**HETA 93-0498-2409**
**MARCH 1994**
**MERCURY MARINE**
**FOND DU LAC, WISCONSIN**

**NIOSH INVESTIGATOR:**
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## I. SUMMARY

On February 2-4, 1993, investigators from the National Institute for Occupational Safety and Health (NIOSH) conducted a health hazard evaluation (HHE) at the outboard motor manufacturing facilities of Mercury Marine in Fond du Lac, Wisconsin. A November 23, 1992, request from the joint union/management team at Mercury Marine asked for assistance from NIOSH to help meet a company noise reduction goal of 82 decibels on an A-weighted scale [dB(A)]. The team felt that a reduction in plant noise would improve workers' ability to communicate, reduce stress in the work place, and improve product quality while protecting workers from occupational hearing loss.

Personal noise exposure measurements collected with noise dosimeters on eighteen employees and octave band analyses of various departments in the facility were completed over two days at the facility. The noise emitted by crankcase, block, flywheel, crankshaft, and connecting rod machining along with assembly operations were documented during the evaluation. Additional noise measurements were made at the dyno and wet test cells.

The mean 8-hour time-weighted average (TWA) noise exposure was 86.6 dB(A) [range: 80.2 to 91.8 dB(A)] for all of the operations measured at the facility. Thirteen of the eighteen dosimeter samples exceeded the NIOSH Recommended Exposure Limit (REL) of 85 dB(A). Employees were observed wearing hearing protection devices throughout the facility during production operations. Prominent noise sources included the use of compressed air in several operations and outboard motor noise generated during the wet and dyno testing operations.

**KEYWORDS:** SIC 3519 (Internal Combustion Engines, Not Elsewhere Classified), outboard marine motor manufacturing, noise dosimetry, octave-band analysis, hearing conservation, engineering controls.

## II. INTRODUCTION

On November 23, 1992, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation (HHE) from a joint union/management team at the Mercury Marine main machining and assembly facility in Fond du Lac, Wisconsin. The team members were asking for the assistance of NIOSH personnel to meet a company goal of the attainment of 82 dB(A) as an occupational noise level to which employees are exposed at the facility. The noise reduction team felt that the lower noise levels in the plant would lead to better communications, reduced stress level in workers, and a better quality product while preserving workers' hearing.

On February 2 and 4, 1993, a thorough noise survey was conducted at the Fond du Lac manufacturing facility. The survey included both personal noise dosimetry to document individual worker's daily noise exposures and area octave band analyses in various department to help identify the sources of the noise. NIOSH investigators also noted areas and operations that appeared to be sources of noise at the facility and possible controls that might be tried to help eliminate the sources. The preliminary noise data and some of the possible noise controls presented later in this report were discussed with the joint union/management noise reduction team during a closing conference on February 4, 1993.

## III. BACKGROUND

Mercury Marine's Fond du Lac, Wisconsin main machining and assembly plant produces several different models of outboard marine engines. The main operations in the plant are machining of engine parts, e.g., flywheels, powerheads, crankcases, connecting rods, and crankshafts, the assembly of the parts into a finished product, and the quality testing of every outboard engine produced at the facility before it is shipped to the customer. The facility employs approximately 1500 workers on three daily work shifts. The plant is a single story building containing many drilling, tapping, grinding, and lathe machines. Assembly of the engine parts is generally completed with compressed air driven tools. The outboard engines may be tested out of water on a dyno test cell. Every engine is placed into a water tank, started, and run through a dynamic test paradigm before being packaged for shipment.

The Mercury Marine Safety Office conducted an area noise survey of the plant in June 1992. They reported noise levels for situations when the plant was in full operation, when production operations were idle but ventilation fans were running, and when both production operations and ventilation fans were off. These point in time noise measurements were generally in the 80-87 dB(A) range when the plant was in full production. The measured noise levels dropped to a low 70 dB(A) range when production operations stopped with an additional drop of 3-6 dB(A) when ventilation systems were turned off. A copy of this noise survey's area map was provided to the NIOSH investigators.

