IN-DEPTH SURVEY REPORT OF CARBON MONOXIDE EMISSIONS AND EXPOSURES ON EXPRESS CRUISERS UNDER VARIOUS OPERATING CONDITIONS

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EXECUTIVE SUMMARY

Under an interagency agreement with the United States Coast Guard, working in collaboration with an industry consultant, National Institute for Occupational Safety and Health (NIOSH) researchers evaluated carbon monoxide (CO) exposures on ten express cruiser boats from several manufacturers. The evaluated boats were new and included several different models. These boats had gasoline-powered propulsion engines and used gasoline-powered generators to provide electricity for onboard appliances.

This study was performed for the U.S. Coast Guard to better understand how CO poisonings may occur on express cruisers, identify the most hazardous conditions, and begin the process of identify controls to prevent/reduce CO exposures. Boats were evaluated while stationary and at multiple speeds, ranging from 5 to 25 miles per hour. CO concentrations were measured by multiple real-time instruments, which were placed at different locations on the boats with overhead, enclosing canopies set at various configurations.

Many of the evaluated boats generated hazardous CO concentrations: peak CO concentrations often exceeded 1,100 parts per million (ppm), while average CO concentrations were well over 100 ppm at the stern (rear). Two boats with a combined exhaust system (exhausting at the sides and underwater) had dramatically lower CO concentrations than any of the other evaluated boats (about 40% lower).
Based on the results and observations made in this report, the following major findings are summarized below:

- When the canvas is deployed and boat is underway, CO concentrations exceeded the immediately dangerous to life and health (IDLH) level near the swim platform for many of the evaluated boats.
- The combination of travel at low speeds into the wind with the canvas fully deployed and no forward hatches, windows or front panels opened maximized the station wagon effect, pulling significant amounts of CO into the cockpit.
- Different exhaust configurations have a major impact on how CO concentrations are entrained into the cockpit and other occupied areas. Accordingly, boats equipped with underwater exhaust exhibited significantly lower CO concentrations than vessels equipped with other exhaust designs.
- CO concentrations are typically higher at the stern of the boat and become gradually lower toward the front of the boat.
- Stationary smoke tests in the engine compartment showed satisfactory sealing of the bulkhead between the engine and adjacent compartments on all boats.

Based on the preceding findings, the following recommendations are made to reduce CO concentrations on express cruisers:

- Boat manufacturers should consider underwater exhaust that will significantly reduce CO concentrations inside the cockpit and other occupied areas compared to surface exhaust.
- Because of the station wagon effect, some canvas configurations should not be used while boat is moving or propulsion and/or generator engines are running.
- The possibility of adding force draft blowers into the cabin, creating a positive pressure to minimize potential CO intrusions, should be studied. Auxiliary blowers can be fitted and routed to ventilate the cockpit and swim platform areas in order to minimize negative pressure areas throughout the vessel.
- Since properly sealed cabin doors directly influenced the CO concentration in the cabin area, door suppliers should be encouraged to develop better sealing methods and designs.
- Windshield manufacturers should be encouraged to study the possibility of maximizing ventilation of occupied areas by improving the design of the center and side wings of the windshield.
- Due care should be exercised when designing the powered ventilation system on the engine compartment, locating the air intake on the opposite side of the generator exhaust. Also, potentially moving the intake much farther forward on the vessel would help minimize the intake of CO exhaust into the engine compartment.
- The development of cleaner burning engines (propulsion and generators) with catalytic converters should continue since they have the potential to greatly reduce CO concentrations to safer levels.
- The American Boat and Yacht Council (ABYC) should examine their standards and emphasize ventilation problems that can lead to CO intrusions, taking a strong position against surface exhaust designs for propulsion engines.

BACKGROUND

On July 6 through December 14, 2005, researchers from the National Institute for Occupational Safety and Health (NIOSH) working with the U.S. Coast Guard and industry consultant evaluated carbon monoxide (CO) emissions and exposures on a variety of express cruisers at various locations in Florida, North Carolina and New Jersey. This evaluation was conducted under an interagency agreement between the U.S. Coast Guard's Office of Boating Safety and NIOSH to become more fully aware of the types of CO emissions and exposures that are occurring on express cruisers used in the United States today. Similar NIOSH surveys regarding houseboats and other types of recreational boats have been conducted and are described in separate reports. Each of the evaluated boats was propelled by gasoline-powered engines and had a gasoline-powered generator to provide electrical power for onboard appliances. This report provides background information and describes the study methods, results, discussion, conclusions, and recommendations.

A great deal of work has already been performed to evaluate CO exposures and controls on houseboats, but less effort has been given to understanding the extent of the CO hazard on other types of recreational boats. Overall, as many as 185 CO poisonings are known to have occurred on or near recreational boats (non-houseboats) [DOI, 2004]. The current study was intended to provide a better understanding of the CO exposures that occur on express cruiser boats, to identify the most hazardous conditions, and begin the process of identify controls to prevent/reduce CO exposures. Collection of environmental data was vital to this effort, by testing the variability between different kinds of boats, engines, and design features.

CO Poisonings on Recreational Boats (Non-Houseboats)

A sampling of cases in which CO is known to have played a role in creating injuries or fatalities on recreational boats is provided below. These cases come from the document "Boat-Related Carbon Monoxide (CO) Poisonings" available at the Department of the Interior and available at http://safetynet.smis.doi.gov/thelistbystate10-19-04.pdf [DOI, 2004] website.

