In this case a T-bar handle, such as those found on a pallet jack, is preferred.

It was noticed that the work areas around the vertical drill fixtures were lacking anti-fatigue floor mats. It is a basic principle of workspace design is to provide anti-fatigue floor mats for standing operators [3]. This is due to the fact it is fatiguing to stand on cement floors for prolonged periods. Mats allow small contractions to occur in the leg muscles (which promotes circulation) and dampens some of the vibrations imparted onto the standing operator of power tools. Small mats cost about $50.

One last recommendation is aimed at mitigating the effect of the drill weight on the operator's condition. Ideally, hand tools should weigh less than 5 lb [3]. The authors measured the various drills used throughout the process and found that all of the drills weighed over 6 lb, most were over 8 lb, and some were up to 13 lb. Regularly lifting these weights could be causing some fatigue on the operator's shoulder area or swelling that contributes to TOS symptoms. A company called Equipois, Inc. has developed a device called the “zeroG”, which is designed to support the weight of heavy hand tools. The zeroG is a fixture that attaches to a surface (such as a wall or floor) and holds a tool (such as a drill gun), but is able to freely bend and move to the various positions required to complete a desired task. This allows tools to “float” around without overstressing the muscles and nerves. As an added benefit the tool is easy to use and requires minimal usage training. However, installing such a device would be relatively expensive and an investigation into its costs and
benefits is highly recommended before proceeding. Such an investigation is beyond the scope of this report.

The authors made no claim that the TOS experienced by the afflicted operator is a cumulative trauma disorder (CTD) caused by work or workspace issues. However, the authors, using their training in ergonomics, did identify work and workspace issues that could cause TOS or agitate an existing TOS condition. The work itself was first observed, both quantitatively and qualitatively, to identify issues. Then the workspace was inspected, again both quantitatively and qualitatively. The findings from these observations were compared to ergonomics principles and best practices to develop recommendations for GD. In general, things seemed to follow best practices; however, a few recommendations were developed. These recommendations (as prescribed above) include the elimination of overtime work, the addition of a handlebar to the operator’s cart, installation of floor mats near the vertical drill fixtures, as well as several more. It is the thought of the authors that the implementation of these recommendations will reduce the TOS symptoms experienced by the afflicted operator; in addition to helping GD better conform to the best practices of ergonomics.
References


