

Evaluation of the Sideswipe™ Exhaust System to Reduce Carbon Monoxide Exposure during Motor Boating and Wake Surfing

(Yosemite Lake, Merced, California)

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REPORT DATE:

December 2005

REPORT NO.:

171-37a

MANUSCRIPT PREPARED BY:

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Public Health Service
Centers for Disease Control and Prevention
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Survey Sites: Yosemite Lake in Merced, California

SIC Code: N/A

Survey Dates: August 24 and 25, 2004

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Employee Representatives Contacted: None

Manuscript Edited by: Diana Campbell

DISCLAIMER

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EXECUTIVE SUMMARY

Under an interagency agreement with the United States Coast Guard, National Institute for Occupational Safety and Health (NIOSH) researchers evaluated carbon monoxide (CO) emissions and exposures from two 2005 Centurion Avalanche ski boats equipped with carbureted inboard engines. One of the boats evaluated was equipped with the Sideswipe exhaust system, while the other was equipped with transom stern exhaust. In the Sideswipe exhaust system the engine exhaust is discharged from the sides of the boat instead of the stern.

This investigation builds upon a series of recent studies to reduce CO exposures and poisonings on houseboats and other recreational boats. Epidemiologic studies have found that from 1990 to 2004, there have been approximately 540 CO poisonings associated with exhaust from gasoline-powered marine engines on recreational boats. Two hundred and twenty-five of the poisonings occurred on non-houseboats (other types of recreational boats).

This study was performed for the U.S. Coast Guard for three purposes: to serve as an independent evaluation of the Sideswipe exhaust system, to gather additional data building upon previous studies related to CO concentrations and exposures near ski boats operating under various conditions, and to collect personal exposure data on an individual performing wake surfing. Ski boats, one with Sideswipe exhaust and one with stern exhaust, were evaluated both while stationary and while moving at multiple speeds ranging from 2.5 to 20 miles per hour (mph). CO concentrations were measured by multiple real-time instruments, placed at different locations on the boats and at various distances (10 to 60 feet) behind the boat in motion.

Study results indicated that CO concentrations on the boat were generally highest while the boat was stationary. CO concentrations were lower when the boat was underway and decreased as boat speed and distance from the boat increased. CO concentrations were highest near the water surface and decreased as height above the water increased. The Sideswipe exhaust system significantly reduced CO concentrations (by 60- 90%) on and behind the boat when operating at speeds of 10 mph or greater. When the boat was stationary or operating at speeds below 10 mph (i.e. slow no-wake speeds), CO reductions were mixed. Average personal CO exposures to a wake surfer (located approximately ten feet behind the boat and slightly off center) were approximately 17 parts per million (ppm) and the Sideswipe system was able to reduce exposures to approximately 3 ppm.

CO concentrations measured 10 to 60 feet behind the boat were relatively low with or without the Sideswipe system. One particular area of concern relates to towed water sports activities where people could be near the boat, operating at slow speeds, and near the water (such as some tubing activities). The Sideswipe system may be beneficial in helping to reduce CO exposures to individuals involved in a variety of towed water sports activities. Further research is warranted to provide a better understanding of the CO reduction mechanisms.

BACKGROUND

On August 24 and 25, 2004, researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted an evaluation of carbon monoxide (CO) emissions and exposures on two gasoline-powered, inboard ski boats, one equipped with Sideswipe™ exhaust and the other with transom stern exhaust. The Sideswipe exhaust is a recently developed device that emits the engine exhaust fumes from the side of the boat instead of the stern. The manufacturer has collected data showing that this device effectively redirects CO from the vicinity of the stern of the boat, as well as numerous distances behind the boat [IMANNA, 2004]. The current evaluation of two ski boats, one with Sideswipe exhaust and the other with transom stern exhaust, occurred on Yosemite Lake in Merced, California.

This evaluation was intended to:

- 1) Serve as an independent evaluation of the Sideswipe exhaust ability to reduce CO exposures.
- 2) Provide a better understanding of how CO concentrations change at various speeds, distances, and heights behind a ski boat, and
- 3) Provide personal CO monitoring for individuals performing wake surfing.

This evaluation was conducted under an interagency agreement between the U.S. Coast Guard's Office of Boating Safety and NIOSH to reduce CO emissions and exposures that occur on recreational boats used in the United States. This report provides background information and describes the NIOSH study methods, results, discussion, conclusions, and recommendations.

Prior Studies Looking at CO Exposure behind ski boats

NIOSH Studies

In spring 2002, working with the United States Coast Guard, NIOSH researchers analyzed the carbon monoxide emissions and exposures on approximately twenty-five recreational boats in Nevada, Arizona, and North Carolina. The evaluated recreational boats (spanning from new to 27 years old) including ski boats, cabin cruisers, deck boats, fishing boats, and personal watercraft, all used gasoline-powered propulsion engines. Many of the cabin cruisers also used gasoline-powered generators to provide electricity.

Air sampling for CO was performed for both stationary and underway boats with speeds ranging from 2.5 to 25 mph. Electrochemical CO monitors were placed at various locations inside and on the stern of the boat. Additional monitors were located 8 to 12 feet behind the boat.

Under stationary conditions, the CO concentrations were relatively high. ToxiUltra monitor measurements ranged from 500 to 1,000 ppm at the stern and less than 20 ppm in the interior of most boats. Cabin cruiser measurements ranged from 800 to 1,000 ppm on the lower deck and less than 15 ppm in the interior. (The upper limit for the ToxiUltra CO monitors is approximately 1,000 ppm and may have been exceeded at times.) CO concentrations were significantly lower

when the boat was moving than when stationary. The highest concentrations were at the boats' stern and lowest in the interior of the boat. CO concentrations were lower on boats with cleaner burning outboard engines and with increasing boat and wind velocities.

Approximately 90% of the boats evaluated in this study had potentially hazardous CO concentrations. The authors recommended use of cleaner burning outboard engines, catalyst development for gasoline-powered, inboard or stern-drive engines, care when operating the boats below 5mph, and alternative ventilation systems for generator exhaust such as the vertical stack.

USCG/ABYC Carbon Monoxide Safe Distance Study

In the fall of 2003, the United States Coast Guard and American Boat and Yacht Council (USCG/ABYC) conducted a subsequent study of CO exposures from a single gasoline powered ski boat. The study was designed to determine the minimum safe distance to tow people behind an engine that generated a relatively large, representative quantity of CO. Tests were conducted using a 19-foot Correct Craft ski boat having a 350 cubic inch V-8 carbureted inboard engine. The ski boat towed a 10.5 ft Boss Boat Hardbody equipped with two ToxiUltra CO detectors at two and five feet above the water.

The main test variables were boat speed and distance from the stern. Data were not collected when wind speeds exceeded 5mph. Concentration levels of CO were recorded at boat speeds of 7.5, 10, 20 and 25 mph and distances of 20, 40, 60, and 80 ft behind the transom of the tow boat. Problems with survey measurements prevented taking data when boat speeds exceeded 10mph at distances less than 60 ft.

The study showed that CO concentrations were the highest above the stern seat of the ski boat, near the water, and at slow boat speeds. The CO concentrations were greater at 2 feet compared to 5 feet above the water. CO concentrations were highest at 20 ft behind the tow boat. At distances beyond 20 ft the CO concentrations remained consistent at approximately 35 ppm with the exception of great distances. At great distances the CO levels increased as the boat speeds increased. In general, highest CO concentrations were at the ski boat's stern seat, at 2 ft above the water, and at distances of 20 feet or less. There was no need for concern at 5 feet above the water level at distances of 60 feet and beyond. CO concentrations at this level were low enough for the safe enjoyment of recreational water sport activities.

Sideswipe CO Study

In April 2004, Fineline Industries contracted Intermodal Matériel and Nautical/Nuclear Analysis Imanna Laboratory, Inc. to measure CO concentrations at various points aft of boats during operation. Three boat configurations were tested: a Centurion Avalanche v-drive with conventional exhaust at the transom; a Centurion Avalanche v-drive with Sideswipe exhaust; and a Centurion Thunder direct drive with after market Sideswipe exhaust. The Sideswipe exhaust system vents the engine exhaust to the side of the boat rather than from the transom. The exhaust can be released from either side or from both sides. All three boats evaluated had 5.7 liter multiple port injector engines.

The CO concentrations were measured by two different meters during the testing. One meter

was a continuous logging type which records the instantaneous CO concentrations over the sample time and prints a mean concentration of the samples taken each ten seconds for record purposes. The other meter was a digital display only meter that must be visually monitored for manual recording. The logging meter had an upper limit of 1000 ppm of CO in the air and the non-logging meter had a 2000 ppm upper limit. CO measurements made 20 ft. and closer to the test boat were performed by attaching one end of a sampling tube to the CO meter and the other end of the sampling tube to a telescoping pole. CO measurements made more than 20 ft. from the boat were taken using a chase boat behind the test boat with someone holding the CO meter in the test position. Measurements were made in the center of the wake, 12° to 15°, and 25° to 30° both port and starboard of the center of the wake in increments of 2 ft.

Towed Water Sports Activities

There are a variety of towed water sports activities in which CO exposures may occur. CO exposures are related to the distance behind the boat, height from the water, and operating speed. The most common of these sports, depicted in Figure 1, are tubing, teak surfing, water skiing, wakeboarding, wake surfing, and knee boarding. A brief description of these common towed water sports activities is provided below.

Tubing: The rider(s) sits in a rubber inner tube and is towed along by a rope that is attached to a vessel. For tubing, the ideal tow rope is approximately 60 feet long. Tubing often consists of one or two persons riding simultaneously (each with a separate tube and tow rope).

Waterskiing: Waterskiing is similar to tubing except the rider wears skis and glides over the water in a standing position. The average tow rope length for waterskiing is about 70 to 75 feet. Water-ski ropes are generally made from polypropylene which, under a normal skiing load, can stretch from 2 to 3 percent of its original length.

Wakeboarding: Wakeboarding is a form of waterskiing in which the rider's feet are bound to a board rather than attached to skis. The rider stands in an upright position on the board with both feet pointing off the side of the board. The average tow rope length is 70 to 75 feet.

Wake Surfing: In this sport the rider is initially towed by a rope of various lengths that is attached to a weighted vessel. Once the desired wave is created by the vessel and the rider is balanced on his/her surfboard, the tow rope is tossed into the boat or on the opposite side of the wave. The rider then proceeds to surf the wave often approximately 10 feet behind and slightly to the side of the boat.

Knee boarding: A sport similar to waterskiing except the rider kneels on a fiberglass board rather than standing on skis. The length of the average tow rope is approximately 60 to 70 feet.

Teak Surfing: Teak surfing has been banned in many areas because it is extremely hazardous. In teak surfing or "platform dragging" there is no rope. The rider holds on to the swim platform of a vessel until the desired wake or wave forms. Once the desired wave has formed, the rider (or body surfer) releases the grip on the swim platform and proceeds to ride the wave on his/her stomach, within a few feet of the back of the boat.

Carbon Monoxide Symptoms and Exposure Limits

CO is a lethal poison produced when fuels such as gasoline or propane are burned. It is one of many chemicals found in engine exhaust which result from incomplete combustion. Because CO is a colorless, odorless, and tasteless gas, it may overcome the exposed person without warning. The initial symptoms of CO poisoning may include headache, dizziness, drowsiness, or nausea. Symptoms may advance to vomiting, loss of consciousness, and collapse if prolonged or high exposures are encountered. If the exposure level is high, loss of consciousness can occur without other symptoms. Coma or death can occur if high exposures continue [NIOSH 1972; NIOSH 1977; NIOSH 1979]. The display of symptoms varies widely from individual to individual, and may occur sooner in susceptible individuals, such as young or aged people, people with preexisting lung or heart disease, or those living at high altitudes [Proctor, Hughes, et al. 1988; ACGIH 1996; NIOSH 2000].

Exposure to CO limits the ability of blood to carry oxygen to tissues because it binds with the hemoglobin to form carboxyhemoglobin (COHb). Blood has an estimated 210 to 250 times greater affinity for CO than oxygen; thus, the presence of CO in the blood interferes with oxygen uptake and delivery to the body [Forbes, Sargent, et al. 1945].

Although NIOSH typically focuses on occupational safety and health issues, the Institute is a public health agency and cannot ignore the overlapping exposure concerns between marine workers and boat passengers in this type of setting. NIOSH researchers have done a considerable amount of work related to controlling CO exposures in the past [Ehlers, McCammon, et al. 1996; Earnest, Mickelsen, et al. 1997; Kovein, Earnest, et al. 1998].

Exposure Criteria

Occupational exposure limits should not be used for general population exposures (such as visitors engaged in boating activities). The effects of CO are more pronounced in a shorter time if the person is physically active, very young, very old, or has preexisting health conditions such as lung or heart disease. Persons at extremes of age and persons with underlying health conditions may have marked symptoms and may suffer serious complications at lower levels of carboxyhemoglobin. Standards relevant to the general population take these factors into consideration, and are listed following the occupational criteria.