Nevada – Lake Powell
Since 1990, 19 people have been poisoned while in the cabin or within a canopy of a pleasure craft (other than houseboat) on Lake Powell. Six of the 19 people were poisoned by generator exhaust while inside a cabin cruiser boat during a single incident. The remaining 13 people were poisoned by propulsion engine exhaust. Eight of the 19 people lost consciousness as a result of their exposure. (Source: Review of NSP EMS Records, Glen Canyon National Recreation Area.)

California - Unspecified water body
In 1998, 4 people were poisoned while occupying the cabin of a cabin cruiser boat powered by an inboard engine. Three people were above deck and four were below deck. There appeared to have been a ventilation system failure that caused CO to enter the cabin area, sickening all four people below deck. The two most seriously affected were a 7-year-old female and a 4-year-old male. All received medical attention and recovered. (Source: US Coast Guard Database.)

Florida - Intercostals Waterway near Jacksonville
In 1991, a woman died while occupying the cabin of a moving 42' cabin cruiser piloted by her husband. She was seated at the table, and her sister was seated near the door. The sea was very rough. When the husband went to the cabin at one point, his wife was ill. They assumed it was sea-sickness due to the rough ride. He returned to the helm. After many miles of returning to the calmer waters of the Intracoastal Waterway, the sister asked him to return to the cabin. He found his wife on the floor beneath the table, dead. The resulting investigation determined that she died of CO poisoning from the propulsion engines exhaust. (Source: personal communication with the husband, United States District Court Middle District of Florida Jacksonville Division records.)

Florida – Ocean near Clearwater
In June 2004, three passengers were overcome by CO while traveling in the air conditioned cabin of a 40-foot cabin cruiser. The boat, with nine passengers aboard, left Island Estates at about 7:00 a.m. for a fishing trip. When the boat returned shortly after noon, one member of the group went into the cabin to wake three people who had decided to take a nap. The sleeping boaters could not be awakened. Rescue crews determined that the passengers had suffered CO poisoning. They were transported to the local hospital, and then on to a hospital where they could be treated in a hyperbaric oxygen chamber. One of the three remained hospitalized for several days. (Source: Tampa Tribune newspaper.)

Florida - Unspecified water body
In 1998, 4 people (ages 6, 9, 10, and 38) survived poisoning aboard a cabin cruiser with an inboard stern drive propulsion engine. The database states that exhaust fumes drifted into the cabin. (Source: US Coast Guard Database.)

Maryland - Broad Creek
In 2000, 3 children survived poisoning aboard a cabin cruiser that was rafted with several others. All of the boats were operating their generators for electrical power. There were 3 juveniles asleep in the cabin of one of the vessels with the windows and doors closed. CO had collected in the cabin. When the juveniles were awakened, they were sluggish, unresponsive, and nauseous. (Source: US Coast Guard Database.)

Maryland - Main Bay Area
In 2000, the operator of a cabin cruiser with an inboard propulsion engine was poisoned. The operator stated that he had the canopy of his vessel closed. There was no wind, and it believed that the exhaust from the engine collected inside. When the operator began to feel ill, he called for help suspecting CO poisoning. (Source: US Coast Guard Database.)

Maryland - Unspecified water body
In May 2001, 2 people (the operator and a passenger) were poisoned aboard a cabin cruiser with an inboard propulsion engine. The cockpit was enclosed by side and back curtains, and a back door was open. A "station wagon effect" caused exhaust to be drawn into the vessel. The passenger went into the cabin and was overcome by CO that had apparently accumulated in the lower areas. Both were treated for CO poisoning and released. (Source: US Coast Guard Database.)

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 results 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 COHb. Blood has an estimated 210–250 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 criteria for CO exposure are applicable to U.S. National Park Service (USNPS) and concessionaire employees who have been shown to be at risk of boat-related CO poisoning. The occupational exposure limits noted below should not be used for interpreting general population exposures (such as visitors engaged in boating activities). Occupational standards do not provide the same degree of protection for the general population as they do for healthy workers; 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 8hour 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/m^3 (87 ppm) for 15 minutes
60 mg/m^3 (52 ppm) for 30 minutes
30 mg/m^3 (26 ppm) for 1 hour
10 mg/m^3 (9 ppm) for 8 hours

METHODS

Air sampling for CO, ventilation, and wind-velocity measurements were collected on 10 different express cruisers built by various manufacturers. The evaluated boats had new drive engines and generator sets, tuned to manufacturer's specifications. Drive engines used on the evaluated boats were manufactured by Volvo Penta, Crusader Marine and Mercury Marine and generators were all manufactured by Kohler. Data was collected to evaluate the CO emissions of gasoline-powered engines and CO exposures on and near the boats, operating under various conditions.

A description of the boats, the drive engines, and generator set is provided below. All boats had inboard engines, and most of them were stern drive units, with the exception of three that had straight inboard units. On inboard engines, the engine and drive train are permanently mounted near the center of the boat's hull, and the propeller shaft penetrates beneath the hull. Stern drives are located near the back of the boat. Stern drives have permanently mounted engines, however, the drive train penetrates the transom of the vessel.

