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**NIOSH INVESTIGATORS:**
**Pete Fatone, M.S.**
**Randy L. Tubbs, Ph.D.**
**Leslie MacDonald, M.M.S.**

## I. SUMMARY

In February 1995, the National Institute for Occupational Safety and Health (NIOSH) conducted a health hazard evaluation at Gulfstream Aerospace Corporation at the request of management. The safety staff of this company were interested in evaluating their pneumatic hand-held power tools for hand-arm vibration (HAV)**.**

The NIOSH investigators collected vibration measurements on 30 tools that are used by workers throughout the plant. In most instances, the tools were tested when a worker was using the tools assigned to them on work pieces that were in the production phase. The vibration of 19 tools exceeded all exposure time zones recommended by the American National Standards Institute (ANSI) and the American Conference of Governmental Industrial Hygienists (ACGIH). The vibration levels of the remaining 11 tools fell into one of the suggested time zones, ranging from one-half hour to eight hours of daily exposure.

A spectral analysis of the acceleration data showed that nine out of ten tools marketed as either "ergonomic" or "vibration-reduced" possessed lower vibration levels than their conventional counterparts. This was found to be the case for drills, rivet guns, routers, bucking bars, and sanders.

The results of this investigation indicate that a potential health hazard exists for employees at Gulfstream Aerospace Corporation from using hand-held pneumatic power tools that produce excessive hand-arm vibration. Continued use of these tools without any intervention by management may lead to employees experiencing tingling and numbness in their fingers as a precursor to hand-arm vibration syndrome. The data show that usage should be restricted for nearly all of the tools tested, as only three tools fell into the 4-8 hour exposure time zone. Recommendations for addressing this potential hazard are provided in Section VIII of this report.

**KEYWORDS:** SIC 3721 (Aircraft), hand-arm vibration, HAV, acceleration, hand-arm vibration syndrome, pneumatic tools, ergonomics.

## II. INTRODUCTION

On September 23, 1994, the National Institute for Occupational Safety and Health (NIOSH) received a management request for a health hazard evaluation from Gulfstream Aerospace Corporation located in Savannah, Georgia. In March 1994, Gulfstream Aerospace Corporation started an ergonomic program, incorporating a medical management program and a system to identify, evaluate, and abate workplace hazards with engineering controls. Gulfstream Aerospace Corporation's next initiative was to develop a rating system for pneumatic hand-held power tools based on several criteria such as: performance, cost, maintenance, durability, and ergonomic factors. These latter factors include tool weight, grip comfort, noise, and vibration. Gulfstream Aerospace Corporation was able to evaluate all the ergonomic issues using in-house expertise with the exception of vibration. Because vibration analysis requires specialized equipment, methodology, and expertise, Gulfstream Aerospace Corporation requested the assistance of NIOSH through the Health Hazard Evaluation Program.

The NIOSH scientists visited Gulfstream Aerospace Corporation on February 21 - 24, 1995. During this visit, the team provided hand-arm vibration (HAV) training for about fifteen Gulfstream Aerospace Corporation employees. Managers, supervisors, engineers, buyers, nurses, technicians, and industrial hygienists attended the HAV training. The NIOSH team devoted the remainder of the visit to collecting data on several pneumatic hand-held power tools. The main objective of the data collection was to compare the vibration acceleration levels of various tools used under identical working conditions.

## III. BACKGROUND

Gulfstream Aerospace Corporation is a non-union aerospace company that designs and manufactures private jet airplanes which are sold to both domestic and foreign customers. Gulfstream Aerospace Corporation employs nearly 4000 workers of which nearly 1000 are assigned to manufacturing and assembly operations. Almost all of the workers use pneumatic hand-held power tools at some point during a typical work day. There are an estimated 10,000 air-driven tools located throughout the plant, including bucking bars, buffers, drills, palm sanders, rivet guns, routers, sanders, and screw guns. Gulfstream Aerospace Corporation purchases these tools from several different manufacturers. A goal of the safety staff at Gulfstream Aerospace Corporation is that their buyers purchase tools designed in accordance with ergonomic principles. The tools tested in this investigation include tools from the following manufacturers: Aro, Chicago Pneumatic, Deutsch, Dotco, Ingersoll-Rand, Sioux, and U.S. Tools.

## IV. EVALUATION CRITERIA

### A. Hand-Arm Vibration (HAV)

In general, vibration is the study of mechanical oscillations of a dynamic system. Frequency, displacement, velocity, and acceleration are four parameters that characterize vibration. Usually, frequency and acceleration are the two quantities that draw the most concern. The vibration data in this report is graphed as acceleration versus frequency in a log-log plot. The motion of a vibrating system is periodic. This means the motion is repetitive, creating a definite cycle or period. Frequency is the inverse of the period (1/T, where T is the period) and has units of Hertz (Hz) or cycles per second. Acceleration levels have the International System of Units (SI) of $m/s^2$ or units of gravity (g's) and are vector quantities that characterize the amplitude and direction of vibration.

Vibration is an ergonomic stressor seen in a number of industries. For example, forestry, electronics, automobile, aerospace, shipbuilding, mining, transportation, road construction, trucking, and even dentistry all are industries that involve vibrating hand-held tools and/or vehicles. Occupational vibration exposure is classified as either whole-body vibration (WBV) or HAV, the latter sometimes referred to as segmental vibration. Occupational WBV usually involves industrial vehicles, public transportation, or vibrating platforms. The vibration enters through the worker's feet and/or seat. In comparison, HAV is produced by power tools that are either electric, pneumatic, or hydraulic. Drills, impact hammers, polishers, buffers, rivet guns, sanders, grinders, routers, and nut runners are all examples of common power tools found in industry that expose workers to HAV.

### B. Hand-Arm Vibration Syndrome

The health effects from over-exposure to HAV is hand-arm vibration syndrome (HAVS). Basically, HAVS involves circulatory, neurological, and musculoskeletal disturbances. Victims experience vasospasms which reduce the blood flow in the fingertips and cause the fingers to turn white or blanch. These attacks are triggered by cold temperatures. Sufferers may also experience numbness, tingling, and sensitivity threshold shifts after years of HAV exposure. These disturbances are caused by damage to the sensory nerves in the hand and arm and are more permanent than circulatory disturbances.[1] Finally, some musculoskeletal problems can be attributed to HAV. Fatigue is the most prevalent issue and is probably linked to the neurological sensitivity threshold shift which may cause workers to unintentionally and unnecessarily over-grip the tool.