## IV. MATERIALS AND METHODS

The personal exposure noise survey was conducted with Quest Electronics Model M-27 Noise Logging Dosimeters placed on selected employees who worked on the days of the site visit. The employees wore the units for their entire work shift. A dosimeter was suspended from the employee's waist, generally through the worker's belt, and a small remote microphone fastened near the top of the worker's shoulder to continuously monitor and record the noise exposure from the employee's daily work activities. The noise dosimeters were set at 90 decibels on an A-weighted scale [dB(A)] criterion level with a 5 dB exchange rate according to noise regulations in effect at the facility. The dosimeters were calibrated according to the manufacturer's instructions both before and after each work shift. Data collected with the dosimeters were downloaded into a laptop computer with supporting Quest M-27 Metrosoft software for later analysis.

Area noise samples were made with a Larson-Davis Laboratories Model 800B Precision Integrating Sound Level Meter. Octave band measurements at consecutive center frequencies of 31.5 Hertz (Hz) to 16 kilohertz (kHz) along with A-weighted and C-weighted scales were made in the various locations of the machining and assembly facility while they were in full operation. Octave measurements were made with the sound level meter integrating the sound energy over a 1-minute period with a 3 dB exchange rate.

## V. EVALUATION CRITERIA

Occupational deafness was first documented among metalworkers in the sixteenth century.[1] Since then, it has been shown that workers have experienced excessive hearing loss in many occupations associated with noise. Noise-induced loss of hearing is an irreversible, sensorineural condition that progresses with exposure. Although hearing ability declines with age (presbycusis) in all populations, exposure to noise produces hearing loss greater than that resulting from the natural aging process. This noise-induced loss is caused by damage to nerve cells of the inner ear (cochlea) and, unlike some conductive hearing disorders, cannot be treated medically.[2]

While loss of hearing may result from a single exposure to a very brief impulse noise or explosion, such traumatic losses are rare. In most cases, noise-induced hearing loss is insidious. Typically, it begins to develop at 4000 or 6000 Hz (the hearing range is 20 Hz to 20000 Hz) and spreads to lower and higher frequencies. Often, material impairment has occurred before the condition is clearly recognized. Such impairment is usually severe enough to permanently affect a person's ability to hear and understand speech under everyday conditions. Although the primary frequencies of human speech range from 200 Hz to 2000 Hz, research has shown that the consonant sounds, which enable people to distinguish words such as "fish" from "fist," have still higher frequency components.[3]

The OSHA standard for occupational exposure to noise (29 CFR 1910.95)[4] specifies a maximum permissible exposure limit (PEL) of 90 dB(A)-slow response for a duration of 8 hours per day. The regulation, in calculating the PEL, uses a 5 dB time/intensity trading relationship. This means that in order for a person to be exposed to noise levels of 95 dB(A), the amount of time allowed at this exposure level must be cut in half in order to be within OSHA's PEL. Conversely, a person exposed to 85 dB(A) is allowed twice as much time at this level (16 hours) and is within his daily PEL. Both NIOSH, in its Criteria for a Recommended Standard,[5] and the American Conference of Governmental Industrial Hygienists (ACGIH), in their Threshold Limit Values (TLVs),[6] propose an exposure limit of 85 dB(A) for 8 hours, 5 dB less than the OSHA standard. Both of these latter two criteria also use a 5 dB time/intensity trading relationship in calculating exposure limits.

Time-weighted average (TWA) noise limits as a function of exposure duration are shown as follows:

| Duration of Exposure (hrs/day) | Sound Level (dB(A)) NIOSH/ACGIH | OSHA |
|---|---|---|
| 16 | 80 | 85 |
| 8 | 85 | 90 |
| 4 | 90 | 95 |
| 2 | 95 | 100 |
| 1 | 100 | 105 |
| 1/2 | 105 | 110 |
| 1/4 | 110 | 115 * |
| 1/8 | 115 * | - |
| | | ** |

* No exposure to continuous or intermittent noise in excess of 115 dB(A).
** Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level.

The OSHA regulation has an additional action level (AL) of 85 dB(A) which stipulates that an employer shall administer a continuing, effective hearing conservation program when the TWA value exceeds the AL. The program must include monitoring, employee notification, observation, an audiometric testing program, hearing protectors, training programs, and recordkeeping requirements. All of these stipulations are included in 29 CFR 1910.95, paragraphs (c) through (o).

The OSHA noise standard also states that when workers are exposed to noise levels in excess of the OSHA PEL of 90 dB(A), feasible engineering or administrative controls shall be implemented to reduce the workers' exposure levels. Also, a continuing, effective hearing conservation program shall be implemented.