Description of the Evaluated Recreational Boats

<u>Boats evaluated</u>

Boat 1 (33')

- **Engines:** Twin Volvo Penta 5.7L
- **Generator:** Gas 120 v 5.0 KW Kohler
- **Approximate dimensions of boat:**
    - Length: 34'8"
    - Beam: 11' 4"
- **Exhaust Configuration:** Exhaust through hub

Boat 2 (30')

- **Engines:** Twin Mercruiser 5.0L
- **Generator:** Gas 120 v 5.0 KW Kohler
- **Approximate dimensions of boat:**
    - Length: 30'10"
    - Beam: 10' 6"
- **Exhaust Configuration:** Exhaust through hub

Boat 3 (31')

- **Engines:** Twin Volvo Penta 8.1L
- **Generator:** Gas 120 v 7.3 KW Kohler
- **Approximate dimensions of boat:**
    - Length: 33'1"
    - Beam: 11'0"

- **Exhaust Configuration:** Exhaust through hub

Boat 4 (37')

- **Engines:** Twin Mercruiser 8.1L
- **Generator:** Gas 120 v 7.3 KW Kohler
- **Approximate dimensions of boat:**
  - Length: 38’4”
  - Beam: 10’ 6”
- **Exhaust Configuration:** Equipped with both through transom and through hub (underwater) selectable by operator.

Boat 5 (36')

- **Engines:** Twin Mercruiser 8.1L
- **Generator:** Gas 120 v 7.3 KW Kohler
- **Approximate dimensions of boat:**
  - Length: 39’0”
  - Beam: 12’6”
- **Exhaust Configuration:** Combined Exhaust Through the Sides and Underwater

Boat 6 (40')

- **Engines:** Twin Mercruiser 8.1L
- **Generator:** Gas 120 v 7.3 kW Kohler
- **Approximate dimensions of boat:**
  - Length: 45’0”
  - Beam: 14’0”
- **Exhaust Configuration:** Combined Exhaust Through the Sides and Underwater

Boat 7 (41’)

- **Engines:** Twin Mercruiser 8.1L
- **Generator:** Gas 120 v 7.3 KW Kohler
- **Approximate dimensions of boat:**
  - Length: 42’6”
  - Beam: 13’8”
- **Exhaust Configuration:** Combined Exhaust Through the Sides and Underwater

Boat 8 (34')

- **Engines:** Twin Mercruiser 8.1L
- **Generator:** Gas 120 v 7.3 kW Kohler
- **Approximate dimensions of boat:**
  - Length: 36’6”
  - Beam: 11’8”
- **Exhaust Configuration:** Side Exhaust only

Boat 9 (38’)

- **Engines:** Twin Crusader 8.1L
- **Generator:** Gas 120 v 8.0 KW Kohler

- **Approximate dimensions of boat:**
  - Length: 38’11”
  - Beam: 14’4”
- **Exhaust Configuration:** Underwater Exhaust

Boat 10 (35’)

- **Engines:** Twin Crusader 8.1L
- **Generator:** Gas 120 v 8.0 KW Kohler
- **Approximate dimensions of boat:**
  - Length: 35’2”
  - Beam: 13’4”
- **Exhaust Configuration:** Underwater Exhaust

Exhaust Configurations Evaluated

The following notes refer to the different exhaust configurations evaluated:

- Through-Hub Exhaust: Through-hub exhaust and over-hub exhaust propellers are used on boats where the exhaust passes out through the rear of the "torpedo" on the lower unit, around the propeller shaft. Most outboards utilize this type of exhaust.

- Through Transom Exhaust: The exhaust is directed through openings located on the transom (stern) of the vessel, usually above water line.

- Side Exhaust: The exhaust is directed through openings located on the sides of the boat near the transom of the vessel, usually above water line.

- Underwater Exhaust: The exhaust is directed through openings located on the transom (stern) of the vessel, and then released through an elbow shaped fiberglass structure about 1.5 ft below the water line.

- Combined Exhaust through Sides and Underwater: The system is engineered to release all the exhaust at the surface through the sides of the vessel when the engine is idling or the rpm has not exceeded 1500 rpm. When the engine exceeds 1500 rpm, a pressure release mechanism is activated releasing most of the exhaust underwater, a foot away from the transom, on the lower part of the vessel hull.

There are several differences between automobile engines and marine engines used on recreational boats relate to the cooling and exhaust systems. The cooling system in an automobile engine is closed-loop having air-to-water radiators. In contrast, marine engines are open-loop drawing sea or lake water into the engine’s water pump. The second big difference between auto and marine engines is that marine engines use water-cooled exhaust manifolds to mix water with exhaust gases for cooling. The objective is to keep all surface temperatures within the boat below 200°F. In contrast, automobile engines do not add water into the engine exhaust. A third difference relates to the treatment of the exhaust gases before releasing them to the atmosphere. In automobile engines, the exhaust passes through a catalytic converter which removes many of the air pollutants, including CO. In contrast, exhausts from marine engines are directly released into the environment without passing through a catalyst.

The hot exhaust gases produced by the generators were injected with water, near the end of the exhaust manifold, in a process commonly called "water-jacketing." Water-jacketing is used for exhaust cooling and noise reduction. All generators in this study exhausted on one side of the boat, close to the transom of the vessel above the water line.