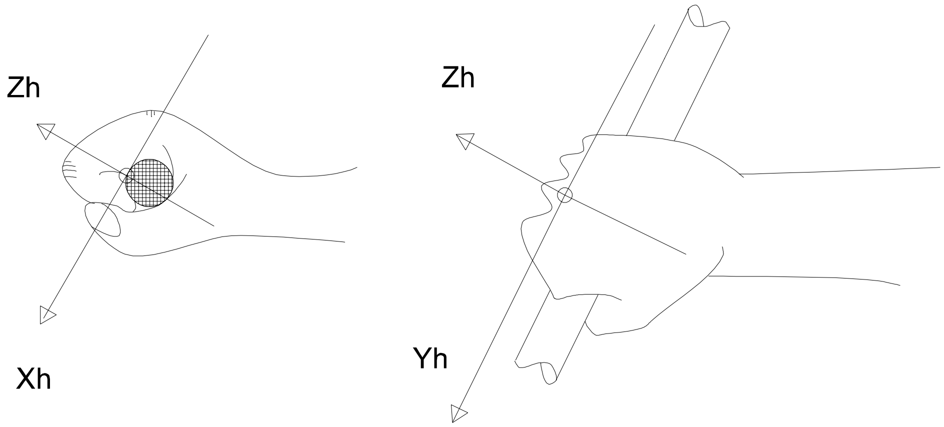
Scientists and physicians are continuously improving screening and monitoring techniques for HAVS. The most widely used scales for classifying the circulatory and neurological symptoms are the Stockholm Workshop Scales.[2,3] Currently, no such scale exists for rating the musculoskeletal symptoms caused by HAV.

## C. Standards and Criteria

The four recommended standards and criteria for assessing HAV exposure are the following: (1) American National Standards Institute (ANSI) S3.34-1986, Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand;[4] (2) International Standards Organization (ISO) 5349-1986, Mechanical vibration - Guidelines for the measurement and the assessment of human exposure to hand-transmitted vibration;[5] (3) Threshold Limit Values (TLVs) and Biological Exposure Indices by the American Conference of Governmental Industrial Hygienists (ACGIH);[6] and (4) NIOSH Criteria for a Recommended Standard: Occupational Exposure to Hand-Arm Vibration.[7]

The ANSI and ISO standards provide similar accepted measurement and reporting techniques. Both documents define the biodynamic and basicentric coordinate systems for positioning the accelerometers used to measure the vibration in the three orthogonal axes of direction; up and down, side to side, and back and forth. The basicentric coordinate system was chosen for this survey. This system seems to be easier to apply since the Y direction is based on the tool geometry rather than the hand position. The Y axis parallels the handle of the tool. The X axis runs perpendicular to plane containing the top of the hand. The Z axis follows and should be aligned with the forearm. Figure 1 shows a typical basicentric coordinate assignment.

**Figure 1: Basicentric Coordinate System**



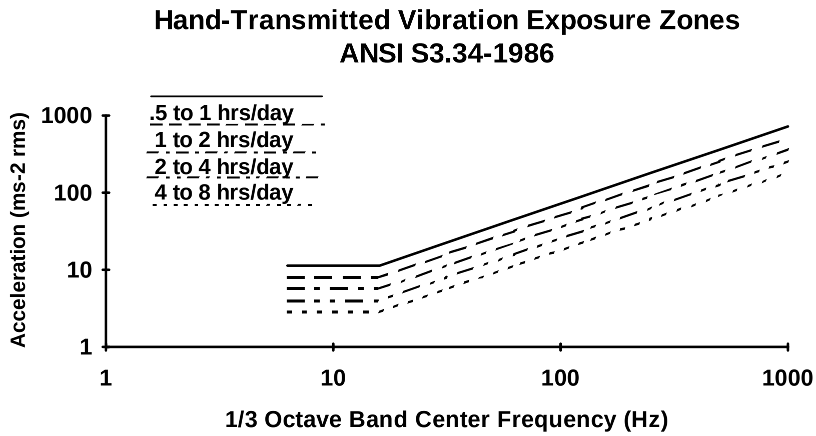

In addition, the ANSI and ISO standard both provide a plot to predict the latent periods before the first stage of HAVS. The plots are not in the body of the standards but are found in an appendix. The accuracy of this approach has recently been questioned;[8] and has therefore been left out of this report.

The ANSI, ISO, and ACGIH require weighting the 1/3 octave band acceleration data ($a_f$) to find an overall acceleration value for the 1/3 octave center band frequencies 6.3 through 1,250 Hz. The weighting factors ($W_f$) for each center band frequency are given in both the ANSI and ISO standards. These factors gradually reduce the significance of acceleration beyond 20 Hz and are used to calculate the overall weighted acceleration (OWA). Equation (1) calculates the OWA.

$$a_{OWA} = \left( \Sigma \left[ W_f \, a_f \right]^2 \right)^{1/2} \qquad \textit{Equation (1)}$$

ANSI incorporates the weighting filter into suggested HAV exposure zones. These zones demonstrate that acceleration levels at higher frequencies are considered to be less dangerous. In the analysis for this report, the exposure zones were over-laid on the unweighted data to reveal the suggested daily use of the hand-held power tool. Figure 2 shows the suggested ANSI exposure zones.

**Figure 2: ANSI Recommended HAV Exposure Zones**




The ACGIH TLVs determine a time-weighted average of the OWA for the dominant axis of each exposure, defined as the axis with the highest overall acceleration. This analysis method provides the investigator with a single number for the HAV assessment of multiple tools and/or tasks.

Table 1 shows the suggested overall daily exposure durations found in the ACGIH TLVs.

**Table 1: Threshold Limit Values for HAV Exposure**

| Total Daily Exposure Duration | Values of Acceleration Not to be Exceeded (m/s$^2$) |
|---|---|
| 4 to 8 hrs | 4 |
| 2 to 4 hrs | 6 |
| 1 to 2 hrs | 8 |
| less than 1 hr | 12 |

Unlike the ANSI and ACGIH criteria, NIOSH does not provide a recommended exposure limit for HAV. The NIOSH criteria document emphasizes reporting unweighted data since the weighting factors used in the other criteria are based on limited research.[9] This criteria document also recommends conducting HAV measurements from 5 to 5,000 Hz. Although no current standard exists that links unweighted acceleration levels to health risks, some recent studies have suggested that high frequency vibration may cause more damage than once believed.[10]