The NIOSH Recommended Exposure Limit (REL) for occupational exposures to CO gas in air is 35 ppm for a full shift time-weighted average (TWA) exposure, and a ceiling limit of 200 ppm, which should never be exceeded [CDC 1988; CFR 1997]. The NIOSH REL of 35 ppm is designed to protect workers from health effects associated with COHb levels in excess of 5% [Kales 1993]. NIOSH has established the immediately dangerous to life and health (IDLH) value for CO as 1,200 ppm [NIOSH 2000]. The American Conference of Governmental Industrial Hygienists (ACGIH) recommends an 8-hour TWA threshold limit value (TLV) for occupational exposures of 25 ppm [ACGIH 1996] and discourages exposures above 125 ppm for more than 30 minutes during a workday. The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for CO is 50 ppm for an 8-hour TWA exposure (CFR 1997).

Health Criteria Relevant to the General Public

The U.S. Environmental Protection Agency (EPA) has promulgated a National Ambient Air Quality Standard (NAAQS) for CO. This standard requires that ambient air contain no more than 9 ppm CO for an 8-hour TWA, and 35 ppm for a 1-hour average [EPA 1991]. The NAAQS for CO was established to protect the most sensitive members of the general population by maintaining increases in carboxyhemoglobin to less than 2.1%.

The World Health Organization (WHO) has recommended guideline values and periods of time-weighted average exposures related to CO exposure in the general population [WHO 1999]. WHO guidelines are intended to ensure that COHb levels not exceed 2.5% when a normal subject engages in light or moderate exercise. Those guidelines are:

100 mg/m³ (87 ppm) for 15 minutes

60 mg/m³ (52 ppm) for 30 minutes

30 mg/m³ (26 ppm) for 1 hour

10 mg/m³ (9 ppm) for 8 hours

METHODS

Description of the Evaluated Boat and Engineering Control

Two boats were used during the evaluation of the Sideswipe exhaust system. Both boats were 2005 Centurion Avalanche with V-drive and a 350 cubic inch Chevy block 315 horsepower multiple port injection engine and used 89 octane gasoline. One of the boats had traditional transom exhaust as shown in Figure 2 while the other had Sideswipe exhaust with exhaust outlets on both sides of the boat as show in Figure 3. Using a valve, the engine exhaust could be directed to either or both sides of the boat. The evaluation was conducted over two days. On the first day of the evaluation the Sideswipe exhaust valve was set to exhaust from both sides of the boat. On the second day of the evaluation, the Sideswipe exhaust valve was set to exhaust on the starboard side of the boat.

Description of the Evaluation Equipment

CO concentrations were measured at various locations on and behind the boats (on a towed Zodiac inflatable boat) as shown in Figures 4. CO measurements were made using ToxiUltra Atmospheric Monitors (Biometrics, Inc.) equipped with CO sensors. CO and nitrogen dioxide (NO₂) concentrations were measured during wake surfing by a PhD Ultra Gas Detector (Biometrics, Ins.) ToxiUltra CO and PhD Ultra Gas Detector monitors were calibrated before and after use, according to the manufacturer's recommendations. These monitors are direct-reading instruments with data logging capabilities.

The ToxiUltra monitors were operated in the passive diffusion mode using a 30 second sampling interval. The nominal range of the ToxiUltra monitors is from 0 ppm to approximately 999 ppm. The PhD Ultra Gas Detectors operated the same as the ToxiUltra monitors except the air was drawn to the monitor by a pump calibrated at 1.5 liters per minute. During wake surfing

sampling, tubing from the PhD monitor was extended out to the person who was wake surfing.

During air sampling, NIOSH researchers also measured wind velocity when the boat was stationary or underway by using a VelociCalc Plus Model 8360 air velocity meter (TSI Inc., St. Paul, MN).

Description of Procedures

Air sampling for CO and wind-velocity measurements were collected at various locations and under various conditions. CO measurements were made while both boats were idling, traveling at speeds of 5, 10, and 15 mph towing a Zodiac inflatable boat at distances of 20, 40, and 60 feet behind the boat on the first day of sampling. CO monitors were fixed to a vertical pole mounted on the boat at heights of 2, 3, and 5 ft. above the water. On the second day of the evaluation, CO concentrations behind both boats traveling at speeds of 5, 10, and 15 mph were measured by holding a CO monitor at the bow of a chase boat (Figure 5). CO concentrations were measured 20 and 40 feet directly behind the boat, 45° behind the boat on both the starboard and port sides of the boat. Also, during the second day of the evaluation, CO concentrations were measured on a person who was wake surfing behind both boats. A PhD Ultra Gas detector was used to measure the CO concentrations on the wake surfer and was mounted along the stern of the boat. It was used to pump air through a small flexible tube that was held near the breathing zone of individuals who were wake surfing (Figure 6). The boat was typically traveling at 10 mph or slightly less during wake surfing.

RESULTS

Results of Air Sampling with ToxiUltra CO Monitors

Monitors were placed at various locations on the boats to approximate passenger position during operation. Because CO emissions originate from engine exhaust near the stern of the boat, multiple CO monitors were placed in this area. Summary statistics for the data collected for both days with the ToxiUltra CO and PhD Ultra Gas monitors are shown in Appendix A. For each sample location and condition, mean CO concentration, standard deviation, number of 30-second CO measurements and peak CO concentration summary statistics are shown. Comparisons were made between the mean CO concentrations for the Sideswipe exhaust boat to the transom exhaust boat.

ToxiUltra CO Samples While the Boat was Stationary

Table 1A provides the summary statistics for CO concentrations on the stationary boats with engines idling during the first day of the evaluation when the Sideswipe exhaust valve was set for both sides of the boat. Performance of the Sideswipe system under these conditions varied. Comparison between CO concentrations taken at the bow and middle positions on both the port and starboard sides on the transom and Sideswipe exhaust boats was not possible due to monitor failure on the transom exhaust boat. The mean CO concentration was 16% greater near the port side of the stern, 17% greater near the middle of the stern, and 31% lower on the starboard side of the stern for the Sideswipe exhaust boat compared to the transom exhaust boat.

Table 1B provides the summary statistics for CO concentrations on the stationary boats with the engines idling during the second day of the evaluation when the Sideswipe exhaust valve was set for the starboard side of the boat. Comparison between the transom exhaust and the Sideswipe exhaust at positions at the bow, middle position on the port side, and stern port side were not possible due to monitor failure on the stern exhaust boat. Mean CO concentrations measured on the Sideswipe boat were 19% greater near the middle of the starboard side and 6% greater near the middle of the stern when compared to the transom exhaust boat. CO concentrations were 83% lower near the stern starboard side of the Sideswipe exhaust boat compared to the transom exhaust boat.

ToxiUltra CO Samples while the Boat was Underway (5 mph)

Air sampling data was collected while the boat was underway to simulate towed water sports activities. Summary statistics comparing CO concentrations between the boat with transom exhaust and the boat with Sideswipe exhaust (with the exhaust valve set to exhaust out both sides of the boat at a speed of 5 mph) are shown in Table 2A. Mean CO data trends behind the transom exhaust boat is shown in Figure 7 and comparison of CO data between transom exhaust and Sideswipe exhaust with exhaust coming from both sides of the boat is shown in Figure 8. Generally, the performance of the Sideswipe exhaust system with the exhaust set for both sides at this speed varied. The mean CO concentration at the front of the passenger compartment of the boat on the port side was 4.47 ppm with the transom exhaust and 7.65 ppm with the Sideswipe exhaust. Mean CO concentrations on the port side near the middle of the boat were 1.86 ppm with transom exhaust and 5.72 ppm with the Sideswipe exhaust. The mean CO concentration was not available near the middle of the starboard side of the transom exhaust boat due to monitor failure and was 6.73 ppm with the Sideswipe exhaust boat. The mean CO concentration near the middle of the stern was 21.6 ppm with the transom exhaust and 11.7 ppm with the Sideswipe exhaust. The mean CO concentration near the stern on the port side was 10.1 ppm with the transom exhaust and 21.2 ppm with the Sideswipe exhaust. The mean CO concentration on the starboard side near the stern was 45.8 ppm with the transom exhaust and 15.7 ppm with the Sideswipe exhaust.

As shown in Figure 7, mean CO concentrations behind the transom exhaust boat fell between 20 feet and 40 feet behind the boat, but for all three heights measured above the water, the mean CO concentration increased between 40 feet and 60 feet. Figure 8 shows that the Sideswipe exhaust system with the exhaust valve set to exhaust from both sides of the boat had mixed results. Mean CO concentrations measured 2 ft. above the water were 70% higher at 20 feet and 170% higher at 40 feet behind the Sideswipe boat compared to the transom exhaust boat. At 60 ft. behind the Sideswipe boat, the CO concentration decreased by 13%. Mean CO concentrations measured 3 ft. above the water were 77 % higher at 20 feet and 107% higher at 40 feet behind the Sideswipe boat compared to the transom exhaust boat. There was a decrease of 32% when comparing the mean CO concentration for Sideswipe to transom exhaust at 60 ft. Mean CO concentrations measured 5 ft. above the water were 8.0% and 66% lower at 20 and 60 ft. behind the boat, respectively, for the Sideswipe boat compared to the transom exhaust boat. At 40 ft. behind the boat, there was a slight increase of 6% when the comparison was made. The peak CO concentration measured using the Zodiac 20 feet behind the transom exhaust boat was 39 ppm at

2 ft. above the water. The peak CO concentration measured using the Zodiac at 60 feet behind the boat with the Sideswipe exhaust on both sides was 56 ppm at 2 ft. above the water.

Summary statistics comparing CO concentrations between the transom exhaust boat and Sideswipe exhaust boat exhausting out the starboard side at 5 mph are shown in Table 2B and illustrated in Figure 9. Measurements were made behind the boats using a CO monitor held at the bow of a chase boat. The chase boat was positioned directly behind the boat and at a 45° angle to the starboard or port side at 20 and 40 ft. At 20 ft. directly behind the boat, the mean CO concentration was 213% greater for the Sideswipe exhaust boat than the transom exhaust boat. The mean concentration was 20% greater for the Sideswipe exhaust boat at 20 ft. and 45° port when compared to the stern exhaust boat. The mean CO concentration was reduced by 55% behind the Sideswipe exhaust boat at 20 ft. and 45° starboard compared to the transom exhaust boat. At 40 ft. directly behind the boat, the mean CO concentration was reduced 3% for the Sideswipe exhaust. The mean CO concentration was 21% greater behind the Sideswipe exhaust boat at 40 ft. and 45° port side compared to the transom exhaust boat. The mean CO concentration was reduced by 29% for the Sideswipe exhaust at 40 ft. and 45° starboard compared to the transom exhaust.

ToxiUltra CO Samples while the Boat was Underway (10 mph)

Summary statistics for the stern exhaust and Sideswipe exhaust boats traveling at 10 mph with the Sideswipe exhaust vented to both sides are listed in Table 3A. The Zodiac could not be towed in the centerline 10 ft. behind the boat at 10 mph due to wake turbulence. The mean CO concentration at the front of the passenger compartment on the port side was 5.33 ppm for Sideswipe exhaust and 3.67 ppm for transom exhaust. Mean CO concentrations measured in the middle of the boat on the starboard side were 3.13 ppm for Sideswipe and 1.28 ppm for transom exhaust. At the stern middle of the boat, the mean CO concentration was 52.7 ppm for the transom exhaust and 11.4 ppm for the Sideswipe exhaust. At the stern port side of the boat, the mean CO concentration was 4.00 ppm for the transom exhaust and 12.4 ppm for the Sideswipe exhaust. At the stern starboard side of the boat, the mean CO concentration was 21.9 ppm for the transom exhaust and 6.71 ppm for the Sideswipe exhaust. Peak CO concentrations measured at the stern were 336 ppm for the transom exhaust boat and 48 ppm for the Sideswipe exhaust boat.

As shown in Figure 10, CO concentrations behind the transom exhaust boat fell between 40 and 60 feet behind the boat. No CO measurements were available 20 feet behind the boat due to monitor failure. Figure 11 shows that the Sideswipe exhaust system set to exhaust from both sides had mixed results. Mean CO concentrations measured 2 ft. above the water were 1% higher at 40 feet and 30% lower at 60 feet behind the Sideswipe exhaust boat compared to the transom exhaust boat. For CO measured 3 ft. above the water, decreases of 2% and 33% at 40 and 60 ft. behind the boat, respectively, were found. For CO concentrations 5 ft. above the water, increases of 33% and 24% were measured at 40 and 60 ft. behind the boat, respectively, when comparing the Sideswipe boat to the transom exhaust boat. The peak CO concentration measured behind the transom exhaust boat was 73 ppm 2 ft. above the water and 60 ft. behind the boat. The peak CO concentration was 69 ppm at 2 ft. above the water and 20 ft. behind the Sideswipe exhaust boat.

Summary statistics comparing CO concentrations between the transom exhaust boat and Sideswipe exhaust boat exhausting out the starboard side at a speed of 10 mph are shown in Table 3B and illustrated in Figure 12. Measurements were made using a CO monitor held at the bow of a chase boat. The chase boat was positioned directly behind the boat and at a 45° angle to either the starboard or port side of the boat at distances of 20 and 40 ft. At 20 ft. directly behind the boat, the mean CO concentration was decreased by 18% behind the Sideswipe exhaust boat. The mean CO concentration behind the Sideswipe exhaust boat was equal to the concentration behind the transom exhaust boat at 20 ft. and 45° port side behind the boat. The mean CO concentration was reduced 17% behind the Sideswipe exhaust boat at 20 ft. and 45° starboard side behind the boat compared to the transom exhaust boat. No comparisons could be made at 40 ft. behind the boat due to monitor failure on the Sideswipe boat.