Description of the Evaluation Equipment

- Biometrics Inc., ToxiUltra Atmospheric Monitors equipped with CO sensors
- TSI Inc., Q-trak equipped with CO sensor
- Sensidyne handheld smoke tubes
- TSI Inc., Velocicalc Plus Model 8360 air velocity meter with micro manometer
- Draeger Accuro Handheld colorimetric detector tubes
- Rosco Fog Machine
- Mine Safety and Health Administration (MSHA) Glass evacuated containers

CO concentrations were measured at various locations on the boat by ToxiUltra Atmospheric Monitors (Biometrics, Inc.), equipped with CO sensors. ToxiUltra CO monitors were calibrated before and after use, according to the manufacturer's recommendations. These monitors are direct-reading instruments, having data logging capabilities. The instruments were operated in the passive diffusion mode, having a 30 second sampling interval. The instruments have a nominal range, from 0 ppm to approximately 999 ppm.

CO concentration data was also collected with colorimetric detector tubes (Draeger A.G. [Lubeck, Germany] CO, CH 29901– range 0.3% [3,000 ppm] to 7% [70,000 ppm]) in the areas near the rear swim deck. Having a bellows–type pump, allows air to be drawn through the tube. The resulting length of the stain in the tube (produced by a chemical reaction with the sorbent) is proportional to the concentration of the air contaminant. Grab samples were collected using MSHA 50–mL glass evacuated containers. These samples were collected by snapping open the top of the glass container and allowing the air to enter. Then, containers were sealed with wax–impregnated MSHA caps. The samples were then sent to DataChem laboratories in Salt Lake City, UT, where a Varian 3800 gas chromatography equipped with a methanizer and thermal conductivity, flame ionization and electron capture detectors, was used to analyze them for CO.

During air sampling, researchers took wind velocity measurements when the boat was stationary or measured air velocity with respect to the boat when it was underway, by using a VelociCalc Plus Model 8360 air velocity meter (TSI Inc., St. Paul, MN). The air velocity meter measured wind speeds based upon the heat transfer to the air from a heated probe. The same instrument was also used as a pressure differential device to compare the pressure between the engine compartment and adjacent cabin space. Boat speed was estimated using Magellan Meridian Marine global positioning system. Smoke tubes and a Rosco fog machine device were used to assess air flow patterns on the moving boat and qualitatively assess whether the engine emissions were being re-entrained into the boat under various operating conditions.

Description of Procedures

Evaluations were conducted on various boats and involved teams of several people. Each team consisted of: 1) a person to steer the boats, start the engines, and provide mechanical assistance when necessary, this person was usually from the collaborating organization; 2) two to three NIOSH researchers to collect data and organize experimentation; 3) an industry consultant; 4) a representative from the USCG to act in an advisory capacity. Following each day of data collection, NIOSH researchers downloaded data and recalibrated instruments. Two boats were typically evaluated per day. Testing took approximately three hours for each boat and included both stationary and underway conditions.

Testing was made with boats' canopies in various configurations. At a minimum, each boat was tested under the following conditions: 1) with canopy enclosing the cockpits fully closed except for the rear flaps open; 2) canopy fully enclosing the cockpit except for the rear and side flaps open; 3) canopy entirely removed except for the top section. Since each boat had a different canopy design, testing between boats was not entirely uniform, although attempts were made to approximate similar conditions from boat to boat. See Tables 1-5 for specifics on testing conditions and canopy configurations. For each canopy configuration, underway boat emissions were evaluated at five different speeds: stationary, 5 miles per hour (mph), 10 mph, 15 mph and 25 mph.

Boat speed was measured by onboard Global Positioning System (GPS) equipment. When possible, researchers conducted testing both into the wind and with the wind; however, this was not possible for testing where boat direction was dictated by channel routes. Temperature and relative humidity were measured every time a new run was initiated. Researchers gathered CO samples at various locations on the boat and in the engine compartment using ToxiUltra monitors (see Figure 1). Monitors were partially wrapped in plastic to protect them from water. All CO monitors and stop watches were synchronized with the computer's clock to accurately correlate each test with downloaded data. Monitors were placed at various locations on the boats, in part, 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.

Through an interactive approach, evaluations were performed to establish how carbon monoxide flows into an express cruiser cabin. First, tests were conducted to determine the presence of CO within the engine room. Potential sources of CO contamination could result from a propulsion engine leak or induction of exhaust gases into the engine compartment via the blower system. For positive results, additional tests were conducted to determine if leakage from the engine compartment was making its way to the cabin (e.g., unsealed firewall). Pressure differential measurements were collected between the engine compartment and the adjacent cabin. If the pressure within the engine compartment is positive with respect to the cabin, the potential for flow from the engine compartment to the cabin exists. Additional measurements using CO real-time detectors and smoke generators were used to track the flow of carbon monoxide from the engine compartment to the adjacent cabin area.

In addition to CO sampling and air velocity measurements, all warning labels placed on the boat, as well as those provided in the owner's manual were inspected for each of the evaluated boats.

RESULTS

Results of Air Sampling with ToxiUltra CO Monitors

Summary statistics for the data collected with the ToxiUltra CO monitors are shown in Tables 6 through 15. These tables are organized so that the experiment number is designated along the left-hand column and ToxiUltra number is listed across the top row. For each sample location and condition a CO mean (Tables 6, 8, 10, 12, and 14) and peak concentration (Tables 7, 9, 11, 13, and 15) is reported. Each CO mean and standard deviation is rounded to the nearest whole number. CO concentrations exceeding approximately 1,000 ppm in Tables 6 through 15 indicate that the upper limit of the instrument was reached and the exact CO concentration and duration is uncertain. Graphs depicting the average CO concentrations in Tables 6 through 15 for selected boats and conditions are shown in Figures 5 through 14.