## VI. RESULTS

Eighteen employees from fourteen different departments in the machining and assembly facility wore noise dosimeters for an entire work shift of approximately 8 hours. The individual readouts of the dosimeter results are presented in Figures 1-18. The mean 8-hour TWA noise exposure for all employees was calculated to be 86.6 dB(A) (Table 1).

Inspection of the individual figures reveals noise exposure patterns that are characterized as being fairly steady. Employees in most of the machining areas and assembly areas had noise exposures that did not vary much throughout the work day. In fact, it is difficult to discern break times and lunch periods in the dosimeter readouts because of the invariant pattern of noise exposure. Examples of the invariant noise patterns can be seen in Figures 6, 7, 8, 12, 13, and 14. The figures represent employees working in machining departments, assembly departments, and testing departments. All six of these examples are characterized as having employee noise exposures between 80 and 90 dB(A) throughout the work shift.

Noticeable differences in the consistent noise exposure pattern were recorded in dosimeter readouts for employees who work in machining operations in Department 527 (Figure 3), Department 515 (Figure 15), and Department 516 (Figure 16). A review of the work practices and machining equipment in these departments reveals the use of compressed air in the operations. In the FMS block and crankcase machining department (Figure 3), the employee was observed using an automatic washer that cleaned the cylinder blocks with a fluid. When the cleaning operation was completed, the operator removed the part and blew the excess liquid and metal chips from the block with a compressed air hose. Because the machine pacing from the automatic washer dictates a set time cycle for the operation, the noise patterns for this worker are very rhythmic, with high peaks near 100 dB(A) and low peaks near 85 dB(A). The employees who worked in Department 516 also used compressed air hoses to clean metal parts after the machining operations were completed by the machines that they operated (Figure 16). Finally, an employee who operated a metal lathe (#04396) in Department 515 was exposed to compressed air noise from the lathe when the crankshafts were moved in and out of position in the machine.

The octave band area noise measurements are presented in Figures 19 - 32. Most of the area measurements were made in the departments where the employees wore noise dosimeters. The octave band analysis confirms that the departments where compressed air was used in an appreciable amount of the work cycle had a high frequency noise component at 4 and 8 kHz that was elevated. Examples of this finding are seen in Department 515 (Figure 21), Department 516 (Figure 24), Department 517 (Figure 29), and Department 527 (Figure 27).

In addition to the area measurements made in departments which also had personal noise dosimetry, octave band area measurements were made in locations where noise was a concern, including the wet test cell area, the Force Assembly area that had an overhead paint line, and the South Paint Line (Department 577) which was adjacent to the air compressors which supplied the compressed air to the plant. The Force Assembly area (Figure 20) was discovered to have low noise levels in all of the octave bands, with all octave bands less than 80 dB. The wet cell test area (Figure 19) and the South Paint Line (Figure 22) were found to have high sound energy in some of the measured octave bands. The sound source in the wet test cell area was the engines being tested, while the major noise source in the painting department was from the air compressors that were located below the paint booth next to the wall of the plant.

During the survey period, many of the employees were observed wearing hearing protection devices (HPDs) at their work locations. A variety of ear plugs and ear muffs were available and were worn by employees in most of the departments. Warning signs concerning excessive noise exposures were posted throughout the facility. The audiometric testing program was not audited during the NIOSH visit.

## VII. DISCUSSION AND CONCLUSIONS

The noise dosimeter survey at Mercury Marine revealed that employees in the departments that were evaluated are potentially exposed to hazardous noise levels in their jobs. The median 8-hour TWA noise value was 86.6 dB(A) for the 18 samples collected over the two days that NIOSH investigators were at the facility. Thirteen employee noise exposures exceeded the NIOSH REL for noise and the OSHA AL for hearing conservation program implementation of 85 dB(A). Three of the surveyed employees also exceeded the OSHA PEL for noise on the days of the evaluation. The maximum noise levels recorded by the dosimeters also indicated a potential for excessive noise exposure since all of the samples had noise levels that exceeded 101 dB(A), including one dosimeter sample (Department 514) that was in excess of 130 dB(A) for a very brief period of time.