## V. METHODS

### A. Data Collection

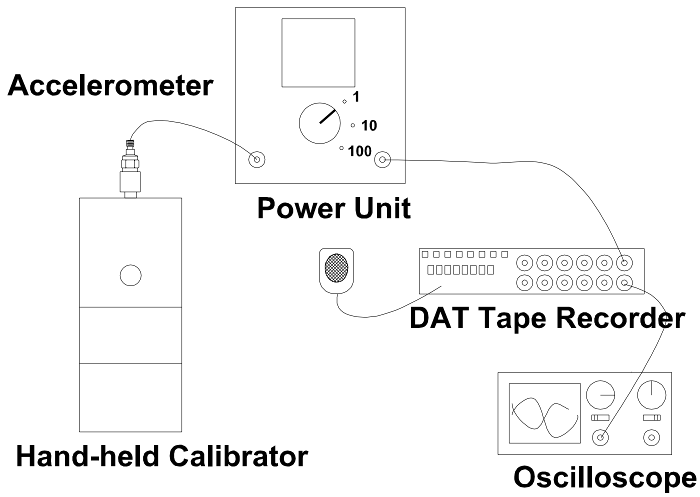
The NIOSH team spent two and one-half days measuring HAV on 30 hand-held pneumatic tools used throughout the plant. The measurement procedures described here were developed from the evaluation criteria described in Section IV. C. The investigators collected vibration data using the equipment listed in Table 2.

**Table 2: Data Collection Equipment**

| Item | Description | Make | Model |
|---|---|---|---|
| 1. | hand-held calibrator (1g rms, 79.6 Hz) | PCB | 394B06 |
| 2. | accelerometers (500g, 10 kHz) | PCB | 353B16 |
| 3. | 5-44 coaxial to BNC cable - 25 ft | PCB | 018C25 |
| 4. | 3-axis mounting block | PCB | 080A16 |
| 5. | ICP sensor power unit (1,10,100) | PCB | 480E09 |
| 6. | digital audio tape (DAT) recorder | TEAC | RD-111TN |
| 7. | oscilloscope (2 channel) | Tektronik | 465 |
| 8. | 8mm video camera recorder/player | Sony | ccd-fx510 |
| 9. | force gage (0-50 lbs) | Chatillon | DFG50 |
| 10. | hose clamp | Tridon | $\phi$33/57mm |
| 11. | hot melt glue gun | Arrow | TR400 |

Before and after each day of data collection, the investigators calibrated the three channels for all the necessary power unit gain settings using a hand-held calibrator. The calibration procedure recorded the channel's system sensitivity, including the accelerometers, cables, power units, and the DAT tape recorder. The NIOSH investigators monitored the calibration signals with an oscilloscope as they were recorded on DAT tape for 30 seconds. The channel information, i.e., channel number, accelerometer serial number, axis, and power unit gain setting, was documented on a separate voice channel of the recorder. Figure 3 shows a schematic of the equipment set-up during calibration.

**Figure 3: Calibration Set-up**

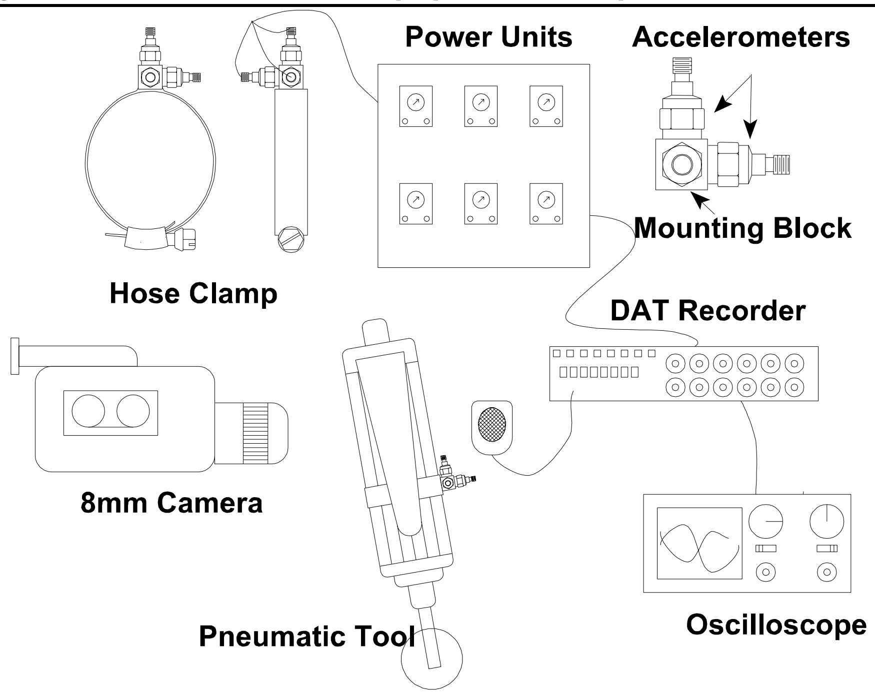



After calibration, the NIOSH team organized the data collection equipment on a cart for maximum mobility. The investigators wheeled the equipment into the assembly and manufacturing areas and started HAV data collection. First the team identified and documented the task performed, duration of task, work piece material, tool type, tool model, tool serial number, power supply, motor speed, tool age, tool condition, maintenance information, tool weight (while attached to the pneumatic hose), tool accessories and attachments, worker's name, worker's age, time on task, worker's tobacco smoking habits, daily usage, grip, hand used, ambient temperature, and relative humidity. All of this information was recorded on an assessment sheet (Appendix A).

The investigators attached accelerometers to the handle of the tool ensuring the three accelerometers were fixed as close to the worker's hand as possible without interfering with normal operation of the tool. Three accelerometer mounting methods were used. For 27 of the tools tested, the accelerometers were screwed into a 3-axis mounting block welded to a hose clamp. Two tools required two hose clamps be put together end-to-end in order to wrap around the handle. One tool’s handle design necessitated that a free, 3-axis mounting block be glued to the handle.

The team identified and recorded the x, y, and z axis for the appropriate accelerometer using the basicentric coordinate system described in Figure 1. The clocks on the DAT tape recorder and 8mm video camera were synchronized, enabling a complete documentation of the worker's and tool's activity during data collection. The worker was instructed to work normally as raw unweighted vibration data and video were recorded. To avoid overloading the DAT tape recorder, the investigators monitored the signal levels on the oscilloscope and DAT level indicator and adjusted the power unit gains accordingly. Figure 4 shows the equipment set-up during data collection and the single hose clamp mounting technique.

**Figure 4: Data Collection Equipment Set-up**




## B. Data Analysis and Reporting Techniques

The analysis and reporting techniques were also developed from the four referenced standards discussed in Section IV., C. The NIOSH investigators used the equipment and software listed in Table 3 to analyze the collected data and generate acceleration versus frequency graphs.