ToxiUltra CO Samples while the Boat was Underway

Air sampling data was collected while the boats were underway, resulting in generally lower concentrations than while the boats were stationary. CO concentrations measured on the boats tended to rise near the cockpit and swimming platform as the boats began to move and as speed increased (see graphs in Figures 5-14). Figure 1 details specific locations that CO concentrations were measured, which include the following:

- On or near the swimming platform (Port, Center and Starboard)
- Inside of the boat (Several locations within the cockpit)
- Inside the cabin (Two locations where beds or sofas are located)
- Inside the engine compartment

In Table 11, the CO concentrations were considerably lower on the swim platform and cockpit of the vessel compared to the other evaluated vessels. The highest mean concentration for a 36’ express cruiser was 293 ppm when going underway at 10 mph. The highest mean concentration on the cockpit of this unit was 73 ppm when going at 15 mph with partial canvas installed. Figures 9 and 10 represent the average concentration of the data presented in Table 11. The boats in these figures were equipped with a combined exhaust system, which exhausted through the sides and underwater.

Measured CO concentrations were substantially higher in boats exhausting above waterline. That is the case for boat depicted in Figure 8, equipped with Twin Mercruisers exhausting through four openings at the transom of the vessel above waterline. The highest mean concentration was 975 ppm (close to the NIOSH IDLH) on the swim platform of the vessel when going underway at 5 mph with canvas fully installed. CO concentrations in the cockpit of this unit were as high as 630 ppm behind the captain seat when canvas was fully installed and going at 5 mph. These results can be observed on Table 9.

In Figure 11, the CO concentration on the center of the swim platform did not followed the same pattern as the other vessels, in where CO concentrations tended to greatly reduce as speed increased. This unit is considered a Motor Yatch which geometric shape on the stern of the vessel is very different from a regular express cruiser. Average CO concentrations were around 250 ppm when going at 5, 10 and 15 mph. These concentrations dropped to 166 ppm when the boat increased speed to 25 mph. This unit was also equipped with a system which exhausted through the sides and underwater.

The data presented in Table 13 from experiment 14 to 29 shows the peak CO concentration for a 34' exhausting solely through the sides. Figure 12 depicts the different conditions with canvas, partial canvas and bimini top only. In this figure, it can be observed that CO concentrations were reduced by a factor of 10 when no canvas was installed (bimini top only) compared to full canvas conditions.

ToxiUltra CO Samples While the Boats were Stationary

CO concentrations measured on stationary boats were generally medium to high. Peak CO concentrations ranged from single digit numbers to approximately 950 ppm. Stationary conditions usually displayed higher CO concentrations than when the boat is moving for all of the evaluated vessels. For most cases, when testing boats on stationary conditions, virtually no air circulation other than environmental wind was sweeping the CO away from the vessel.

Detector Tubes and Evacuated Container Results

Colorimetric detector tubes, and glass evacuated containers were primarily used to characterize CO concentrations at the rear of the vessel. These instruments were used because they are capable of reading higher CO concentrations than the ToxiUltra CO monitors, which have an upper limit of approximately 1,000 ppm.

Summaries of the detector tube and evacuated container air sampling results are shown in Tables 16 through 25. In general, detector tube and evacuated container air sampling results support measurements made with the ToxiUltra instruments. Any variations in readings among different CO detection instruments for a particular experiment can be explained by one of several, expected reasons: 1) readings for ToxiUltra CO monitors have an upper limit of approximately 1000 ppm so that any readings above this level may be skewed; 2) although colorimetric detector tubes' accuracy is well established, this method makes a less precise measurement than other instruments used (typically within +/- 10%); and 3) measurements for any instrument will vary depending on the localized conditions at that instant.

Relative Wind Velocity Measurements

On the whole, wind velocity measurements were taken to be used as a reference to further investigate unexpected trends in CO concentrations. Wind velocity measurements were collected using a hot wire anemometer. Tables 26 to 29 provide relative wind velocities for various boats and test conditions. As expected, wind velocities varied relative to boat speed depending upon whether the boat was traveling into the wind or with the wind. It should be noted that relative wind velocities were not measured for boats evaluated in

Millville, NJ since the tests were conducted on an S-shaped river which produced constantly changing wind directions.

Smoke and Pressure Differential Tests
When underway, smoke tests revealed several trends on all the evaluated boats. When traveling at 5 – 10 mph with the canvas fully installed, the recirculation patterns were observed to be as high as 4ft measured from the cockpit floor. When traveling at 15 mph with canvas fully installed, this height was reduced to 3 ft from the cockpit floor. Finally when traveling at 25 mph the recirculation pattern was observed to be shifted to two feet measured from the cockpit floor. Figures 2, 3 and 4 provide an illustration of this scenario.