It was the impression of the NIOSH investigators that a major source of noise in the plant was from the use of compressed air in various operations. The air compressors themselves are included as a source. In the machining operations, compressed air hoses and nozzles are used to clean excess metal chips and filings from parts, as well as to dry parts in other operations. There was also one example of a metal lathe in Department 515 that had a very audible compressed air noise when parts were moved in and out of this particular lathe. In the assembly operations, the compressed air was generally used to power pneumatic hand tools used to assemble outboard motors. Because of the variability of the types and ages of the different pneumatic tools, the efficiency of the mufflers on the tools also varied, resulting in some tools that were very quiet while others were very noisy when they were used. It would reduce employee noise exposures if the compressed air noise were reduced throughout the assembly plant.

The outboard motor testing areas, both the dry dyno test cells and the wet test cells, have intense noise levels that impact the employees in the adjacent areas of the facility. While the west test cell area has been isolated from other areas through the use of separate enclosures and acoustic materials lining the walls, the operations performed in the test area are loud and can be heard in adjacent areas of the building. The tests performed at the dyno test cells are also very loud, but the enclosures around the outboard engines are not as well isolated from the adjacent areas.

Management officials of Mercury Marine stressed that mobility and flexibility of the building's structure and the operations of manufacturing outboard marine engines are important limiting factors when suggesting controls for the facility, i.e., the use of permanent structures and enclosures is not encouraged because of future constraints on flexibility if the product line has to be altered or changed. This may not be a overwhelming problem for the dyno test area since a great deal of expense and alteration of the building has already been undertaken to provide the necessary piping and electrical connections for the dyno tests to the cells. As long as this kind of dry test run of an outboard engine is needed, it will very likely be done at the current location in the facility. Thus, the use of some form of a more permanent enclosure around the individual dyno test cells would reduce the noise impact on employees in the adjacent assembly departments. Also, using this same logic, the further isolation of the wet test cells from the adjacent Force assembly areas through the use of doors or acoustical panels would be possible in order to reduce the noise impact of outboard engine tests on employees in the assembly areas.

## VIII. RECOMMENDATIONS

Because of the employee noise exposures measured in excess of 85 dB(A) for an 8-hr TWA during the survey period, the NIOSH investigator is offering the following recommendations to help reduce the noise levels in the facility. Some of the recommendations are made to reduce noise that has a particularly distinct or annoying sound associated with it, but is not hazardous noise by itself. Additionally, it is recognized that management officials at Mercury Marine wish to keep the operations at this facility in an open environment to maximize the flexibility of the building's equipment and layout in case production pressures necessitate a change in the plant's general organization. Therefore, the noise control concept of isolating and enclosing specific noisy operations will not be expanded upon in this report, with the exception of the dyno test cell area.

1. In general, the movement of compressed air at Mercury Marine is a major noise source at the facility. The compressed air is used as an energy source for many tools and machines, as well as a method for cleaning engine parts. Any operation where the use of the compressed air can be eliminated will reduce the overall noise levels in the building. If the operation can use a liquid bath or stream of liquid for cleaning purposes, then the liquid cleaning should be substituted for the compressed air. If electrical hand tools are quieter and can be used instead of pneumatic tools, then they should be substituted in the assembly operations.

2. In cleaning and drying operations where the use of compressed air is necessary, the use of nozzles that have been designed for quiet air delivery should be substituted for nozzles and air hoses that are currently in use. The turbulence in the airstream caused by the rapidly moving jet of compressed air hitting the dormant ambient air in the surrounding space results in eddy currents surrounding the center core of high speed air which cause the characteristic high frequency, "hissing", noise associated with this operation. Air nozzles are available that reduce the turbulent eddie currents and can reduce the noise levels by 10 to 20 dB(A). Publications, such as the Thomas Register of American Manufacturers, can be consulted to find sources of these types of air nozzles.

3. All pneumatic hand tools should have mufflers installed that are effective in eliminating the high frequency noise emitted by the release of air from the tool. Whenever tools are in need of replacement, the purchasing department should take noise levels into account when specifications are given to the tool manufacturers.

4. The air compressors located along an outside wall of the facility at Column C-41 were observed as being a significant source of noise. In addition to the air compressors, an air drying operation for the South Paint Line was also responsible for high frequency noise emissions from the use of a compressed air hose that had no nozzle. The air compressors were located underneath a paint booth and already were ventilated because of the heat produced from the compression of the air supply. It is recommended that this area be enclosed with clear curtains that are made of acoustical materials or with a solid wall that has acoustical doors for access to the compressors. The air hose used for drying the motor covers needs to be equipped with an air nozzle with noise reducing properties.