ToxiUltra CO Samples while the Boat was Underway (15 mph)

Summary statistics for CO concentrations for the Sideswipe exhaust and stern exhaust boats while traveling 15 mph are listed in Table 4A. The Zodiac could not be towed as close as 10 ft. behind the boat at 15 mph. The mean CO concentration at the front of the passenger compartment on the port side with the transom exhaust was not available due to monitor failure and was 4.44 ppm with the Sideswipe exhaust. The mean CO concentration near the middle of the boat on the starboard side was 0.9 ppm for the transom exhaust and 3.2 ppm with the Sideswipe exhaust. The mean CO concentration near the center of the stern was 11.4 ppm for the transom exhaust and 10.1 ppm for the Sideswipe exhaust. The mean CO concentration near the port side of the stern was 5.4 ppm for transom exhaust and 11.8 ppm for the Sideswipe exhaust. The mean CO concentration near the starboard side of the stern was 11.8 ppm for transom exhaust and 9.3 ppm for the Sideswipe exhaust. Peak CO concentrations measured at the stern were 64 ppm for the transom exhaust and 41 ppm for the Sideswipe exhaust.

Figure 13 shows that mean CO concentrations measured with the Zodiac increased with distance from the boat and height above the water. Increases in mean CO concentrations at 40 ft. behind the boat and 2, 3.5, and 5 ft. above the water were between 10 and 22% when comparing Sideswipe exhaust to transom exhaust (Figure 14). Decreases in mean CO concentrations at 60 ft. behind the boat and 2, 3.5, and 5 ft. above the water were between 14 and 72% when comparing Sideswipe exhaust to transom exhaust. The peak CO concentration measured on the Zodiac was 68 ppm 2 ft. above the water and 40 ft. behind the boat with transom exhaust. The peak CO concentration measured on the Zodiac was 79 ppm 2 ft. above the water and 20 ft. behind the boat with Sideswipe exhaust. No CO measurements were available on the Zodiac 20 ft. behind the stern exhaust boat due to monitor failure.

Summary statistics for comparing CO concentrations between the stern exhaust boat and Sideswipe exhaust boat with the exhaust valve set for exhausting out the starboard side at 15 mph are shown in Table 4B and illustrated in Figure 15. Measurements were made using a CO monitor at the bow of a chase boat. The chase boat was positioned directly behind the boat and at a 45° angle to either the starboard or port side of the boat at 20 and 40 ft. At 20 ft. directly behind the boat, the mean CO concentration decreased 45% behind the Sideswipe exhaust boat compared to the transom exhaust boat. The mean CO concentration increased 850% behind the Sideswipe exhaust boat at 20 ft. and 45° port side compared to the transom exhaust boat. The

mean CO concentration was reduced 35% behind the Sideswipe exhaust boat at 20 ft. and 45° starboard side compared to the transom exhaust boat. No comparisons could be made at 40 ft. behind the boat due to monitor failure while behind the Sideswipe exhaust boat.

ToxiUltra Personal CO Samples while Wake Surfing (10 mph)

Summary statistics for CO concentrations behind the transom exhaust boat and behind the Sideswipe exhaust boat at various locations on the boat and on individuals who were wake surfing are listed in Table 5. The Sideswipe exhaust was set to exhaust on the starboard side. The boat typically travels at approximately 10 mph to produce the desired wake size for surfing, and the surfer rides on the port side of the boat. For the CO measurements collected in the middle of the boat on the starboard side, the mean CO concentration was 13.1 ppm behind the Sideswipe exhaust boat compared to 2.5 ppm behind the transom exhaust boat. At the middle of the stern, the mean CO concentration was 685 ppm for the stern exhaust boat and 68.2 ppm for the Sideswipe exhaust boat. At the starboard side of the stern of the boat the mean CO concentration was 247 ppm for the transom exhaust boat and 50.6 ppm for the Sideswipe exhaust boat. Peak CO concentrations of 998 ppm were measured at the stern of the transom exhaust boat compared to 212 ppm for the Sideswipe exhaust boat. The mean CO exposure measured on a wake surfer was 1.82 ppm behind the Sideswipe exhaust boat and 105 ppm behind the transom exhaust boat. The peak CO exposure to the wake surfer was 832 ppm behind the transom exhaust and 5 ppm behind the Sideswipe exhaust boat.

Environmental Measurements

Ambient air temperature and relative humidity measurements were periodically take throughout the two days of CO monitoring. During two days of sampling, the mean ambient air temperature was 34°C and ranged from 29° to 37°C. Average relative humidity was 30% and ranged from 20% to 40%.

DISCUSSION AND CONCLUSIONS

The mean CO concentrations measured on or behind the evaluated ski boat were similar to results from previous evaluations by Echt et al. 2003, Earnest et al. 2003, the U.S. Coast Guard (USCG/ABYC 2003), Mann (Mann_2004), and Marlow et al. 2004. The highest CO concentration measured on the boats was at the stern. Peak CO concentrations at the stern of the idling boat were 1089 ppm for the transom exhaust boat and 153 ppm for the Sideswipe exhaust boat with the exhaust from both sides of the boat, and 154 ppm with the exhaust from the starboard side. Peak CO concentrations at the stern of the boat while traveling at 5 mph were 382 ppm for the transom exhaust boat and 163 ppm for the Sideswipe boat exhausting from both sides of the boat and 111 ppm exhausting from the starboard side. Peak CO concentrations at the stern of the boat while traveling at 10 mph were 336 ppm for the transom exhaust boat and 48 ppm for the Sideswipe boat exhausting from both sides of the boat and 242 ppm exhausting from the starboard side. Peak CO concentrations at the stern of the boat while traveling at 15 mph were 226 ppm for the transom exhaust boat and 41 ppm for the Sideswipe boat exhausting from both sides of the boat and 72 ppm exhausting from the starboard side. All of the CO

concentrations for transom exhaust boat at various speeds exceeded the NIOSH REL of 200 ppm ceiling, while none of the CO concentration for the Sideswipe exhaust boat whether exhausting from both sides or from the starboard side exceeded this REL.

At all speeds the CO concentrations behind the boat were mixed with the CO concentration being higher behind the transom exhaust boat while on other occasions being higher behind the Sideswipe boat. Whether the Sideswipe exhaust was set to exhaust from both sides of the boat or from the starboard side of the boat didn't seem to make any difference when comparing CO concentrations to those measured behind the transom exhaust boat. Lake Yosemite was a very small lake and numerous passes across the same course traveled previously were made and may have contributed to the mixed results.

The wake surfer's CO exposures were reduced by 99% when wake surfing behind the Sideswipe exhaust boat on the starboard side and the exhaust on the port side when compared to wake surfing behind the transom exhaust boat. This reduction in CO exposure to the wake surfer was statistically significant ($\alpha < 0.05$). The mean CO concentration for the wake surfer was 237 ppm exceeding the NIOSH REL ceiling limit of 200 ppm.

Mean CO concentration measured behind the boat show that at all speeds and distances from the boat the CO concentration decreases with height above the water surface. None of the mean CO concentrations measured at various distances from the boat exceeded the World Health Organization (WHO) guideline of 87 ppm for 15 minutes.

The Sideswipe exhaust system significantly reduced CO exposures to the wake surfing during the current evaluation. Mixed results were found when comparing mean CO concentrations on and behind the Sideswipe exhaust boat in either both sides exhaust or port side exhaust to the transom exhaust boat. Further testing should be conducted on a large lake where cross contamination from previous boat passes can be avoided.

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Appendix A
Sideswipe Exhaust System Evaluation Summary Data
Yosemite Lake
Merced, California
August 24 and 25, 2004

Sample Date	Monitor Number	Monitor Location	Number of Samples	Mean CO Conc. (ppm)	SD CO Conc. (ppm)	Max CO Conc. (ppm)	Boat Speed (mph)	Boat Direction	Distance from Boat (ft.)	Exhaust System Type
8/24/2004	3628	Red boat, bow, starboard passenger seat	40	8.30	3.83	23	5	north		Sideswipe
8/24/2004	3628	Red boat, bow, starboard passenger seat	60	7.22	7.42	44	5	south		Sideswipe
8/24/2004	3628	Red boat, bow, starboard passenger seat	36	5.92	2.43	11	10	north		Sideswipe
8/24/2004	3628	Red boat, bow, starboard passenger seat	36	4.75	4.12	14	10	south		Sideswipe
8/24/2004	3628	Red boat, bow, starboard passenger seat	26	3.73	2.27	9	15	north		Sideswipe
8/24/2004	3628	Red boat, bow, starboard passenger seat	26	5.15	3.12	11	15	south		Sideswipe
8/24/2004	3628	Red boat, bow, starboard passenger seat	24	23.00	26.16	81	idling			Sideswipe
8/24/2004	3564	Red boat, middle, port side	40	3.53	0.93	6	5	north		Sideswipe
8/24/2004	3564	Red boat, middle, port side	60	7.18	11.24	66	5	south		Sideswipe
8/24/2004	3564	Red boat, middle, port side	72	3.89	1.35	7	10	north		Sideswipe
8/24/2004	3564	Red boat, middle, port side	36	3.28	1.72	8	10	south		Sideswipe
8/24/2004	3564	Red boat, middle, port side	26	6.88	3.00	14	15	north		Sideswipe
8/24/2004	3564	Red boat, middle, port side	26	6.27	3.12	13	15	south		Sideswipe
8/24/2004	3564	Red boat, middle, port side	24	22.50	28.71	112	idling			Sideswipe
8/24/2004	3633	Red boat, middle, starboard side	40	5.58	7.96	47	5	north		Sideswipe
8/24/2004	3633	Red boat, middle, starboard side	60	7.50	15.20	96	5	south		Sideswipe

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Sideswipe Exhaust System Evaluation Summary Data
Yosemite Lake
Merced, California
August 24 and 25, 2004

8/24/2004	3633	Red boat, middle, starboard side	36	3.22	1.05	5	10	north		Sideswipe
8/24/2004	3633	Red boat, middle, starboard side	36	3.03	1.36	6	10	south		Sideswipe
8/24/2004	3633	Red boat, middle, starboard side	26	3.19	1.10	5	15	north		Sideswipe
8/24/2004	3633	Red boat, middle, starboard side	26	3.12	1.07	5	15	south		Sideswipe
8/24/2004	3633	Red boat, middle, starboard side	24	17.04	22.83	78	idling			Sideswipe
8/24/2004	3634	Red boat, stern, middle	40	6.75	4.35	19	5	north		Sideswipe
8/24/2004	3634	Red boat, stern, middle	60	15.05	17.35	91	5	south		Sideswipe
8/24/2004	3634	Red boat, stern, middle	36	9.03	8.04	37	10	north		Sideswipe
8/24/2004	3634	Red boat, stern, middle	36	13.69	13.08	48	10	south		Sideswipe
8/24/2004	3634	Red boat, stern, middle	26	9.81	8.72	41	15	north		Sideswipe
8/24/2004	3634	Red boat, stern, middle	26	10.35	7.66	26	15	south		Sideswipe
8/24/2004	3634	Red boat, stern, middle	24	35.58	38.71	153	idling			Sideswipe
8/24/2004	3629	Red boat, stern, port side	40	11.13	1.91	19	5	north		Sideswipe
8/24/2004	3629	Red boat, stern, port side	60	27.95	25.34	121	5	south		Sideswipe
8/24/2004	3629	Red boat, stern, port side	36	11.69	3.35	20	10	north		Sideswipe
8/24/2004	3629	Red boat, stern, port side	36	13.06	3.04	20	10	south		Sideswipe
8/24/2004	3629	Red boat, stern, port side	26	12.65	5.52	29	15	north		Sideswipe
8/24/2004	3629	Red boat, stern, port side	26	10.85	5.79	22	15	south		Sideswipe
8/24/2004	3629	Red boat, stern, port side	24	36.17	37.20	130	idling			Sideswipe
8/24/2004	3593	Red Boat, stern, starboard side	40	11.40	8.96	39	5	north		Sideswipe
8/24/2004	3593	Red Boat, stern, starboard side	60	18.52	28.26	163	5	south		Sideswipe
8/24/2004	3593	Red Boat, stern, starboard side	36	7.25	5.41	30	10	north		Sideswipe
8/24/2004	3593	Red Boat, stern, starboard side	36	6.17	1.52	10	10	south		Sideswipe
8/24/2004	3593	Red Boat, stern, starboard side	32	7.69	5.66	26	15	north		Sideswipe
8/24/2004	3593	Red Boat, stern, starboard side	20	11.90	7.35	38	15	south		Sideswipe
8/24/2004	3593	Red Boat, stern, starboard side	24	34.42	41.54	149	idling			Sideswipe

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Sideswipe Exhaust System Evaluation Summary Data
Yosemite Lake
Merced, California
August 24 and 25, 2004