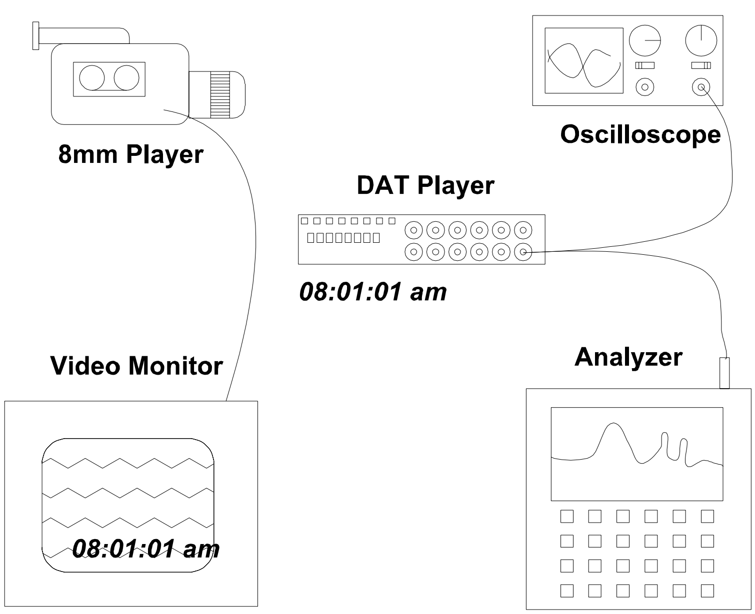
**Table 3: Data Analysis Equipment**

| Item | Description | Make | Model |
|---|---|---|---|
| 1. | digital audio tape (DAT) recorder | TEAC | RD-111TN |
| 2. | oscilloscope (2 channel) | Tektronik | 465 |
| 3. | 8mm video camera recorder/player | Sony | ccd-fx510 |
| 4. | real time signal analyzer | Larson\|Davis | 2800 |
| 5. | video monitor | Panasonic | TR-124MA |
| 6. | spreadsheet graphics and macros | Microsoft | Excel 4.0 |

In the laboratory, a NIOSH investigator analyzed over 100 measurements on 30 tools. Each measurement included analyzing data from the x, y, and z axis. Before any analysis, a log sheet of the DAT data tape was created. By watching the video in synch with the vibration data, the investigator was able to record measurement locations on the DAT tape. The tape counter (start/finish), event number, measurement number, approximate actual time and date of the data collection, tool number, tool and attachment description, power unit gain setting, and the averaging time of the measurement were all contained in the log sheet.

Next, the investigator set up the unit conversions (mV to $m/s^2$) on the analyzer for each channel and power unit gain setting. This was accomplished by running the calibration signals on the DAT tape through the real-time analyzer. The sensitivities were measured and stored on the analyzer. Referring to the log sheet, the investigator played HAV data through the analyzer using the 1/3 octave band filters, converting the real time data into the frequency domain. Each measurement maximized the available averaging time to ensure credible data. A few tests were limited to 4 seconds, but a majority of the measurements had averaging times lasting over 30 seconds. Figure 5 shows the equipment set-up used during data analysis. Notice that the video and DAT recorders are now players. This set-up allows the investigator to totally recreate the test recorded in the field.

**Figure 5: Data Analysis Equipment Set-up**



Each of the measurements graphed acceleration versus frequency across the 1/3 octave center frequency bands of 6.3 Hz to 1,250 Hz. The ANSI suggested exposure zones were overlaid on the tool data to identify excessive acceleration levels. In addition, the OWA for each measurement was calculated using equation 1.

The post-processing was automated with a Microsoft Excel 4.0 macro code. This program accepts binary data files and generates graphs showing the acceleration levels of all three axis. The program also calculates the overall weighted accelerations and overall unweighted acceleration (OUA) levels for the 1/3 octave band center frequencies 6.3 through 1,250 Hz. Appendix B documents the decision logic for this program.

## VI. RESULTS

The analysis provided two useful results for each measurement. The OWA values were calculated, and graphs showing the tool's acceleration levels compared to the suggested ANSI exposure zones were generated. Although this investigation involved over 100 measurements, only the results of tests most representative of the tools are included in this report.

Appendix C compiles a complete list of information for the tests conducted during this survey: tool manufacturers, model numbers, serial numbers, tool types, motor speeds, handle configurations, tool weights (while attached to the pneumatic hose), measurement averaging times, highest OWAs, measurement numbers, ANSI exposure zones, ACGIH exposure zones, and Appendix D page numbers where the individual tool data are presented. According to the ANSI criterion, tools 4, 7, 25, 30, and 31 had vibration levels low enough to allow for four to eight hours of daily exposure. Tools 26, 29, and 33 fell within the two to four hour ANSI zone. And finally, the ANSI zones suggest one-half to one hour daily usage for tools 2, 3, 8, 10, 19, and 28. In comparison, the ACGIH suggested exposure zones based on the OWA values seem to be more conservative. Only tools 7, 30, and 31 are considered safe for four to eight hours. In addition, according to ACGIH, only one to two hours of exposure for the right handle of tool 33[*] are recommended. Tools 4 and 25 and the left handle of tool 33 were in the less than one hour zone.

One objective of the analysis was to compare the vibration of different tools of similar design when used by the same workers for identical applications. The

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*Tool 33 was a buffer that was operated with two hands; therefore, the analysis required measurements on both handles.

ergonomic team at Gulfstream Aerospace Corporation was interested in determining the vibration levels for different models and manufacturers of the same tool type under the same working conditions. Comparisons were available for drills, rivet guns, routers, bucking bars, and sanders. Figures 6 through 13 show the acceleration versus frequency data for these comparisons. These graphs contain the acceleration data for the axis possessing the highest OWA. With the exception of the Figure 13, the ANSI suggested exposure zones (Figure 2) are overlaid on the tool data. A complete set of the data analysis is found in Appendix D which contains the frequency versus acceleration graphs, OWA values, and OUA for all three axes of all the tools listed in Appendix C.

The data shown in Figure 6 reveal a reduction in vibration for a similar drill model made by the same manufacturer. These Dotco tools were right angle drills with lever throttles. The OWA's of 45 m/s$^2$ and 26 m/s$^2$ for tools 1 and 2, respectively, quantify the impact of this decrease. Tool 1 was nearly 15 years old, and tool 2 was only one month old at the time of the data collection. Although the OWA of tool 2 exceeds the limits of the ACGIH TLV (12 m/s$^2$), the OWA of tool 2 is over 40% less than the OWA of the older tool 1. In addition, the 1/3 octave band center frequency data of tool 2 fall within the ANSI ½ to one hour/day exposure zone. This is a substantial improvement from tool 1 which exceeded all ANSI exposure zones.