Smoke tests into the engine compartment of all of the evaluated vessels revealed satisfactory sealing of the bulkhead between the engine room and adjacent compartments. Virtually no migration was observed to adjacent rooms or cabin area when releasing smoke in the engine room. This test was performed without the operation of the powered ventilation of the engine compartment. When energizing the powered ventilation of the engine compartment, a good configuration of the intake and exhaust opening was observed for all of the evaluated vessels.

When underway, pressure differential measures revealed a slightly negative pressure in the cabin room compared to the cockpit area for some of the evaluated express cruisers.

DISCUSSION

Description of Trends for Individual Boats

Boat 1: 33' Twin Volvo Penta 5.7L Exhausting Through the Hub.
This boat exhibited CO levels exceeding 1000 ppm near the center of the stern for 10 and 15 mph into the wind and with the wind (with canvas fully installed). Fairly high concentrations were observed in the engine compartment when no canvas was installed (Bimini top only) at speeds of 15 and 25 mph. Potential CO leakage from the engine compartment was possible since the boat's drive engines and generator set were brand new.

CO levels inside the cabin ranged from 0 ppm to 170 ppm. This can partially be explained by continuous opening and closing of the cabin sliding door. CO levels varied within the vessel even at similar locations, a phenomenon that can be explained by wind factors and aerodynamics of the vessel. In general, CO distributions were higher at the stern of the boat (near source) and tended to decline toward the front of the vessel. Refer to Tables 6 and 7 and the graphs in Figure 5 for more details.

Boat 2: 30' Twin Mercruiser 5.0L Exhausting Through the Hub.
This boat exhibited CO concentrations that not only exceeded 1000 ppm but also approached the 1200 ppm NIOSH IDLH limit on the center of the stern, with and without canvas. The engine compartment on this vessel experienced CO concentrations approaching the NIOSH IDLH when canvas was installed and close to 1000 ppm when canvas was fully removed (bimini top only). The cockpit of this unit was usually cleared by fresh air, with the exception of 15 mph and no canvas installed. This fact can be attributed to weather conditions since no wind was present during that particular experiment. Cabin concentrations ranged from 0 to 180 ppm. Several attendees entered the cabin on different occasions allowing contaminated air to migrate from the cockpit to the cabin.

Exhibiting a trend seen on other tested boats, CO concentrations were higher on the stern of the vessel (near source), and tended to decrease toward the front of the vessel. The engine compartment consistently exhibited CO concentrations above 150 ppm, with a couple peaks at 1100 ppm; this might be indicative of a problem with the powered ventilation of this compartment. More details about this particular boat can be found in Tables 6 and 7 and the graphs in Figure 6.

Boat 3: 31' Twin Volvo Penta 8.1L Exhausting Through the Hub.
Peak concentration on this vessel exceeded 650 ppm at the stern of the boat when the canvas was fully installed. CO concentrations in the cockpit were below the NIOSH ceiling of 200 ppm at all times, and considerably lower when the canvas was fully removed (bimini top only). Inside the cabin CO concentrations never exceeded 60 ppm with an average concentration of 27 ppm. Engine compartment concentrations were well below 120 ppm when canvas was fully installed and below 45 ppm when canvas was fully removed. As with the other vessels, CO concentrations were consistently higher at

the stern of the boat, and gradually reduced toward the front of the vessel. Tables 8 and 9 and the graphs in Figure 7 contain additional information for this vessel.

Boat 4: 37' Twin Mercruiser 8.1L Exhausting Through the Transom.
This vessel was equipped with an adjustable exhaust system that allowed the operator to choose an exhaust configuration: through the transom above waterline or though the hub. For all experiments, the exhaust was routed through the transom. CO concentrations were consistently higher near the stern of the boat and reduced gradually toward the front of the vessel. CO concentrations ranged between 24 and 658 ppm at the stern of the boat. Inside the cabin, concentrations ranged from 3 to 166 ppm. The cabin door was closed at all times except when occupants visited the cabin. Overall, the engine compartment had low CO concentrations ranging from 17 to 100 ppm; however with the canvas fully installed, CO levels did rise to between 237 and 297 ppm. Cockpit concentrations tended to be higher when canvas was installed with an average of 200 ppm compared to 20 – 70 ppm when canvas was fully removed. Refer to Tables 8 and 9 and the graphs in Figure 8 for more details.

Boat 5: 36' Twin Mercruiser 8.1L Combined Exhaust Through the Sides and Underwater.
In terms of onboard CO concentrations, this boat performed remarkably better than other evaluated boats. The main reason for this is that the vessel was equipped with a combined exhaust configuration - the exhaust was directed not only through the sides of the vessel but also underneath the hull of the boat under certain conditions. As long as the engine was idling or the rpm had not exceeded 1500 rpm, the exhaust was directed through the sides of the vessel only. However when the engine built enough pressure on the exhaust to overcome the pressure below the hull, 85% of the exhaust was directed underwater and the remaining 15% exhausted through the sides of the vessel.

CO concentrations at the stern of the unit were consistently below the NIOSH ceiling limit of 200 ppm with the canvas fully installed and below 50 ppm when the canvas was fully removed. The engine compartment was completely clear of CO contamination indicating a good design and operation of the powered ventilation system on the engine compartment. CO concentrations in the cabin never exceeded 18 ppm when the canvas was fully installed and 10 ppm when the canvas was fully removed. Cockpit concentrations were consistently below 90 ppm at all times when the canvas was fully installed and below 12 ppm when the canvas was removed. More details about this particular boat can be found in Tables 10 and 11 and the graphs in Figure 9.