5. Acoustical enclosures around the dyno test cells should be installed. A more permanent structure that has been designed to effectively reduce noise transmission into surrounding areas of the facility will reduce noise exposures for employees in the adjacent assembly areas more efficiently than the plexiglass/acoustic blanket enclosures that were observed during the survey. The acoustical enclosures have better transmission loss characteristics and they are always in place around an outboard engine that is being tested. The plexiglass or acoustic blanket enclosures are only effective at blocking noise when the worker takes the time to put them in place and makes sure that all covers are closed and sealed. Although this is contrary to the management's ideal of an open assembly building, a great deal of capital has already been expended to make these dyno cells operational. Even if the assembly flow of the facility is changed drastically, it is unlikely that Mercury Marine would change the location where the dry dyno test of outboard engines is conducted because of the expense associated with the relocation of the piping and electrical conduit needed to perform the tests. The fairly central location of the dyno test cells also gives the company great flexibility in changing the production flow in and around this area.

6. The specifications for the purchase of new drill presses, lathes, grinders, and other machining equipment should stipulate noise emission standards that are low enough to have little impact on the current noise environment in the plant. The noise map generated by the Mercury Marine Safety Office should be consulted to give purchasing agents an idea of the noise standard that should be specified to equipment vendors. A goal should be to purchase equipment that is at least 3-6 dB(A) less than the "full operation" sound level given in the map. This will assure that the new piece of equipment will add little or nothing to the existing noise environment of the facility. This recommendation necessitates that the noise map is updated on a periodic basis (e.g., every six months) or whenever changes are made in the production process.

7. The metal lathe (#04396) in Department 515 should be checked to see if mufflers can be added to silence the escaping air noise heard whenever the engine parts are moved to different positions in the machine. If mufflers are not available, it should then be investigated to see if the escaping air can be redirected or piped to an area where employees are not likely to be located during normal operations. This particular lathe should be marked for replacement with a quieter machine when capital becomes available.

8. All hearing conservation program efforts at Mercury Marine should be continued at a level that meets the requirements set forth in OSHA's noise regulation.[4] The company should also consider new audiometric database analysis techniques that have been recently developed to obtain feedback concerning the effectiveness of the hearing conservation program and its various elements.[7-11]

## IX. REFERENCES

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## X. INVESTIGATORS AND ACKNOWLEDGEMENTS


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1. Safety Manager, Mercury Marine
2. Union Representative, International Association of Machinists, Local 1947
3. OSHA Region V

**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.**

TABLE 1
Noise Dosimeter Survey Results
Mercury Marine
Fond Du Lac, Wisconsin
HETA 93-0498
February 2-4, 1993

| DEPARTMENT | SAMPLING TIME [hh:mm] | 8-hr TWA [dB(A)] | MAXIMUM RMS LEVEL [dB(A)] | COMPANY'S JUNE 23, '93 NOISE SURVEY[1] |
|---|---|---|---|---|
| 523 | 07:47 | 86.5 | 109.1 | 85 |
| 527 | 07:44 | 85.4 | 113.3 | 88 |
| 527 | 07:40 | 91.8 | 117.4 | 88 |
| 517 | 07:31 | 90.1 | 115.9 | 85 |
| 519 | 07:25 | 88.1 | 105.8 | 87 |
| 567 | 07:31 | 84.6 | 109.5 | 83 |
| 567 | 07:29 | 83.6 | 113.3 | 83 |
| 578 | 07:17 | 86.6 | 115.9 | 81 |
| 575 | 07:16 | 83.8 | 112.9 | 78 |
| 575 | 07:55 | 80.2 | 118.5 | 78 |
| 467 | 07:58 | 86.6 | 121.1 | 83 |
| 569 | 07:52 | 83.5 | 101.6 | 84 |
| 524 | 08:03 | 87.7 | 110.3 | 86 |
| 515 | 07:53 | 85.3 | 109.9 | 85 |
| 515 | 07:47 | 91.4 | 119.3 | 85 |
| 516 | 07:41 | 89.3 | 111.8 | 86 |
| 514 | 07:41 | 86.6 | 130.5 | 85 |
| 506 | 07:40 | 86.9 | 115.5 | 86 |

[1] For cases where the company reports more than one noise level per department, the highest noise level is recorded in the table. The nearest adjacent department's noise levels are recorded where no measurement is given. The "full plant operation" figure is given in all cases.