**Figure 6: Tools 1 and 2**

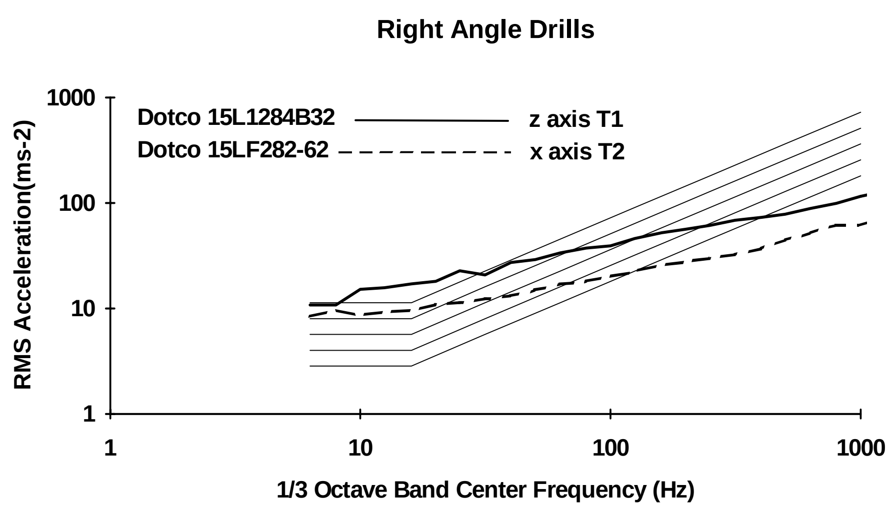



Figure 7 shows vibration levels for a manufacturer's improved tool and also compares vibration from similar tools made by different companies. These tools were right angle drills with a pistol or power grip. Tools 3 and 4 were Ingersoll-Rand right angle drills of the same series or group of similar models of Ingersoll-

Rand tools. Tool 3 was two years old and tool 4 was a brand new model. Tool 4 proved to have significantly lower vibration levels than tool 3. According to the ANSI exposure zones, tool 4 was safe for 4 to 8 hours/day where tool 3 approached the limits of ½ to 1 hour/day of usage. This improvement was also evident in the OWA values: 10 $m/s^2$ (tool 4) versus 29 $m/s^2$ (tool 3). Ingersoll-Rand reduced the vibration in this type of drill by 65%. Tool 5, a new Dotco right angle drill model advertised as an ergonomic tool, was also tested under the same conditions. The vibration levels of this tool exceeded both ANSI and ACGIH criteria. The OWA was found to be 46 $m/s^2$.

**Figure 7: Tools 3, 4, and 5**

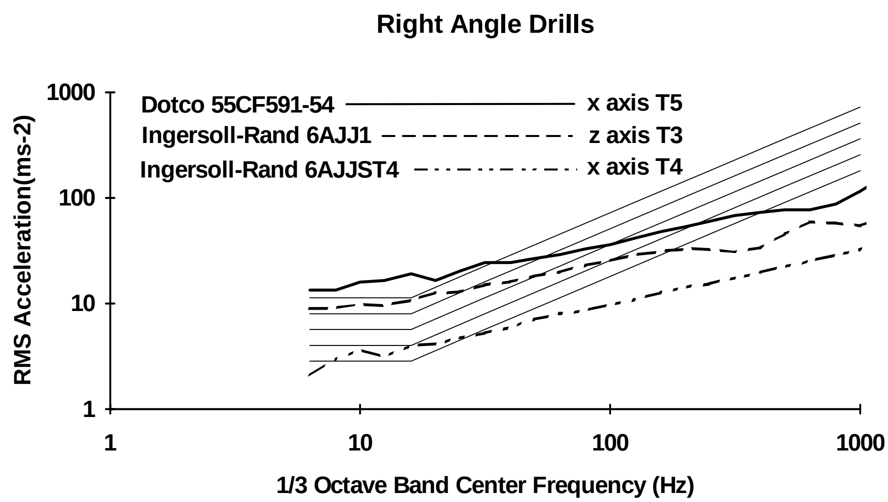



Figure 8 compares the vibration of three right-angle rivet guns under identical conditions. These guns were categorized as 2X rivet guns. Tool 6 was considered to be the conventional rivet gun which was not advertised as an ergonomic tool. As a result, the vibration levels were relatively high when compared to the ANSI exposure zones. The OWA value of 66 $m/s^2$ was also excessive. Unlike tool 6, tools 7 and 8 were marketed as ergonomic and vibration-reduced models. When compared to tool 6, the OWA values of 3 $m/s^2$ and 20 $m/s^2$ were a 95% and 70% reduction for tools 7 and 8, respectively.

**Figure 8: Tools 6, 7, and 8**

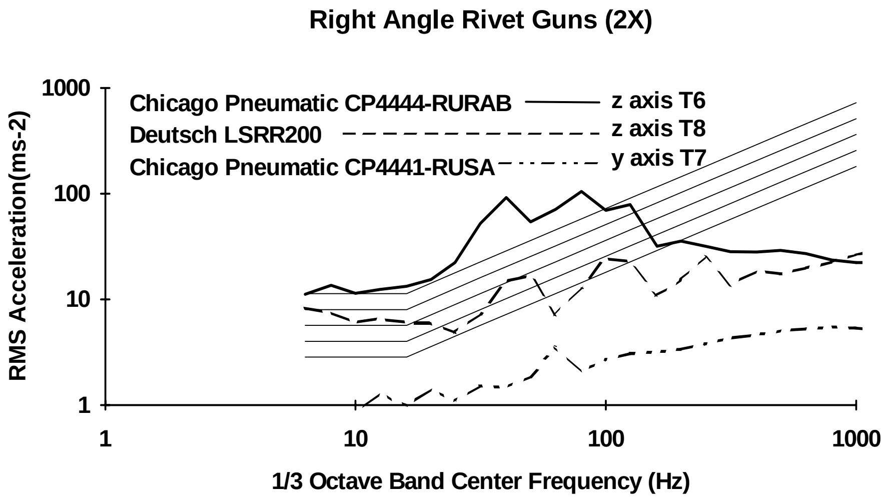



Figure 9 compares vibration levels of two 3X rivet guns and one 4X rivet gun. Tool 11 was a conventional right angle 4X rivet gun that was not designed for reducing the vibration. As a result, the OWA (137 m/$s^2$) for tool 11 was more than ten times greater than the most stringent ACGIH suggested exposure zone. The situation for tool 9 was similar. Tool 9 was an old conventional inline 3X rivet gun, and the model was unknown. The high acceleration levels of tool 9 (OWA = 134 m/$s^2$) were similar to tool 11. In comparison to these tools, tool 10 was a 3X rivet gun designed to minimize the vibration transmitted to the hand. Figure 9 shows that the acceleration levels were within the ½ to 1 hour/day ANSI exposure zone. The OWA was decreased to a more reasonable level of 21 m/$s^2$. This is a 84% improvement when compared to the conventional 3X and 4X models.