8/24/2004	3588	Yellow boat, bow, starboard seat	18	4.67	1.08	8	5	north		Transom
8/24/2004	3588	Yellow boat, bow, starboard seat	12	4.17	2.04	9	5	south		Transom
8/24/2004	3588	Yellow boat, bow, starboard seat	12	3.33	0.65	4	10	north		Transom
8/24/2004	3588	Yellow boat, bow, starboard seat	12	4.00	1.35	6	10	south		Transom
8/24/2004	3566	Yellow boat, middle, starboard side	40	1.95	5.55	36	5	north		Transom
8/24/2004	3566	Yellow boat, middle, starboard side	36	1.75	3.25	20	5	south		Transom
8/24/2004	3566	Yellow boat, middle, starboard side	24	1.04	0.81	4	10	north		Transom
8/24/2004	3566	Yellow boat, middle, starboard side	34	1.44	2.77	16	10	south		Transom
8/24/2004	3566	Yellow boat, middle, starboard side	29	0.83	0.54	2	15	north		Transom
8/24/2004	3566	Yellow boat, middle, starboard side	7	0.88	0.82	2	15	south		Transom
8/24/2004	3631	Yellow boat, stern, middle	40	21.03	25.10	91	5	north		Transom
8/24/2004	3631	Yellow boat, stern, middle	36	22.31	27.80	108	5	south		Transom
8/24/2004	3631	Yellow boat, stern, middle	24	69.71	82.93	336	10	north		Transom
8/24/2004	3631	Yellow boat, stern, middle	26	37.04	62.10	298	10	south		Transom
8/24/2004	3631	Yellow boat, stern, middle	24	11.17	11.87	44	15	north		Transom
8/24/2004	3631	Yellow boat, stern, middle	22	11.73	12.92	64	15	south		Transom
8/24/2004	3631	Yellow boat, stern, middle	20	30.40	36.55	140	idling			Transom
8/24/2004	3572	Yellow boat, stern, port side	40	4.50	5.95	32	5	north		Transom
8/24/2004	3572	Yellow boat, stern, port side	36	16.36	22.85	98	5	south		Transom
8/24/2004	3572	Yellow boat, stern, port side	24	4.33	3.31	12	10	north		Transom
8/24/2004	3572	Yellow boat, stern, port side	24	3.67	4.79	20	10	south		Transom
8/24/2004	3572	Yellow boat, stern, port side	18	5.17	2.68	10	15	north		Transom
8/24/2004	3572	Yellow boat, stern, port side	28	5.61	7.76	24	15	south		Transom
8/24/2004	3572	Yellow boat, stern, port side	20	31.10	57.70	175	idling			Transom
8/24/2004	3630	Yellow boat, stern, starboard side	34	23.74	40.81	236	5	north		Transom
8/24/2004	3630	Yellow boat, stern, starboard side	36	66.72	66.11	235	5	south		Transom

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Sideswipe Exhaust System Evaluation Summary Data
Yosemite Lake
Merced, California
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8/24/2004	3630	Yellow boat, stern, starboard side	24	20.67	16.38	62	10	north		Transom
8/24/2004	3630	Yellow boat, stern, starboard side	24	23.21	22.67	112	10	south		Transom
8/24/2004	3630	Yellow boat, stern, starboard side	22	3.82	3.53	15	15	north		Transom
8/24/2004	3630	Yellow boat, stern, starboard side	24	19.08	14.77	54	15	south		Transom
8/24/2004	3630	Yellow boat, stern, starboard side	20	49.95	84.56	342	idling			Transom
8/24/2004	3567	Zodiac, 2 ft. above the water	16	106.00	97.83	329	5	south	10	Sideswipe
8/24/2004	3567	Zodiac, 2 ft. above the water	12	33.50	9.30	48	5	north	20	Sideswipe
8/24/2004	3567	Zodiac, 2 ft. above the water	10	15.30	15.32	39	5	south	20	Sideswipe
8/24/2004	3567	Zodiac, 2 ft. above the water	14	4.14	2.11	11	5	north	40	Sideswipe
8/24/2004	3567	Zodiac, 2 ft. above the water	16	21.25	12.30	43	5	south	40	Sideswipe
8/24/2004	3567	Zodiac, 2 ft. above the water	14	18.71	17.37	56	5	north	60	Sideswipe
8/24/2004	3567	Zodiac, 2 ft. above the water	22	3.14	5.27	19	5	south	60	Sideswipe
8/24/2004	3567	Zodiac, 2 ft. above the water	12	23.42	11.87	39	5	north	20	Transom
8/24/2004	3567	Zodiac, 2 ft. above the water	12	6.25	7.89	25	5	south	20	Transom
8/24/2004	3567	Zodiac, 2 ft. above the water	10	8.40	6.28	18	5	north	40	Transom
8/24/2004	3567	Zodiac, 2 ft. above the water	12	2.00	0.43	3	5	south	40	Transom
8/24/2004	3567	Zodiac, 2 ft. above the water	18	15.28	11.91	35	5	north	60	Transom
8/24/2004	3567	Zodiac, 2 ft. above the water	12	3.42	6.01	22	5	south	60	Transom
8/24/2004	3567	Zodiac, 2 ft. above the water	12	47.00	9.79	61	10	north	20	Sideswipe
8/24/2004	3567	Zodiac, 2 ft. above the water	12	47.42	14.02	69	10	south	20	Sideswipe
8/24/2004	3567	Zodiac, 2 ft. above the water	12	30.00	10.08	55	10	north	40	Sideswipe
8/24/2004	3567	Zodiac, 2 ft. above the water	12	22.33	12.09	43	10	south	40	Sideswipe
8/24/2004	3563	Zodiac, 2 ft. above the water	12	11.58	9.48	34	10	north	60	Sideswipe
8/24/2004	3563	Zodiac, 2 ft. above the water	12	20.75	6.47	34	10	south	60	Sideswipe
8/24/2004	3571	Zodiac, 2 ft. above the water	12	19.42	7.86	37	10	north	40	Transom
8/24/2004	3571	Zodiac, 2 ft. above the water	12	32.67	11.25	52	10	south	40	Transom

Appendix A
Sideswipe Exhaust System Evaluation Summary Data
Yosemite Lake
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8/24/2004	3567	Zodiac, 2 ft. above the water	12	20.50	10.77	39	10	north	60	Transom
8/24/2004	3567	Zodiac, 2 ft. above the water	12	25.92	20.72	73	10	south	60	Transom
8/24/2004	3567	Zodiac, 2 ft. above the water	4	66.25	12.69	79	15	north	20	Sideswipe
8/24/2004	3567	Zodiac, 2 ft. above the water	10	46.80	14.84	80	15	north	40	Sideswipe
8/24/2004	3567	Zodiac, 2 ft. above the water	14	45.36	9.11	58	15	south	40	Sideswipe
8/24/2004	3567	Zodiac, 2 ft. above the water	12	21.33	23.92	75	15	north	60	Sideswipe
8/24/2004	3567	Zodiac, 2 ft. above the water	12	0.67	0.49	1	15	south	60	Sideswipe
8/24/2004	3571	Zodiac, 2 ft. above the water	7	40.14	3.76	45	15	north	40	Transom
8/24/2004	3571	Zodiac, 2 ft. above the water	17	42.53	13.17	68	15	south	40	Transom
8/24/2004	3571	Zodiac, 2 ft. above the water	14	47.00	6.98	54	15	north	60	Transom
8/24/2004	3571	Zodiac, 2 ft. above the water	8	26.88	11.15	46	15	south	60	Transom
8/24/2004	3569	Zodiac, 3 ft. above the water	12	29.92	18.75	72	5	south	10	Sideswipe
8/24/2004	3569	Zodiac, 3 ft. above the water	12	26.00	10.26	38	5	north	20	Sideswipe
8/24/2004	3569	Zodiac, 3 ft. above the water	10	4.80	4.89	14	5	south	20	Sideswipe
8/24/2004	3569	Zodiac, 3 ft. above the water	14	2.07	0.92	4	5	north	40	Sideswipe
8/24/2004	3569	Zodiac, 3 ft. above the water	16	15.31	9.62	31	5	south	40	Sideswipe
8/24/2004	3569	Zodiac, 3 ft. above the water	13	15.15	14.96	49	5	north	60	Sideswipe
8/24/2004	3569	Zodiac, 3 ft. above the water	22	2.73	2.51	11	5	south	60	Sideswipe
8/24/2004	3569	Zodiac, 3 ft. above the water	10	15.20	7.42	25	5	north	20	Transom
8/24/2004	3569	Zodiac, 3 ft. above the water	14	5.00	6.75	19	5	south	20	Transom
8/24/2004	3569	Zodiac, 3 ft. above the water	11	7.64	5.71	16	5	north	40	Transom
8/24/2004	3569	Zodiac, 3 ft. above the water	11	1.18	0.40	2	5	south	40	Transom
8/24/2004	3569	Zodiac, 3 ft. above the water	18	14.06	10.83	36	5	north	60	Transom
8/24/2004	3569	Zodiac, 3 ft. above the water	12	5.75	9.38	29	5	south	60	Transom
8/24/2004	3569	Zodiac, 3 ft. above the water	12	37.50	7.60	53	10	north	20	Sideswipe
8/24/2004	3569	Zodiac, 3 ft. above the water	12	33.17	11.50	53	10	south	20	Sideswipe

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8/24/2004	3569	Zodiac, 3 ft. above the water	12	21.08	10.14	42	10	north	40	Sideswipe
8/24/2004	3569	Zodiac, 3 ft. above the water	12	14.42	10.00	31	10	south	40	Sideswipe
8/24/2004	3569	Zodiac, 3 ft. above the water	12	7.25	6.47	18	10	north	60	Sideswipe
8/24/2004	3569	Zodiac, 3 ft. above the water	12	11.25	4.47	22	10	south	60	Sideswipe
8/24/2004	3569	Zodiac, 3 ft. above the water	12	14.00	9.07	36	10	north	40	Transom
8/24/2004	3569	Zodiac, 3 ft. above the water	14	21.71	9.22	42	10	south	40	Transom
8/24/2004	3569	Zodiac, 3 ft. above the water	12	15.08	9.35	33	10	north	60	Transom
8/24/2004	3569	Zodiac, 3 ft. above the water	12	12.42	9.70	28	10	south	60	Transom
8/24/2004	3569	Zodiac, 3 ft. above the water	4	44.25	14.22	53	15	north	20	Sideswipe
8/24/2004	3569	Zodiac, 3 ft. above the water	10	36.40	6.02	51	15	north	40	Sideswipe
8/24/2004	3569	Zodiac, 3 ft. above the water	14	39.93	12.75	58	15	south	40	Sideswipe
8/24/2004	3569	Zodiac, 3 ft. above the water	12	21.58	9.10	34	15	north	60	Sideswipe
8/24/2004	3569	Zodiac, 3 ft. above the water	12	16.92	8.06	32	15	south	60	Sideswipe
8/24/2004	3588	Zodiac, 3 ft. above the water	14	27.64	6.10	40	15	north	40	Transom
8/24/2004	3588	Zodiac, 3 ft. above the water	10	43.30	10.39	63	15	south	40	Transom
8/24/2004	3588	Zodiac, 3 ft. above the water	16	37.94	11.16	51	15	north	60	Transom
8/24/2004	3588	Zodiac, 3 ft. above the water	6	21.00	12.81	365	15	south	60	Transom
8/24/2004	3589	Zodiac, 5 ft. above the water	12	1.42	0.67	3	5	south	10	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	12	1.33	0.65	2	5	north	20	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	10	1.10	0.57	2	5	south	20	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	14	0.71	0.47	1	5	north	40	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	16	1.63	1.09	4	5	south	40	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	14	2.64	2.53	7	5	north	60	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	22	0.82	1.01	4	5	south	60	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	12	1.25	0.45	2	5	north	20	Transom
8/24/2004	3589	Zodiac, 5 ft. above the water	12	1.42	1.56	6	5	south	20	Transom

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8/24/2004	3589	Zodiac, 5 ft. above the water	10	1.30	0.67	3	5	north	40	Transom
8/24/2004	3589	Zodiac, 5 ft. above the water	12	1.00	0.00	1	5	south	40	Transom
8/24/2004	3589	Zodiac, 5 ft. above the water	18	6.61	6.99	22	5	north	60	Transom
8/24/2004	3589	Zodiac, 5 ft. above the water	12	2.17	2.92	11	5	south	60	Transom
8/24/2004	3589	Zodiac, 5 ft. above the water	12	3.92	1.73	6	10	north	20	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	12	3.58	2.64	9	10	south	20	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	12	3.83	3.13	10	10	north	40	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	12	3.25	2.63	8	10	south	40	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	12	2.42	1.98	6	10	north	60	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	12	4.42	4.74	16	10	south	60	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	12	2.50	2.91	10	10	north	40	Transom
8/24/2004	3589	Zodiac, 5 ft. above the water	12	2.83	2.62	9	10	south	40	Transom
8/24/2004	3589	Zodiac, 5 ft. above the water	12	1.92	1.08	4	10	north	60	Transom
8/24/2004	3589	Zodiac, 5 ft. above the water	12	3.58	3.40	10	10	south	60	Transom
8/24/2004	3589	Zodiac, 5 ft. above the water	4	6.50	2.38	9	15	north	20	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	10	10.30	7.42	23	15	north	40	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	14	11.71	4.46	19	15	south	40	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	12	7.00	4.53	16	15	north	60	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	12	7.00	3.59	14	15	south	60	Sideswipe
8/24/2004	3589	Zodiac, 5 ft. above the water	10	8.90	7.49	23	15	north	40	Transom
8/24/2004	3589	Zodiac, 5 ft. above the water	14	9.29	6.33	21	15	south	40	Transom
8/24/2004	3589	Zodiac, 5 ft. above the water	14	10.07	4.05	20	15	north	60	Transom
8/24/2004	3589	Zodiac, 5 ft. above the water	8	4.88	3.23	9	15	south	60	Transom
8/24/2004	51	Red boat, middle, port side	26	4.58	8.22	33	5	north		Sideswipe
8/24/2004	51	Red boat, middle, port side	74	3.03	5.44	31	5	south		Sideswipe
8/24/2004	51	Red boat, middle, port side	36	1.67	2.00	10	10	north		Sideswipe