Boat 6: 40' Twin Mercruiser 8.1L Combined Exhaust Through the Sides and Underwater.
This boat was equipped with the combined exhaust configuration described above - the exhaust was directed not only through the sides of the vessel but also underneath the hull of the boat under certain conditions. As long as the engine was idling or the rpm had not exceeded 1500 rpm, the exhaust was directed through the sides of the vessel only. However when the engine built enough pressure on the exhaust to overcome the pressure below the hull, 85% of the exhaust was directed underwater and the remaining 15%

exhausted through the sides of the vessel. Although this vessel performed better than other boats evaluated, it still exhibited higher concentrations at the stern of the vessel than boats equipped with the same exhaust configuration.

CO concentrations at the stern of the vessel ranged from 30 to 430 ppm when the canvas was fully installed and between 0 and 67 ppm when the canvas was fully removed. The engine compartment was completely clear of CO contamination indicating a good design and operation of the powered ventilation system. Cockpit concentrations never exceeded 75 ppm when the canvas was fully installed and 25 ppm without the canvas.

Concentrations in the cabin never exceeded 20 ppm even with the canvas fully installed. This indicates a good sealing of the cabin sliding door. Tables 10 and 11 and the graphs in Figure 10 contain additional information for this vessel.

Boat 7: 41' Motor Yatch Twin Mercruiser 8.1L Combined Exhaust Through the Sides and Underwater.

This unit was slightly different from the other tested boats, since the cockpit was located much higher from the water level than for other express cruisers. CO concentrations at the stern of the vessel were consistently above 300 ppm with or without the canvas installed. ToxiUltra CO monitors were placed on the stern of the unit where the canvas configuration recessed a few inches higher than the sensor locations. The “station wagon” effect caused by exhaust being drawn into the vessel at this location might be an explanation of why levels remained high throughout all experiments despite the installation of rear and side curtains.

The cabin door was kept closed at all times, and inside levels never exceeded 17 ppm. This indicates a good sealing of the sliding cabin door and adjacent compartments. CO concentrations in the engine compartment never exceeded 80 ppm when the canvas was installed and 41 ppm when the canvas was fully removed. Cockpit concentrations ranged between 0 and 50 ppm with the canvas fully installed. Refer to Tables 12 and 13 and the graphs in Figure 11 for more details.

Boat 8: 34’ Twin Mercruiser 8.1L Combined Exhaust Through the Sides.

CO concentrations near the stern of this particular vessel were much higher with the canvas fully installed than without it. When all curtains were installed, peak concentrations of 500 ppm were observed for extended periods of time at speeds of 10 mph. When the canvas was fully removed (bimini top only), peak concentrations ranged from 70 to 80 ppm at 25 mph.

In the engine compartment, peak concentrations up to 143 ppm were displayed with the canvas installed, compared to 31 ppm without the canvas. CO concentrations inside the cockpit were reduced by a magnitude of 10 when the canvas was fully removed for all experiments (350 ppm vs. 7 – 35 ppm). More details about this particular boat can be found in Tables 12 and 13 and the graphs in Figure12.

Boat 9: 38' Twin Crusader 8.1 L Exhaust Underwater.
Peak concentration on this vessel exceeded 500 ppm at the stern of the boat when the canvas was fully installed. CO concentrations in the cockpit were below the NIOSH ceiling of 200 ppm at all times, and lower when the canvas was fully removed (bimini top only). Inside the cabin CO concentrations never exceeded 60 ppm. Engine compartment concentrations were well below 120 ppm at all times. As with the other vessels, CO concentrations were consistently higher at the stern of the boat and were gradually reduced toward the front of the vessel. Tables 14 and 15 and the graphs in Figure 13 contain additional information for this vessel.

Boat 10: 35' Motor Yacht Twin Crusader 8.1 L Exhaust Underwater.
This boat exhibited CO concentrations that not only exceeded 1000 ppm but also approached the 1200 NIOSH IDLH limit on the center of the stern, with and without the canvas. CO concentrations in the cockpit were below the NIOSH ceiling of 200 ppm at all times, and much lower when the canvas was fully removed (bimini top only). Engine compartment concentrations were well below 200 ppm at all times. In general, CO concentrations were consistently higher at the stern of the boat, and were gradually reduced toward the front of the vessel. Furthermore, CO concentrations tended to decrease at higher speeds. Refer to Tables 14 and 15 and the graphs in Figure 14 for more details.

Summary of Trends for All Boats
As shown above, there was a high degree of variation in the performance of different boats in terms of onboard CO concentrations. Several of the factors influencing these results include:

- Exhaust configuration (Hub, Transom, Underwater, Sides)
- Canvas configurations
- Boat speed
- Wind conditions
- CO generation rate
- Boat design and shape
- Distance between exhaust outlets and individual's breathing zone
- Fresh air ventilation of the cockpit and occupied areas

Behavior of Exhaust Gases in Underwater Exhaust Configurations
In terms of positively influencing onboard CO concentrations, the results above demonstrate that boats equipped with underwater exhaust exhibited significantly lower CO concentrations than vessels equipped with other exhaust designs. Since this factor is also one controllable by boat manufacturers, a discussion of the mechanics underlying this method of CO control is presented here.