## Figure 9: Tools 9, 10, and 11

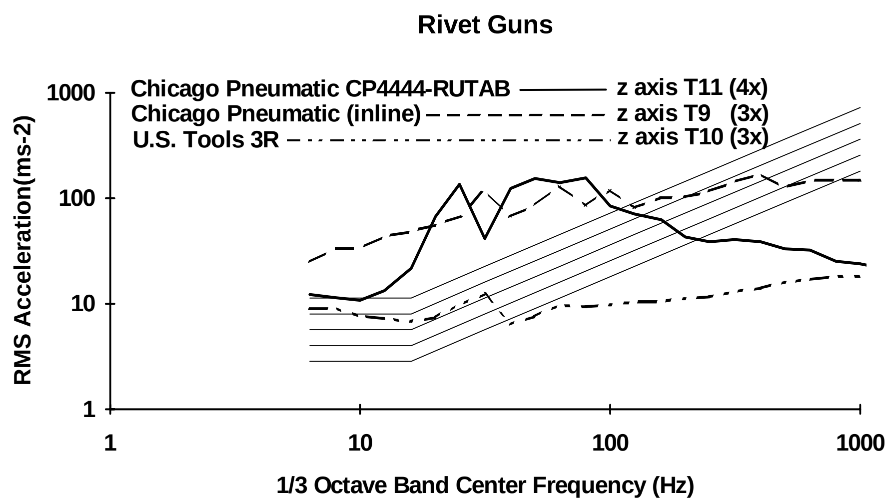



Figure 10 displays the vibration levels of three inline routers tested under the same conditions. Tool 27 was a fairly old tool and had extremely high acceleration levels. The high vibration was also evident in the OWA of 236 $m/s^2$. In addition, this tool became uncomfortably cold to the touch during operation. Tools 22 and 23 proved to be significant improvements, but the accelerations still exceeded all the ANSI and ACGIH exposure zones. The OWA for tools 22 and 23 were 30 and 72 $m/s^2$, respectively.

## Figure 10: Tools 22, 23, and 27

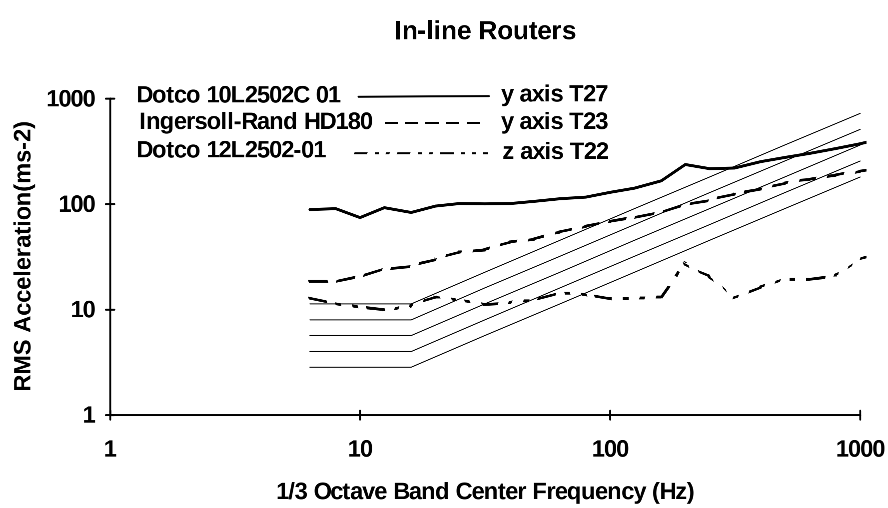


Figure 11 compares the vibration levels of three right angle sanders operated under identical conditions. According to the ANSI exposure zones, tool 25 had the longest allowable daily usage of 4 to 8 hours/day. Tool 26, an "ergonomic series" tool, was found to fall in the 2 to 4 hours/day exposure zone, and tool 24 approached the limits of ½ to 1 hour/day exposure zone. The OWA values for tools 24, 25, and 26 were 29 $m/s^2$, 10 $m/s^2$, and 15 $m/s^2$, respectively. Tool 25 had the only OWA value that was acceptable according to the ACGIH criteria (Table 1).

**Figure 11: Tools 24, 25, and 26**

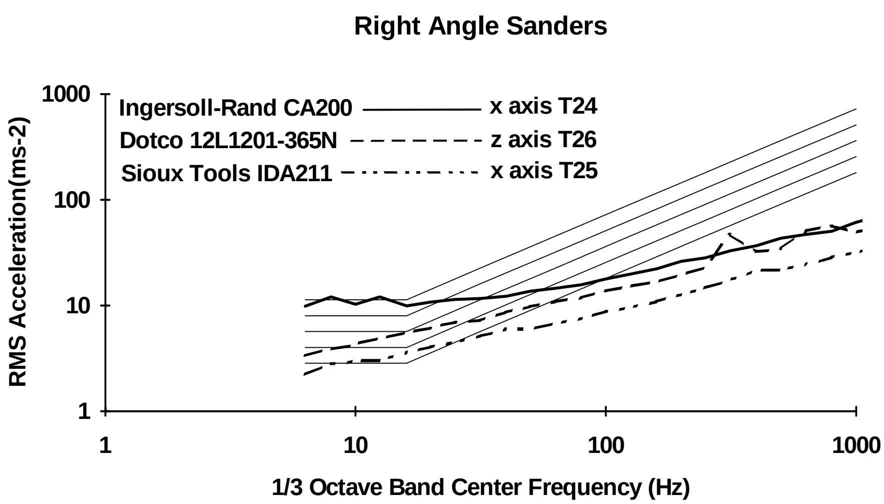
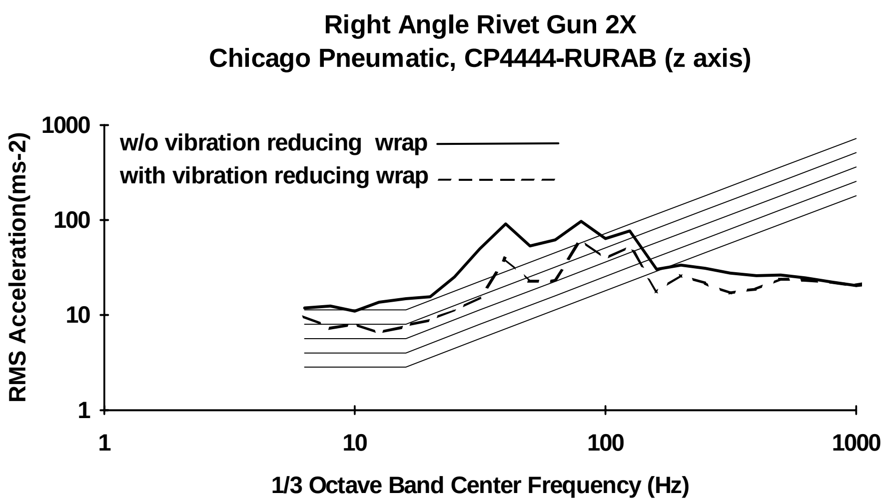