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8/24/2004	51	Red boat, middle, port side	36	0.39	0.90	3	10	south		Sideswipe
8/24/2004	51	Red boat, middle, port side	26	0.50	0.65	2	15	north		Sideswipe
8/24/2004	51	Red boat, middle, port side	27	1.93	1.07	3	15	south		Sideswipe
8/24/2004	51	Red boat, middle, port side	23	0.04	0.21	1	idling			Sideswipe
8/24/2004	53	Red boat, middle, starboard side	26	3.12	7.42	29	5	north		Sideswipe
8/24/2004	53	Red boat, middle, starboard side	56	2.20	6.56	40	5	south		Sideswipe
8/24/2004	53	Red boat, middle, starboard side	36	0.17	0.85	5	10	north		Sideswipe
8/24/2004	53	Red boat, middle, starboard side	36	0.06	0.23	1	10	south		Sideswipe
8/24/2004	53	Red boat, middle, starboard side	26	0.08	0.27	1	15	north		Sideswipe
8/24/2004	53	Red boat, middle, starboard side	27	0.00	0.00	0	15	south		Sideswipe
8/24/2004	53	Red boat, middle, starboard side	23	1.13	3.73	18	idling			Sideswipe
8/24/2004	58	Red boat, stern, middle	40	3.15	7.84	42	5	north		Sideswipe
8/24/2004	58	Red boat, stern, middle	60	3.72	7.55	49	5	south		Sideswipe
8/24/2004	58	Red boat, stern, middle	36	3.72	5.50	25	10	north		Sideswipe
8/24/2004	58	Red boat, stern, middle	36	4.97	6.42	31	10	south		Sideswipe
8/24/2004	58	Red boat, stern, middle	27	4.00	9.13	36	15	north		Sideswipe
8/24/2004	58	Red boat, stern, middle	25	3.08	4.46	13	15	south		Sideswipe
8/24/2004	58	Red boat, stern, middle	16	5.19	8.51	27	idling			Sideswipe
8/24/2004	55	Red boat, stern, port side	24	0.63	1.69	8	5	north		Sideswipe
8/24/2004	55	Red boat, stern, port side	74	3.20	8.29	47	5	south		Sideswipe
8/24/2004	55	Red boat, stern, port side	36	2.11	5.15	27	10	north		Sideswipe
8/24/2004	55	Red boat, stern, port side	36	0.08	0.28	1	10	south		Sideswipe
8/24/2004	55	Red boat, stern, port side	26	1.00	1.39	5	15	north		Sideswipe
8/24/2004	55	Red boat, stern, port side	26	0.35	0.80	3	15	south		Sideswipe
8/24/2004	55	Red boat, stern, port side	25	4.04	11.89	51	idling			Sideswipe
8/24/2004	59	Red Boat, stern, starboard side	26	6.23	9.55	38	5	north		Sideswipe

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8/24/2004	59	Red Boat, stern, starboard side	74	6.41	10.59	67	5	south		Sideswipe
8/24/2004	59	Red Boat, stern, starboard side	36	5.39	7.88	43	10	north		Sideswipe
8/24/2004	59	Red Boat, stern, starboard side	36	2.67	2.10	9	10	south		Sideswipe
8/24/2004	59	Red Boat, stern, starboard side	27	1.81	1.64	5	15	north		Sideswipe
8/24/2004	59	Red Boat, stern, starboard side	25	3.08	2.72	9	15	south		Sideswipe
8/24/2004	59	Red Boat, stern, starboard side	24	9.63	11.66	51	idling			Sideswipe
8/24/2004	60	Yellow boat, middle, starboard side	18	0.67	2.06	8	5	north		Transom
8/24/2004	60	Yellow boat, middle, starboard side	12	0.00	0.00	0	5	south		Transom
8/24/2004	60	Yellow boat, middle, starboard side	12	0.00	0.00	0	10	north		Transom
8/24/2004	60	Yellow boat, middle, starboard side	12	0.58	1.38	4	10	south		Transom
8/24/2004	60	Yellow boat, middle, starboard side	13	3.46	6.80	22	15	north		Transom
8/24/2004	60	Yellow boat, middle, starboard side	8	9.88	11.75	29	15	south		Transom
8/24/2004	60	Yellow boat, middle, starboard side	11	0.00	0.00	0	idling			Transom
8/24/2004	54	Yellow boat, stern, middle	39	17.90	58.72	365	5	north		Transom
8/24/2004	54	Yellow boat, stern, middle	36	12.67	16.74	58	5	south		Transom
8/24/2004	54	Yellow boat, stern, middle	24	30.04	44.73	178	10	north		Transom
8/24/2004	54	Yellow boat, stern, middle	24	7.79	10.97	40	10	south		Transom
8/24/2004	54	Yellow boat, stern, middle	20	6.20	11.69	51	15	north		Transom
8/24/2004	54	Yellow boat, stern, middle	26	8.65	14.78	65	15	south		Transom
8/24/2004	54	Yellow boat, stern, middle	20	7.35	11.42	39	idling			Transom
8/24/2004	57	Yellow boat, stern, port side	40	1.90	2.94	10	5	north		Transom
8/24/2004	57	Yellow boat, stern, port side	36	7.67	13.57	68	5	south		Transom
8/24/2004	57	Yellow boat, stern, port side	24	3.13	3.98	13	10	north		Transom
8/24/2004	57	Yellow boat, stern, port side	24	3.29	7.98	30	10	south		Transom
8/24/2004	57	Yellow boat, stern, port side	20	5.05	7.37	32	15	north		Transom
8/24/2004	57	Yellow boat, stern, port side	26	2.73	4.82	17	15	south		Transom

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8/24/2004	57	Yellow boat, stern, port side	20	5.75	12.02	47	idling			Transom
8/24/2004	52	Yellow Boat, middle, port side	40	0.30	1.74	11	5	north		Transom
8/24/2004	52	Yellow Boat, middle, port side	36	0.17	0.51	2	5	south		Transom
8/24/2004	52	Yellow Boat, middle, port side	24	0.00	0.00	0	10	north		Transom
8/24/2004	52	Yellow Boat, middle, port side	24	0.00	0.00	0	10	south		Transom
8/24/2004	52	Yellow Boat, middle, port side	20	0.60	2.26	10	15	north		Transom
8/24/2004	52	Yellow Boat, middle, port side	26	0.00	0.00	0	15	south		Transom
8/24/2004	52	Yellow Boat, middle, port side	42	0.38	1.32	8	idling			Transom
8/25/2004	3593	Chase monitor, 45° port side	12	2.50	0.90	4	5		20	Sideswipe
8/25/2005	3593	Chase monitor, 45° starboard side	12	2.73	1.34	6	5		20	Sideswipe
8/25/2004	3593	Chase monitor, directly behind the boat	12	36.25	14.56	56	5		20	Sideswipe
8/25/2004	3593	Chase monitor, 45° port side	14	1.93	1.27	6	5		40	Sideswipe
8/25/2004	3593	Chase monitor, 45° starboard side	8	3.00	1.93	7	5		40	Sideswipe
8/25/2004	3593	Chase monitor, directly behind the boat	12	2.58	2.07	8	5		40	Sideswipe
8/25/2004	3593	Chase monitor, 45° port side	12	2.08	1.98	8	5		20	Transom
8/25/2004	3593	Chase monitor, 45° starboard side	10	6.30	3.43	13	5		20	Transom
8/25/2004	3593	Chase monitor, directly behind the boat	12	11.58	4.06	16	5		20	Transom
8/25/2004	3593	Chase monitor, 45° port side	10	1.60	0.70	3	5		40	Transom
8/25/2004	3593	Chase monitor, 45° starboard side	10	4.20	5.37	19	5		40	Transom
8/25/2004	3593	Chase monitor, directly behind the boat	12	2.67	0.65	4	5		40	Transom
8/25/2004	3593	Chase monitor, 45° port side	12	1.50	0.52	2	10		20	Sideswipe
8/25/2005	3593	Chase monitor, 45° starboard side	10	2.40	2.72	10	10		20	Sideswipe
8/25/2004	3593	Chase monitor, directly behind the boat	14	7.43	7.14	29	10		20	Sideswipe
8/25/2004	3593	Chase monitor, 45° port side	12	1.50	1.17	4	10		20	Transom
8/25/2004	3593	Chase monitor, 45° starboard side	10	6.70	9.65	25	10		20	Transom

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8/25/2004	3593	Chase monitor, directly behind the boat	12	9.08	8.55	34	10		20	Transom
8/25/2004	3593	Chase monitor, 45° port side	10	1.80	2.20	8	10		40	Transom
8/25/2004	3593	Chase monitor, 45° starboard side	8	3.00	1.60	6	10		40	Transom
8/25/2004	3593	Chase monitor, directly behind the boat	10	4.10	3.07	11	10		40	Transom
8/25/2004	3593	Chase monitor, 45° port side	8	2.38	0.52	3	15		20	Sideswipe
8/25/2005	3593	Chase monitor, 45° starboard side	8	2.38	3.89	12	15		20	Sideswipe
8/25/2004	3593	Chase monitor, directly behind the boat	6	11.17	4.07	15	15		20	Sideswipe
8/25/2004	3593	Chase monitor, 45° port side	8	0.25	0.46	1	15		20	Transom
8/25/2004	3593	Chase monitor, 45° starboard side	8	3.63	0.74	5	15		20	Transom
8/25/2004	3593	Chase monitor, directly behind the boat	10	20.40	7.88	31	15		20	Transom
8/25/2004	3593	Chase monitor, 45° port side	8	1.25	2.05	6	15		40	Transom
8/25/2004	3593	Chase monitor, 45° starboard side	8	4.38	3.29	12	15		40	Transom
8/25/2004	3593	Chase monitor, directly behind the boat	10	3.30	1.89	7	15		40	Transom
8/25/2004	3568	Red boat, bow, starboard passenger seat	60	3.88	1.67	10	5	north		Sideswipe
8/25/2004	3568	Red boat, bow, starboard passenger seat	76	5.99	4.86	25	5	south		Sideswipe
8/25/2004	3568	Red boat, bow, starboard passenger seat	38	5.89	3.96	18	10	north		Sideswipe
8/25/2004	3568	Red boat, bow, starboard passenger seat	56	6.96	5.13	24	10	south		Sideswipe
8/25/2004	3568	Red boat, bow, starboard passenger seat	40	5.68	5.46	21	15	north		Sideswipe
8/25/2004	3568	Red boat, bow, starboard passenger seat	34	5.62	3.55	19	15	south		Sideswipe
8/25/2004	3568	Red boat, bow, starboard passenger seat	12	3.92	1.24	7	idling			Sideswipe
8/25/2004	3628	Red boat, middle, port side	60	1.23	1.45	7	5	north		Sideswipe
8/25/2004	3628	Red boat, middle, port side	77	12.97	14.09	63	5	south		Sideswipe
8/25/2004	3628	Red boat, middle, port side	38	2.55	2.37	10	10	north		Sideswipe
8/25/2004	3628	Red boat, middle, port side	56	10.57	16.61	86	10	south		Sideswipe
8/25/2004	3628	Red boat, middle, port side	40	4.55	6.24	22	15	north		Sideswipe