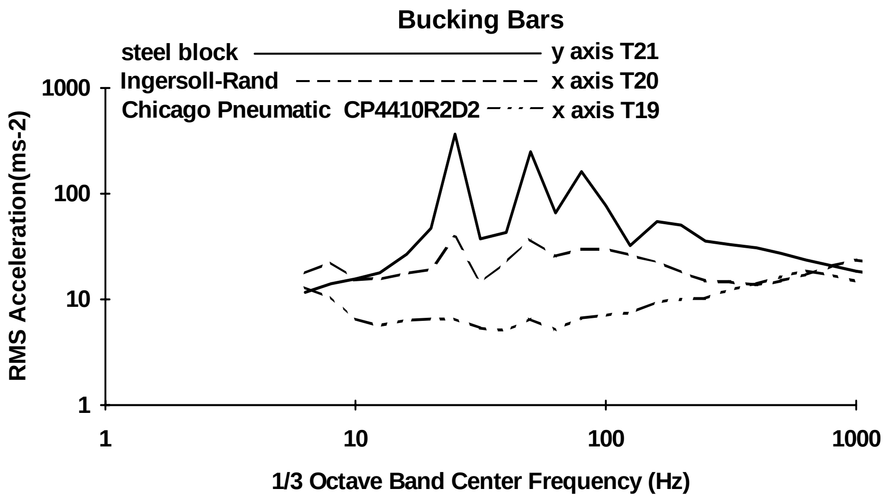

Figure 12 shows the effect of wrapping a rivet gun with one layer of a vibration reducing material, Ergo-wrap Tool Covering sold by Chicago Pneumatic. The wrap reduced the vibration from 66 $m/s^2$ to 32 $m/s^2$ or a 51% decrease in acceleration. The improvement may actually be a conservative difference since fastening the hose clamp unavoidably reduced the thickness of the wrapping material between the accelerometers and the tool handle.

**Figure 12: Tool 6**




Unlike Figures 6 through 12, Figure 13 intentionally omits the ANSI exposure zones for the results of measurements conducted on two "recoilless" bucking bars (Tools 19 and 20) and a standard steel bucking bar (Tool 21). The zones were not included since the measurements were not collected during actual work practices. The set-up for this test consisted of a small piece of aluminum scrap metal clamped in a vice. Rivets were driven with the same 4X rivet gun for each bucking bar. Although these data do not represent a real task, the relative differences reveal the importance of using the "recoilless" bucking bars. The OWA values for tools 19 and 20 were 21 m/s$^2$ and 53 m/s$^2$, respectively. When compared to the OWA value for tool 21 (253 m/s$^2$), the improvement is 91% and 79% for tools 19 and 20.

**Figure 13: Tools 19, 20, and 21**



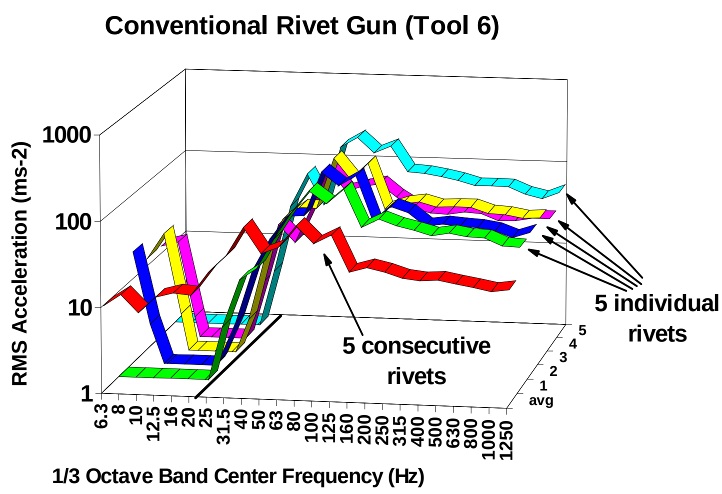

## VII. DISCUSSION

The primary object of this investigation was to provide Gulfstream Aerospace Corporation with HAV assessment. This was accomplished by conducting HAV measurements on 30 hand-held pneumatic power tools. A majority of the measurements were devoted to comparing similar tool types under the same conditions. The right angle drill, rivet gun, router, sander, and bucking bar comparisons revealed lower vibration levels for tools catalogued as "ergonomic" or "vibration-reduced." Tools 2, 4, 7, 8, 10, 19, 20, 22, 25, and 26 possessed lower vibration than their older conventional counterparts. Tool 5 was the only "ergonomic" tool that was found to have higher acceleration levels than conventional models.

These data have some limitations. The comparisons were based on one specific tool for each model. This means that the comparisons may be only valid for the specific combination of the particular tools, workers, and jobs tested. The comparisons would have been more credible if the NIOSH investigators had access to several tools of the same model. Due to the shortage of the new ergonomic tools in the plant and the time constraints of the survey, this limitation was unavoidable. The NIOSH investigators feel this study provides useful information for rating tools based on vibration, despite this limitation. Even though the acceleration measurements of the vibration-reducing material proved that the material was effective in lowering vibration, and the workers' approval confirmed this effectiveness, the success was experienced with only one rivet gun. Further testing on different tools and with varying material thicknesses is necessary to assess the true impact of this abatement.