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8/25/2004	3628	Red boat, middle, port side	34	2.09	2.47	13	15	south		Sideswipe
8/25/2004	3628	Red boat, middle, port side	12	4.67	2.87	10	idling			Sideswipe
8/25/2004	3572	Red boat, middle, starboard side	60	1.15	1.51	11	5	north		Sideswipe
8/25/2004	3572	Red boat, middle, starboard side	76	4.78	9.27	63	5	south		Sideswipe
8/25/2004	3572	Red boat, middle, starboard side	38	2.50	2.87	12	10	north		Sideswipe
8/25/2004	3572	Red boat, middle, starboard side	56	3.45	5.98	37	10	south		Sideswipe
8/25/2004	3572	Red boat, middle, starboard side	40	4.05	5.77	21	15	north		Sideswipe
8/25/2004	3572	Red boat, middle, starboard side	34	2.35	4.51	22	15	south		Sideswipe
8/25/2004	3572	Red boat, middle, starboard side	12	13.58	14.91	43	idling			Sideswipe
8/25/2004	3589	Red boat, stern, middle	60	1.70	2.63	20	5	north		Sideswipe
8/25/2004	3589	Red boat, stern, middle	76	9.26	16.61	85	5	south		Sideswipe
8/25/2004	3589	Red boat, stern, middle	37	15.84	15.07	70	10	north		Sideswipe
8/25/2004	3589	Red boat, stern, middle	56	5.64	7.68	44	10	south		Sideswipe
8/25/2004	3589	Red boat, stern, middle	40	5.70	7.24	29	15	north		Sideswipe
8/25/2004	3589	Red boat, stern, middle	34	1.94	3.68	22	15	south		Sideswipe
8/25/2004	3589	Red boat, stern, middle	12	38.00	43.00	122	idling			Sideswipe
8/25/2004	3634	Red boat, stern, port side	60	6.73	3.25	27	5	north		Sideswipe
8/25/2004	3634	Red boat, stern, port side	76	15.14	15.41	91	5	south		Sideswipe
8/25/2004	3634	Red boat, stern, port side	40	8.50	5.35	29	10	north		Sideswipe
8/25/2004	3634	Red boat, stern, port side	54	20.91	25.19	91	10	south		Sideswipe
8/25/2004	3634	Red boat, stern, port side	40	10.58	6.88	35	15	north		Sideswipe
8/25/2004	3634	Red boat, stern, port side	34	7.06	12.34	72	15	south		Sideswipe
8/25/2004	3634	Red boat, stern, port side	12	51.00	50.72	154	idling			Sideswipe
8/25/2004	3594	Red Boat, stern, starboard side	60	7.87	10.57	81	5	north		Sideswipe
8/25/2004	3594	Red Boat, stern, starboard side	76	16.33	18.91	111	5	south		Sideswipe
8/25/2004	3594	Red Boat, stern, starboard side	38	42.68	48.59	242	10	north		Sideswipe

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8/25/2004	3594	Red Boat, stern, starboard side	56	9.82	10.61	78	10	south		Sideswipe
8/25/2004	3594	Red Boat, stern, starboard side	40	9.33	8.09	32	15	north		Sideswipe
8/25/2004	3594	Red Boat, stern, starboard side	34	5.62	3.13	16	15	south		Sideswipe
8/25/2004	3594	Red Boat, stern, starboard side	12	32.17	35.32	121	idling			Sideswipe
8/25/2004	3564	Yellow boat, middle, port side	60	3.72	4.91	19	5	north		Transom
8/25/2004	3564	Yellow boat, middle, port side	76	2.30	1.74	8	5	south		Transom
8/25/2004	3564	Yellow boat, middle, port side	38	1.89	1.11	5	10	north		Transom
8/25/2004	3564	Yellow boat, middle, port side	56	4.16	6.17	33	10	south		Transom
8/25/2004	3564	Yellow boat, middle, port side	40	2.53	3.01	12	15	north		Transom
8/25/2004	3564	Yellow boat, middle, port side	34	4.68	17.02	98	15	south		Transom
8/25/2004	3564	Yellow boat, middle, port side	12	3.92	6.01	19	idling			Transom
8/25/2004	3569	Yellow boat, middle, starboard side	60	4.78	7.88	42	5	north		Transom
8/25/2004	3569	Yellow boat, middle, starboard side	76	2.92	5.35	43	5	south		Transom
8/25/2004	3569	Yellow boat, middle, starboard side	39	1.46	0.64	3	10	north		Transom
8/25/2004	3569	Yellow boat, middle, starboard side	55	2.78	6.89	52	10	south		Transom
8/25/2004	3569	Yellow boat, middle, starboard side	40	3.08	3.75	14	15	north		Transom
8/25/2004	3569	Yellow boat, middle, starboard side	34	6.97	22.58	120	15	south		Transom
8/25/2004	3569	Yellow boat, middle, starboard side	12	12.83	19.22	57	idling			Transom
8/25/2004	3563	Yellow boat, stern, middle	60	4.42	5.12	27	5	north		Transom
8/25/2004	3563	Yellow boat, stern, middle	76	15.45	28.14	194	5	south		Transom
8/25/2004	3563	Yellow boat, stern, middle	36	28.36	22.29	82	10	north		Transom
8/25/2004	3563	Yellow boat, stern, middle	58	8.88	13.68	66	10	south		Transom
8/25/2004	3563	Yellow boat, stern, middle	40	11.65	22.64	105	15	north		Transom
8/25/2004	3563	Yellow boat, stern, middle	34	9.00	16.56	85	15	south		Transom
8/25/2004	3563	Yellow boat, stern, middle	12	233.50	373.20	864	idling			Transom
8/25/2004	3631	Yellow boat, stern, starboard side	60	10.67	11.79	80	5	north		Transom

Appendix A
 Sideswipe Exhaust System Evaluation Summary Data
 Yosemite Lake
 Merced, California
 August 24 and 25, 2004

8/25/2004	3631	Yellow boat, stern, starboard side	76	63.84	94.76	382	5	south		Transom
8/25/2004	3631	Yellow boat, stern, starboard side	40	29.98	33.43	146	10	north		Transom
8/25/2004	3631	Yellow boat, stern, starboard side	58	41.86	29.44	175	10	south		Transom
8/25/2004	3631	Yellow boat, stern, starboard side	40	22.65	44.20	226	15	north		Transom
8/25/2004	3631	Yellow boat, stern, starboard side	34	17.15	24.87	119	15	south		Transom
8/25/2004	3631	Yellow boat, stern, starboard side	12	293.08	458.52	1089	idling			Transom

Table 1A
 Summary of Carbon Monoxide Concentrations
 On an Inboard Motor Boat Idling
 Yosemite Lake
 Merced, California
 24-Aug-04

Sample Location	CO Conc. With Transom Exhaust System (ppm)	CO Conc. With Sideswipe Exhaust System (ppm)	Percent Difference
Bow, port side (passenger seat)	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 23.00 Std. Dev. = 26.16 Peak = 81 N = 24	NA
Middle of the boat, port side	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 22.50 Std. Dev. = 28.71 Peak = 112 N = 24	NA
Middle of the boat, starboard side	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 17.04 Std. Dev. = 22.83 Peak = 78 N = 24	NA
Stern, middle	mean = 30.40 Std. Dev. = 36.55 Peak = 140 N = 20	mean = 35.58 Std. Dev. = 38.71 Peak = 153 N = 24	-17.1%
Stern, port side	mean = 31.10 Std. Dev. = 57.70 Peak = 175 N = 20	mean = 36.17 Std. Dev. = 37.20 Peak = 130 N = 24	-16.3%
Stern, starboard	mean = 49.95 Std. Dev. = 84.56 Peak = 342 N = 20	mean = 34.42 Std. Dev. = 41.54 Peak = 149 N = 24	31.1%

Table 1B
 Summary of Carbon Monoxide Concentrations
 On an Inboard Motor Boat Idling
 Yosemite Lake
 Merced, California
 25-Aug-04

Sample Location (monitor numbers)	CO Conc. With Transom Exhaust System (ppm)	CO Conc. With Sideswipe Exhaust System (ppm)	Percent Difference
Bow, port side	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 3.92 Std. Dev. = 1.24 Peak = 7.00 N = 12	NA
Middle of boat, starboard side	mean = 3.92 Std. Dev. = 6.01 Peak = 19 N = 12	mean = 4.67 Std. Dev. = 2.87 Peak = 10 N = 12	-19.1%
Stern, middle	mean = 12.83 Std. Dev. = 19.22 Peak = 57 N = 12	mean = 13.58 Std. Dev. = 14.91 Peak = 43 N = 12	-5.8%
Stern, port side	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 38 Std. Dev. = 43.003 Peak = 122 N = 12	NA
Stern, starboard side	mean = 293.08 Std. Dev. = 458.52 Peak = 1089 N = 12	mean = 51 Std. Dev. = 50.717 Peak = 154 N = 12	82.6%

Table 2A
 Summary of Carbon Monoxide
 Concentrations
 On and Behind an Inboard Motor Boat Traveling at 5 Miles Per Hour
 Yosemite Lake
 Merced, California
 24-Aug-04

Sample Location	CO Conc. With Transom Exhaust System (ppm)	CO Conc. With Sideswipe Exhaust System (ppm)	Percent Difference
Bow, port side (passenger seat)	mean = 4.47 Std. Dev. = 1.53 Peak = 9 N = 30	mean = 7.65 Std. Dev. = 6.23 Peak = 44 N = 100	-71.3%
Middle of the boat, port side	mean = 1.86 Std. Dev. = 4.58 Peak = 36 N = 76	mean = 5.72 Std. Dev. = 8.88 Peak = 66 N = 100	-208.3%
Middle of the boat, starboard side	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 6.73 Std. Dev. = 12.79 Peak = 96 N = 100	NA
Stern, middle	mean = 21.63 Std. Dev. = 26.25 Peak = 108 N = 71	mean = 11.73 Std. Dev. = 14.26 Peak = 91 N = 100	45.8%
Stern, port side	mean = 10.12 Std. Dev. = 17.25 Peak = 98 N = 76	mean = 21.22 Std. Dev. = 21.28 Peak = 121 N = 100	-109.7%
Stern, starboard	mean = 45.84 Std. Dev. = 59.01 Peak = 236 N = 70	mean = 15.67 Std. Dev. = 22.80 Peak = 163 N = 100	65.8%
20 ft. behind boat, 2 ft. above the water	mean = 14.83 Std. Dev. = 13.19 Peak = 39 N = 24	mean = 25.23 Std. Dev. = 15.23 Peak = 48 N = 22	-70.07%

Table 2A - Cont'd

20 ft. behind boat, 3 ft. above the water	mean = 9.25 Std. Dev. = 8.6 Peak = 25 N = 24	mean = 16.36 Std. Dev. = 13.50 Peak = 38 N = 22	-76.9%
20 ft. behind boat, 5 ft. above the water	mean = 1.33 Std. Dev. = 1.13 Peak = 6 N = 24	mean = 1.23 Std. Dev. = 0.61 Peak = 2 N = 22	8.0%
40 ft. behind boat, 2 ft. above the water	mean = 4.91 Std. Dev. = 5.25 Peak = 18 N = 22	mean = 13.27 Std. Dev. = 12.47 Peak = 43 N = 30	-170.2%
40 ft. behind boat, 3 ft. above the water	mean = 4.41 Std. Dev. = 5.15 Peak = 16 N = 22	mean = 9.13 Std. Dev. = 9.66 Peak = 31 N = 30	-107.1%
40 ft. behind boat, 5 ft. above the water	mean = 1.14 Std. Dev. = 0.47 Peak = 3 N = 22	mean = 1.20 Std. Dev. = 0.96 Peak = 4 N = 30	-5.6%
60 ft. behind boat, 2 ft. above the water	mean = 10.53 Std. Dev. = 11.48 Peak = 35 N = 30	mean = 9.19 Std. Dev. = 13.71 Peak = 56 N = 36	12.7%
60 ft. behind boat, 3 ft. above the water	mean = 10.73 Std. Dev. = 10.92 Peak = 36 N = 30	mean = 7.34 Std. Dev. = 10.95 Peak = 49 N = 35	31.6%
60 ft. behind boat, 5 ft. above the water	mean = 4.83 Std. Dev. = 6.06 Peak = 22 N = 30	mean = 1.53 Std. Dev. = 1.95 Peak = 7 N = 36	68.4%

Table 2B
 Summary of Carbon Monoxide Concentrations
 On and Behind an Inboard Motor Boat Traveling at 5 Miles Per Hour
 Yosemite Lake
 Merced, California
 25-Aug-04

Sample Location	CO Conc. With Transom Exhaust System (ppm)	CO Conc. With Sideswipe Exhaust System (ppm)	Percent Difference
Bow, port side (passenger seat)	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 5.06 Std. Dev. = 3.93 Peak = 25 N = 136	NA
Middle of boat, port side	mean = 2.9 Std. Dev. = 3.6 Peak = 19 N = 136	mean = 7.8 Std. Dev. = 12.1 Peak = 63 N = 137	-167.6%
Middle of boat, starboard side	mean = 3.7 Std. Dev. = 6.6 Peak = 43 N = 136	mean = 3.2 Std. Dev. = 7.2 Peak = 63 N = 136	15.1%
Stern middle	mean = 10.6 Std. Dev. = 22 Peak = 194 N = 136	mean = 5.9 Std. Dev. = 13.1 Peak = 85 N = 136	44.0%
Stern port	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 11.4 Std. Dev. = 12.4 Peak = 91 N = 136	NA
Stern starboard	mean = 40.4 Std. Dev. = 76 Peak = 382 N = 136	mean = 12.6 Std. Dev. = 16.3 Peak = 111 N = 136	68.8%
Chase monitor 20 ft. directly behind boat	mean = 11.6 Std. Dev. = 4.1 Peak = 16 N = 12	mean = 36.3 Std. Dev. = 14.6 Peak = 56 N = 12	-212.95%
Chase monitor 20 ft. 45° port side	mean = 2.08 Std. Dev. = 2.0 Peak = 8 N = 12	mean = 2.50 Std. Dev. = 0.90 Peak = 4 N = 12	-20.0%
Chase monitor 20 ft. 45° starboard side	mean = 6.30 Std. Dev. = 3.4	mean = 2.83 Std. Dev. = 1.34	55.0%

	Peak = 13	Peak = 6
	N = 10	N = 12

Table 2B – Cont'd

Chase monitor 40 ft. directly behind boat	mean = 2.67 Std. Dev. = 0.7 Peak = 4 N = 12	mean = 2.58 Std. Dev. = 2.07 Peak = 8 N = 12	3.1%
Chase monitor 40 ft. 45° port side	mean = 1.60 Std. Dev. = 0.70 Peak = 3 N = 10	mean = 1.93 Std. Dev. = 1.27 Peak = 6 N = 14	-20.5%
Chase monitor 40 ft. 45° starboard side	mean = 4.20 Std. Dev. = 5.37 Peak = 19 N = 10	mean = 3.00 Std. Dev. = 1.93 Peak = 8 N = 12	28.6%

Table 3A
 Summary of Carbon Monoxide Concentrations
 On and Behind an Inboard Motor Boat Traveling at 10 Miles Per Hour
 Yosemite Lake
 Merced, California
 24-Aug-04

Sample Location	CO Conc. With Transom Exhaust System (ppm)	CO Conc. With Sideswipe Exhaust System (ppm)	Percent Difference
Bow, port side (passenger seat)	mean = 3.67 Std. Dev. = 1.09 Peak = 6 N = 24	mean = 5.33 Std. Dev. = 3.41 Peak = 14 N = 72	-45.5%
Middle of the boat, port side	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 3.58 Std. Dev. = 1.56 Peak = 8 N = 72	NA
Middle of the boat, starboard side	mean = 1.28 Std. Dev. = 2.17 Peak = 16 N = 58	mean = 3.13 Std. Dev. = 1.21 Peak = 6 N = 72	-144.9%
Stern, middle	mean = 52.72 Std. Dev. = 73.95 Peak = 336 N = 50	mean = 11.36 Std. Dev. = 11.03 Peak = 48 N = 72	78.5%
Stern, port side	mean = 4.00 Std. Dev. = 4.08 Peak = 20 N = 48	mean = 12.38 Std. Dev. = 3.25 Peak = 20 N = 72	-209.4%
Stern, starboard	mean = 21.94 Std. Dev. = 19.61 Peak = 112 N = 48	mean = 6.71 Std. Dev. = 3.98 Peak = 30 N = 72	69.4%
20 ft. behind boat, 2 ft. above the water	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 47.21 Std. Dev. = 11.83 Peak = 69 N = 24	NA
20 ft. behind boat, 3 ft. above the water	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 35.33 Std. Dev. = 9.79 Peak = 53 N = 24	NA

Table 3A Cont'd

20 ft. behind boat, 5 ft. above the water	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 3.75 Std. Dev. = 2.19 Peak = 9 N = 24	NA
40 ft. behind boat, 2 ft. above the water	mean = 26.04 Std. Dev. = 11.7 Peak = 52 N = 24	mean = 26.17 Std. Dev. = 11.57 Peak = 55 N = 24	-0.5%
40 ft. behind boat, 3 ft. above the water	mean = 18.15 Std. Dev. = 9.78 Peak = 42 N = 26	mean = 17.75 Std. Dev. = 10.42 Peak = 42 N = 24	2.2%
40 ft. behind boat, 5 ft. above the water	mean = 2.67 Std. Dev. = 2.71 Peak = 10 N = 24	mean = 3.54 Std. Dev. = 2.84 Peak = 10 N = 24	-32.8%
60 ft. behind boat, 2 ft. above the water	mean = 23.21 Std. Dev. = 16.38 Peak = 73 N = 24	mean = 16.17 Std. Dev. = 9.22 Peak = 34 N = 24	30.3%
60 ft. behind boat, 3 ft. above the water	mean = 13.75 Std. Dev. = 9.41 Peak = 33 N = 24	mean = 9.25 Std. Dev. = 5.81 Peak = 22 N = 24	32.7%
60 ft. behind boat, 5 ft. above the water	mean = 2.75 Std. Dev. = 2.61 Peak = 10 N = 24	mean = 3.42 Std. Dev. = 3.69 Peak = 16 N = 24	-24.2%

Table 3B
 Summary of Carbon Monoxide Concentrations
 On and Behind an Inboard Motor Boat Traveling at 10 Miles Per Hour
 Yosemite Lake
 Merced, California
 25-Aug-04

Sample Location	CO Conc. With Transom Exhaust System (ppm)	CO Conc. With Sideswipe Exhaust System (ppm)	Percent Difference
Bow, port side (passenger seat)	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 6.53 Std. Dev. = 4.70 Peak = 24 N = 94	NA
Middle of boat, port side	mean = 3.2 Std. Dev. = 4.9 Peak = 33 N = 94	mean = 7.3 Std. Dev. = 13.5 Peak = 86 N = 94	-125.9%
Middle of boat, starboard side	mean = 2.2 Std. Dev. = 5.3 Peak = 52 N = 94	mean = 3.1 Std. Dev. = 5.0 Peak = 37 N = 94	-37.1%
Stern, middle	mean = 16.3 Std. Dev. = 20 Peak = 82 N = 94	mean = 9.7 Std. Dev. = 12.2 Peak = 70 N = 93	40.6%
Stern, port	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 15.6 Std. Dev. = 20.3 Peak = 91 N = 94	NA
Stern, starboard	mean = 37.0 Std. Dev. = 32 Peak = 175 N = 98	mean = 23.1 Std. Dev. = 35.6 Peak = 242 N = 94	37.6%
Chase monitor, 20 ft. directly behind boat	mean = 9.1 Std. Dev. = 8.6 Peak = 34 N = 12	mean = 7.4 Std. Dev. = 7.1 Peak = 29 N = 14	18.22%
Chase monitor, 20 ft. 45o port side	mean = 1.50 Std. Dev. = 1.2 Peak = 4 N = 12	mean = 1.50 Std. Dev. = 0.52 Peak = 2 N = 12	0.0%

Table 3B – Cont'd

Chase monitor, 20 ft. 45o starboard side	mean = 6.70 Std. Dev. = 9.6 Peak = 25 N = 10	mean = 5.56 Std. Dev. = 2.72 Peak = 10 N = 10	17.0%
Chase monitor, 40 ft. directly behind boat	mean = 4.10 Std. Dev. = 3.1 Peak = 11 N = 10	mean = NA Std. Dev. = NA Peak = NA N = NA	NA
Chase monitor, 40 ft. 45o port side	mean = 1.80 Std. Dev. = 2.20 Peak = 8 N = 10	mean = NA Std. Dev. = NA Peak = NA N = NA	NA
Chase monitor, 40 ft. 45o starboard side	mean = 3.00 Std. Dev. = 1.60 Peak = 6 N = 8	mean = NA Std. Dev. = NA Peak = NA N = NA	NA

Table 4A
 Summary of Carbon Monoxide Concentrations
 On and Behind an Inboard Motor Boat Traveling at 15 Miles Per Hour
 Yosemite Lake
 Merced, California
 24-Aug-04

Sample Location	CO Conc. With Transom Exhaust System (ppm)	CO Conc. With Sideswipe Exhaust System (ppm)	Percent Difference
Bow, port side (passenger seat)	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 4.44 Std. Dev. = 2.80 Peak = 11 N = 52	NA
Middle of the boat, port side	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 6.58 Std. Dev. = 3.04 Peak = 14 N = 52	NA
Middle of the boat, starboard side	mean = 0.9 Std. Dev. = 0.6 Peak = 2 N = 36	mean = 3.2 Std. Dev. = 1.1 Peak = 5 N = 52	-266.3%
Stern, middle	mean = 11.4 Std. Dev. = 12 Peak = 64 N = 46	mean = 10.1 Std. Dev. = 8.1 Peak = 41 N = 52	11.9%
Stern, port side	mean = 5.4 Std. Dev. = 6 Peak = 24 N = 46	mean = 11.8 Std. Dev. = 5.7 Peak = 29 N = 52	-116.2%
Stern, starboard	mean = 11.8 Std. Dev. = 13 Peak = 54 N = 46	mean = 9.3 Std. Dev. = 6.6 Peak = 38 N = 52	21.0%
20 ft. behind boat, 2 ft. above the water	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 66.3 Std. Dev. = 12.7 Peak = 79 N = 4	NA
20 ft. behind boat, 3 ft. above the water	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 44.25 Std. Dev. = 14.22 Peak = 53 N = 4	NA

Table 4A – Cont'd

20 ft. behind boat, 5 ft. above the water	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 6.50 Std. Dev. = 2.38 Peak = 9 N = 4	NA
40 ft. behind boat, 2 ft. above the water	mean = 41.83 Std. Dev. = 11.2 Peak = 68 N = 24	mean = 45.96 Std. Dev. = 11.56 Peak = 80 N = 24	-9.9%
40 ft. behind boat, 3 ft. above the water	mean = 34.17 Std. Dev. = 11.20 Peak = 63 N = 24	mean = 38.46 Std. Dev. = 10.45 Peak = 58 N = 24	-12.6%
40 ft. behind boat, 5 ft. above the water	mean = 9.13 Std. Dev. = 6.68 Peak = 23 N = 24	mean = 11.13 Std. Dev. = 5.77 Peak = 23 N = 24	-21.9%
60 ft. behind boat, 2 ft. above the water	mean = 39.68 Std. Dev. = 13.03 Peak = 54 N = 22	mean = 11.00 Std. Dev. = 19.63 Peak = 75 N = 24	72.3%
60 ft. behind boat, 3 ft. above the water	mean = 33.32 Std. Dev. = 13.70 Peak = 51 N = 22	mean = 19.25 Std. Dev. = 8.74 Peak = 34 N = 24	42.2%
60 ft. behind boat, 5 ft. above the water	mean = 8.18 Std. Dev. = 4.49 Peak = 20 N = 22	mean = 7.00 Std. Dev. = 4.00 Peak = 16 N = 24	14.4%

Table 4B
 Summary of Carbon Monoxide Concentrations
 On and Behind an Inboard Motor Boat Traveling at 15 Miles Per Hour
 Yosemite Lake
 Merced, California
 25-Aug-04

Sample Location	CO Conc. With Transom Exhaust System (ppm)	CO Conc. With Sideswipe Exhaust System (ppm)	Percent Difference
Bow, port side (passenger seat)	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 5.65 Std. Dev. = 4.65 Peak = 21 N = 74	NA
Middle of boat, port side	mean = 3.5 Std. Dev. = 11.7 Peak = 98 N = 74	mean = 3.4 Std. Dev. = 5.0 Peak = 22 N = 74	2.7%
Middle of boat, starboard side	mean = 4.9 Std. Dev. = 15.6 Peak = 120 N = 74	mean = 3.3 Std. Dev. = 5.3 Peak = 22 N = 74	32.8%
Stern, middle	mean = 11.5 Std. Dev. = 23 Peak = 105 N = 52	mean = 4.0 Std. Dev. = 6.1 Peak = 29 N = 74	65.5%
Stern, port	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 9.0 Std. Dev. = 9.9 Peak = 72 N = 74	NA
Stern, starboard	mean = 20.1 Std. Dev. = 36 Peak = 226 N = 74	mean = 7.6 Std. Dev. = 6.5 Peak = 32 N = 74	62.1%
Chase monitor, 20 ft. directly behind boat	mean = 20.4 Std. Dev. = 7.9 Peak = 31 N = 10	mean = 11.2 Std. Dev. = 4.1 Peak = 15 N = 6	45.26%
Chase monitor, 20 ft. 45o port side	mean = 0.25 Std. Dev. = 0.46 Peak = 1 N = 8	mean = 2.38 Std. Dev. = 0.52 Peak = 3 N = 8	-850.0%

Table 4B – Cont'd

Chase monitor, 20 ft. 45o starboard side	mean = 3.63 Std. Dev. = 0.74 Peak = 5 N = 8	mean = 2.38 Std. Dev. = 3.89 Peak = 12 N = 8	34.5%
Chase monitor, 40 ft. directly behind boat	mean = 3.30 Std. Dev. = 1.9 Peak = 7 N = 10	mean = NA Std. Dev. = NA Peak = NA N = NA	NA
Chase monitor, 40 ft. 45o port side	mean = 1.25 Std. Dev. = 2.05 Peak = 6 N = 8	mean = NA Std. Dev. = NA Peak = NA N = NA	NA
Chase monitor, 40 ft. 45o starboard side	mean = 4.38 Std. Dev. = 3.29 Peak = 12 N = 2008	mean = NA Std. Dev. = NA Peak = NA N = NA	NA

Table 5
 Summary of Carbon Monoxide Concentrations
 On an Inboard Motor Boat and a Wake Surfer Traveling at 10 Miles Per Hour
 Yosemite Lake
 Merced, California
 25-Aug-04

Sample Location	CO Conc. With Transom Exhaust System (ppm)	CO Conc. With Sideswipe Exhaust System (ppm)	Percent Difference
Bow, port side (passenger seat)	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 4.99 Std. Dev. = 4.47 Peak = 15 N = 22	NA
Middle of the boat, port side	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 4.14 Std. Dev. = 4.49 Peak = 20 N = 22	NA
Middle of the boat, starboard side	mean = 13.1 Std. Dev. = 12.1 Peak = 41 N = 22	mean = 2.5 Std. Dev. = 2.0 Peak = 7 N = 22	80.9%
Stern, middle	mean = 684.6 Std. Dev. = 341 Peak = 998 N = 22	mean = 68.2 Std. Dev. = 57.4 Peak = 154 N = 22	90.0%
Stern, port side	mean = NA Std. Dev. = NA Peak = NA N = NA	mean = 50.9 Std. Dev. = 41.3 Peak = 121 N = 22	NA
Stern, starboard	mean = 246.9 Std. Dev. = 138 Peak = 608 N = 22	mean = 50.6 Std. Dev. = 42.8 Peak = 212 N = 22	79.5%
Wake Surfer	mean = 105.36 Std. Dev. = 236.64 Peak = 832 N = 22	mean = 1.82 Std. Dev. = 1.59 Peak = 5 N = 17	98.3%