The typical on\off operation of pneumatic drills, rivet guns, and bucking bars created "dead" spaces in the vibration data. In other words, the collected vibration data for these tools was not continuous. This situation posed a data analysis question of whether the data should be analyzed for each individual energy burst or over several consecutive bursts including the "dead" spaces. After reviewing rivet gun data, it was determined that analyzing data over several consecutive rivets proved to be most representative. Figure 14 shows an example of how this solution was determined. The waterfall graph represents an analysis over five rivets and five individual analyses of each rivet. Notice that the analyses for the individual rivets do not begin to match the analysis over five rivets until after 25 Hz. Since the averaging time of each individual analysis was only 0.75 seconds, the analyzer was unable to measure low frequency vibration. Because low frequency (6.3 to 20 Hz) vibration is so critical in HAV assessment, the tools had to be measured over several rivets. In addition, note that the levels for the individual rivets beyond 25 Hz were slightly higher than the level over five consecutive rivets. This slight difference was expected due to the "dead" spaces included in the analysis.

**Figure 14: Five Consecutive vs. Five Individual Rivets**




The consecutive versus individual analysis comparison was also conducted for tools 7 and 8. The waterfall graphs for these comparisons were consistent with the results of tool 6 shown in Figure 14.

## VIII. RECOMMENDATIONS

Based on the data analysis and observations made by NIOSH investigators during the survey, the following recommendations are made to address the potential health hazard caused by HAV exposures from hand-held pneumatic power tools currently in use at Gulfstream Aerospace Corporation.

1. Gulfstream Aerospace Corporation should continue purchasing new vibration-reduced pneumatic tools and replacing the older conventional models. Many manufacturers of pneumatic tools are aware of vibration effects on workers and are offering “reduced-vibration” models as part of their tool lines. This replacement strategy will eventually lower the HAV experienced by employees at Gulfstream who use pneumatic tools.

2. Gulfstream Aerospace Corporation should monitor the vibration levels of new and old pneumatic tools to protect their workers from excessive HAV exposure. This monitoring could also initiate maintenance and/or replacement of tools that are found to have high vibration levels caused by wear and tear or damage to the tool. It is the impression of the NIOSH investigators that personnel at Gulfstream will be able to perform this monitoring in house after some measurement equipment purchases are made.

3. The results of the vibration-reducing wrap comparison suggest that Gulfstream Aerospace Corporation should apply the wrap on high vibration tools until these tools can be replaced. In addition, the effects of this wrap should be further investigated. Different tools with various wrap thicknesses should be tested. Gulfstream should use caution when applying multiple layers since this will enlarge the handle of the tool which may prove uncomfortable for some workers.

4. A medical monitoring program designed for early identification of HAVS should be implemented at Gulfstream Aerospace Corporation. NIOSH has recommended the necessary components for a medical monitoring program.[7]

5. Employees should be given breaks from HAV exposures to allow for recovery from hand-tool vibration. Careful attention should be given to workers using tools that tested extremely high when compared to the ANSI and ACGIH suggested exposure zones.

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## X. AUTHORSHIP AND ACKNOWLEDGMENTS

| | |
|---|---|
| Report Prepared: | Pete Fatone, M.S.<br>Mechanical Engineer<br>Applied Psychology and Ergonomics Branch<br>Division of Biomedical and Behavioral Science |
| Field Assistance: | Randy L. Tubbs, Ph.D.<br>Psychoacoustician<br>Hazard Evaluations and Technical Assistance Branch<br>Division of Surveillance, Hazard Evaluations and Field Studies |
| | Leslie A. MacDonald, M.M.S.<br>Research Engineer \ Ergonomist<br>Industrywide Studies Branch<br>Division of Surveillance, Hazard Evaluations and Field Studies |
| Originating Office: | Hazard Evaluations and Technical Assistance Branch<br>Division of Surveillance, Hazard Evaluations and Field Studies<br>National Institute for Occupational Safety and Health<br>4676 Columbia Parkway<br>Cincinnati, Ohio 45226 |

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Copies of this report have been sent to:

1. Gulfstream Aerospace Corporation
2. Occupational Safety and Health Administration, Region IV

**For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.**

## Appendix A

**HETA 94-0425**
**Gulfstream Aerospace Corp.**

**Field Data Collection Sheet**

# Assessment Sheet

**Time and Temperature**
date:________ time:________ temperature:________ RH%:________

**Worker Information**
name:_______________ number:_____ age:_____ years on job:___ smoker:____

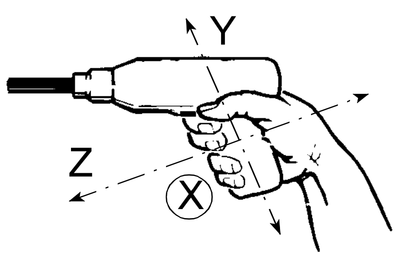
**Tool Description**
tool type:________________ number:_____________ make:________ model:________
serial number:____________ power supply:________ volts or psi:__________________
motor speed:_____________ tool age:____________ last maintenance date:_________
general condition:________ tool weight:_________ attachments:_________________

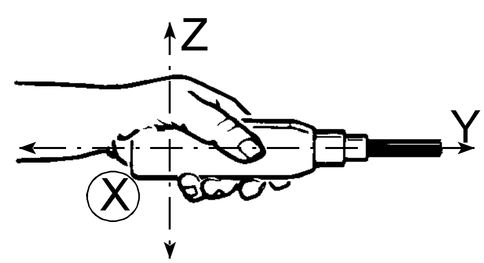
**Tool Usage**
minutes/hour:____________ hours/day:___________ days/week:___________

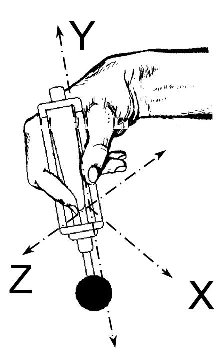
**Work Piece**
material:________________ task description:________________

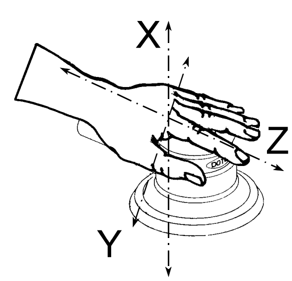
**Measurement Documentation**
event:________ clamp:________ time:________
location of triax:________ (circle the figure for coordinates and mark location of the triax)
*accelerometer assignments:* serial number direction recorder channel

| serial number | direction | recorder channel |
|---|---|---|
| ____________ | ________ | _______________ |
| ____________ | ________ | _______________ |
| ____________ | ________ | _______________ |



# Appendix C

## HETA 94-0425
## Gulfstream Aerospace Corp.

## Raw Data Tables

## Appendix D

## HETA 94-0425
## Gulfstream Aerospace Corp.

## Individual Tool Graphs of Vibration Levels