Figure 1

Various Types of Towed Water Sports Activities



Tubing



Water skiing



Wake boarding



Teak boarding or Platform dragging



Knee boarding



Wake surfing

Figure 2
2005 Centurion Avalanche Ski Boat with Traditional
Transom Exhaust



Figure 3
2005 Centurion Avalanche Ski Boat with Sideswipe Exhaust



Figure 4
Zodiac Inflatable Boat



Figure 5
Measuring CO Concentrations Behind the Boat by Holding
a CO Monitor at the Bow of a Chase Boat



Figure 6
Wake Surfer



Figure 7
CO Concentrations Behind the Transom Exhaust Boat Traveling at 5 Miles Per Hour

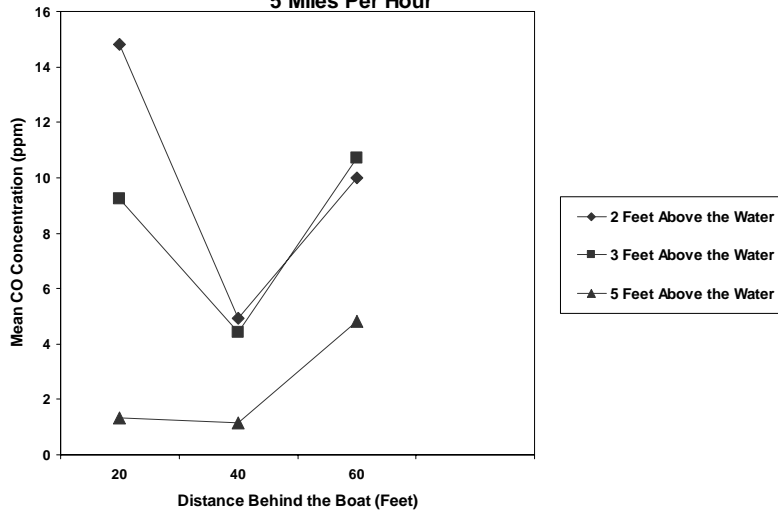


Figure 8
Comparison of CO Concentrations Behind Sideswipe Exhaust
From Both Sides of the Boat to Transom Exhaust Boat Traveling
at 5 Miles Per Hour

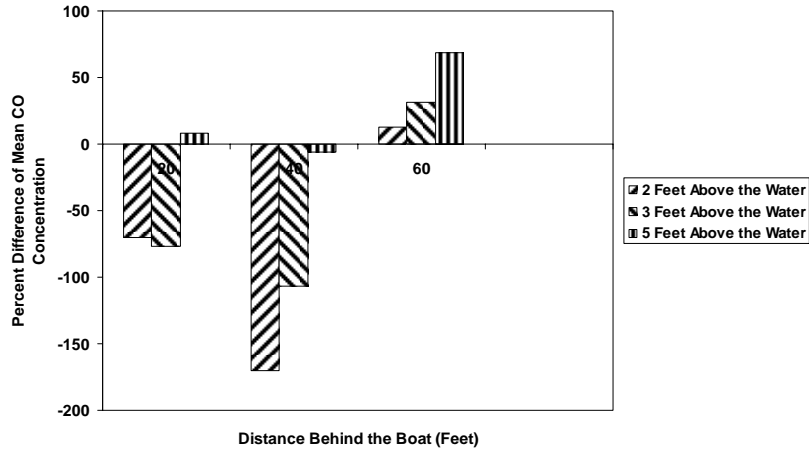


Figure 9
Comparison of CO Concentrations Behind Sideswipe Exhaust From
Starboard Side of the Boat to Transom Exhaust Boat Traveling at 5 Miles
Per Hour

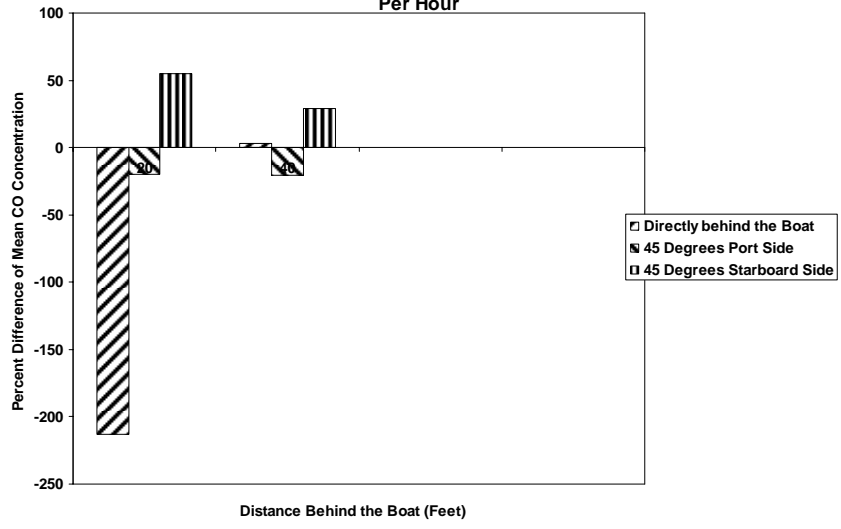


Figure 10
CO Concentrations Behind the Transom Exhaust Boat
Traveling at 10 Miles Per Hour

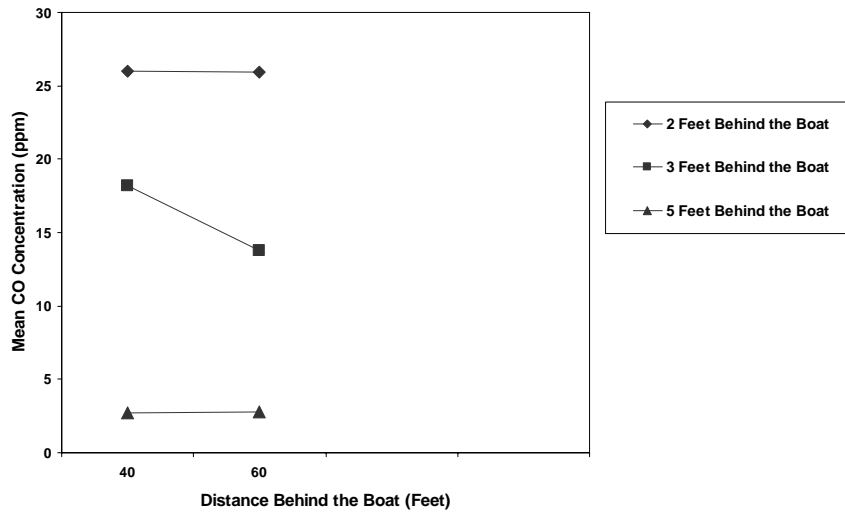


Figure 11
Comparison of CO Concentrations Behind the Sideswipe Exhaust
From Both Sides of the Boat to Transom Exhaust Boat Traveling
at 10 Miles Per Hour

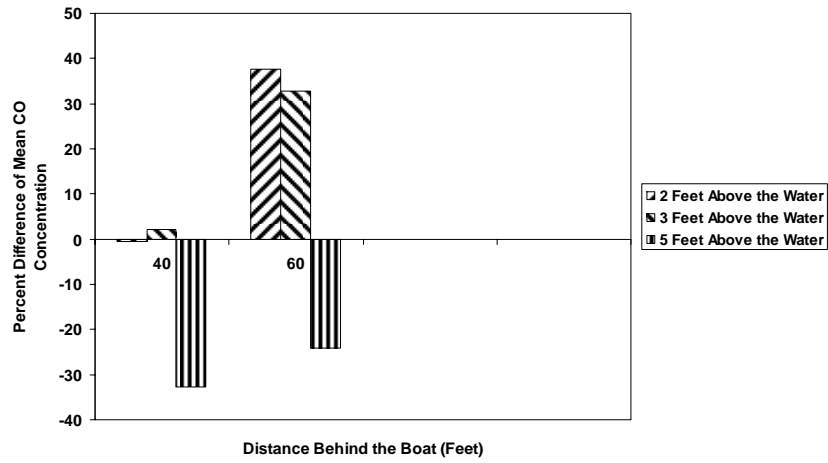


Figure 12
Comparison of CO Concentrations Behind the Sideswipe Exhaust From
Starboard Side of the Boat to Transom Exhaust Boat Traveling at 10
Miles Per Hour

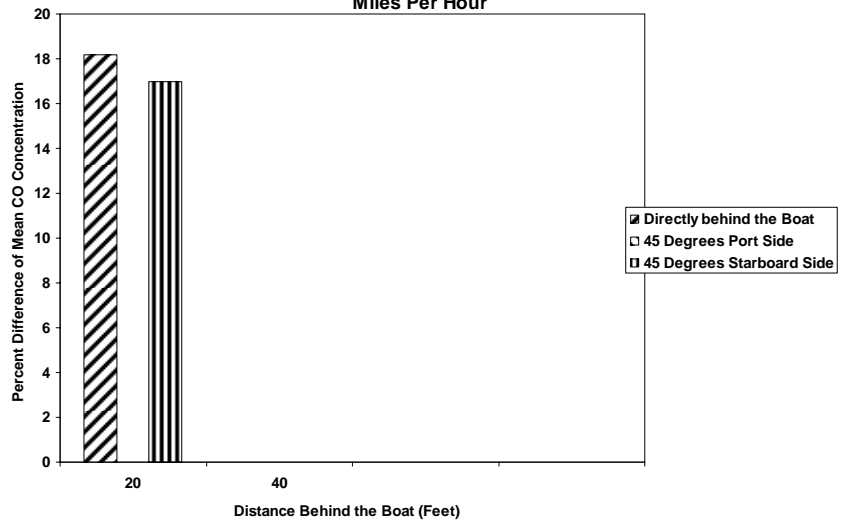


Figure 13
CO Concentrations Behind the Transom Exhaust Boat Traveling at 15 Miles Per Hour

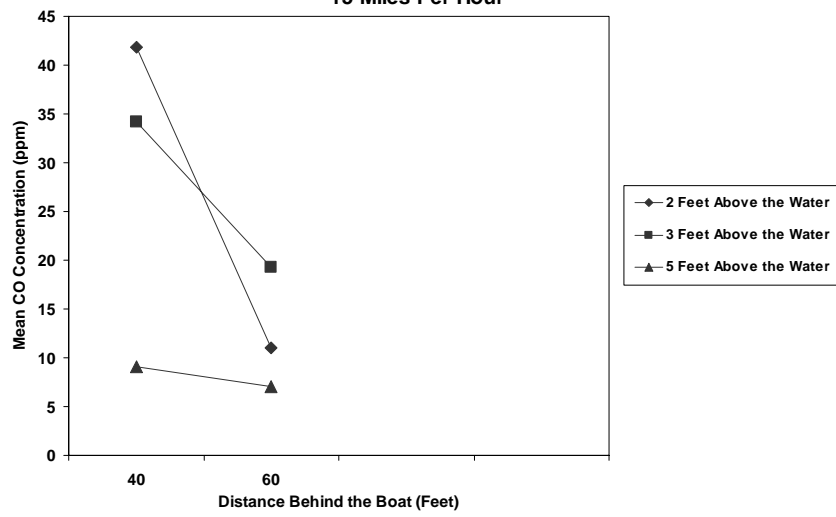


Figure 14
Comparison of CO Concentrations Behind the Sideswipe Exhaust
From Starboard Side of the Boat to Transom Exhaust Boat
Traveling at 15 Miles Per Hour

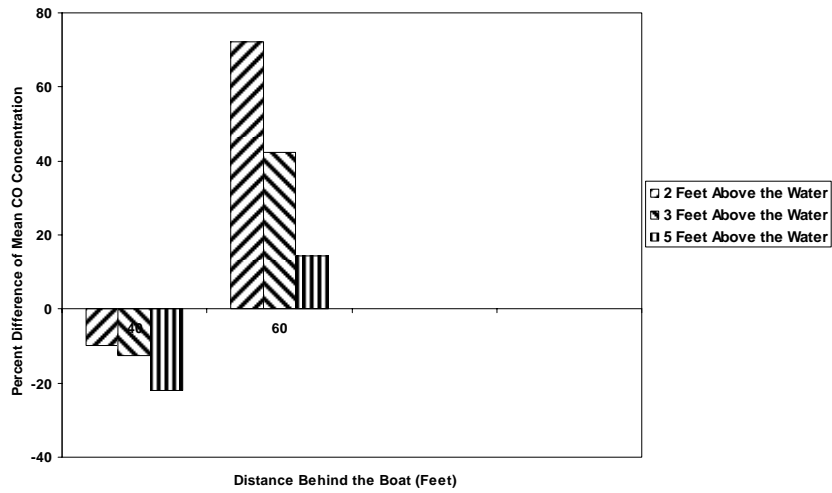


Figure 15
Comparison of CO Concentrations Behind the Sideswipe Exhaust
From Starboard Side of the Boat to Transom Exhaust Boat
Traveling at 15 Miles Per Hour