For underwater exhaust systems, the rise of gases through water is governed by bubble size and depth of injection. The prop wash, or turbulent churning of water by the boat's propeller, may also affect the rate of release of gas into the atmosphere by: 1) breaking large bubbles into smaller bubbles, 2) causing bubbles to coalesce, or 3) by propelling bubbles deeper into the water [NIOSH 2005].

Regarding the behavior of individual bubbles, small bubbles (less than 1 millimeter in diameter) have a low rise velocity, and as a result, are likely to be spherical and rise in a straight path. As bubbles grow larger, their rise velocity increases, resulting in a less stable ellipsoidal bubble shape. The prop may cause some of the larger bubbles to break up and become smaller, giving more time for the bubbles to reach the surface and further reducing CO concentrations close to the boat. By implementing underwater exhaust configurations that entrain exhaust through the prop wash, the potential for CO from the exhaust to be pulled and re-entrained into the boat is greatly reduced.

Influence of Canvas Configuration on Station Wagon Effect

As stated previously, a significant station wagon effect was documented for many of the experiments conducted. This effect is produced when negative pressures at the rear of the boat and cockpit areas, which are generated when the boat is underway, draw exhaust gases, including CO, from behind the boat into inhabited areas. This effect was maximized when the boat was traveling at low speeds into the wind with the canvas fully deployed and no forward hatches, windows, or front panels opened. This stands to reason since the protection of the canvas and windows while underway serves to create a pocket of negative pressure relative to the outside. Conversely, when the canvas was removed not only was a negative pressure pocket less likely to be created, but air being drawn directly into the cockpit tended to ventilate the area.

Another interesting trend regarding the station wagon effect was observed. With the canvas installed, CO concentrations did not always change as much as expected at higher speeds. Rather it was documented that areas of high onboard CO concentration merely shifted. Figures 12-14 show a typical scenario. At lower speeds of 5-10 mph, exhaust air was re-entrained into the cockpit up to four feet from the cockpit floor. However, at 15 mph, higher CO levels were found closer to the cockpit floor. And at 25 mph, with the canvas installed, high CO concentrations were found only very close to the cockpit floor (as low at 2 ft.) on most models of boat tested. The significance of these observations is that, depending on the various boat designs and ambient factors, operating the boat at higher speeds is no guarantee of adequately ventilating inhabited areas of the boat when the canvas is installed.

CONCLUSIONS AND RECOMMENDATIONS

Analysis of the results made several trends apparent. Chief among these are the following:

- When the canvas is deployed, CO concentrations reached instantaneous levels above the IDLH near the swimming platform for some of the evaluated boats.
- Canvas configuration significantly affects CO concentrations in the cockpit area.
- The combination of travel at low speeds into the wind with the canvas fully deployed and no forward hatches, windows or front panels opened maximized the station wagon effect, pulling significant amounts of CO into the cockpit.
- Different exhaust configurations have a major impact on how CO concentrations are entrained into the cockpit and other occupied areas. Accordingly, boats equipped with underwater exhaust exhibited significantly lower CO concentrations than vessels equipped with other exhaust designs.
- CO concentrations are typically higher at the stern of the boat and become gradually lower toward the front of the boat.
- Recirculation patterns varied with the boat speed. At lower speeds the recirculation was observed to be as high as 4 ft measured from cockpit floor. This height was reduced to 2 ft when going at 25 mph.
- Stationary smoke tests in the engine compartment showed satisfactory sealing of the bulkhead between the engine and adjacent compartments on all boats.
- Warning labels were missing important information to properly warn users of potential hazards and preventive/corrective measures to prevent CO poisonings.
- When underway, with the cabin door closed, the cabin is typically under negative pressure when the A/C is running. This condition can lead to CO intrusions if a leak should occur.

Based on the preceding results and observations, the following recommendations are made regarding lowering CO concentrations on express cruisers to appropriate levels, and also future research regarding the issue:

- Underwater exhaust will significantly reduce CO concentrations inside the cockpit and other occupied areas compared to surface exhaust.
- Because of the station wagon effect, some canvas configurations should not be used while the boat is moving or propulsion and/or generator engines are running.
- The possibility of adding force draft blowers into the cabin, creating a positive pressure to minimize CO intrusions, should be studied. Auxiliary blowers can be fitted and routed to ventilate the cockpit and swim platform areas in order to minimize or break negative pressure areas throughout the vessel.
- Since properly sealed cabin doors directly influenced the level of CO in cabins, door suppliers should be encouraged to develop better sealing methods and designs.
- Windshield manufacturers should be encouraged to study the possibility of maximizing ventilation of occupied areas by improving the design of the center

and side wings of the windshield.

- Due care should be exercised when designing the powered ventilation system on the engine compartment to locate the air intake on the opposite side of the generator exhaust. Also, potentially moving the intake farther forward on the vessel would help minimize the intake of CO exhaust into the engine compartment.
- The development of cleaner burning engines with catalytic converters should be continued since they have the potential to greatly reduce CO concentrations to safer levels.
- It is recommended that the American Boat and Yacht Council (ABYC) examine their standards and emphasize ventilation problems that can lead to CO intrusions, taking a strong position against through-transom exhaust designs. Since the National Marine Manufacturers Association (NMMA) uses ABYC standards in their certification, the result will be a large number of boats built to this higher standard.
- Computational fluid dynamics (CFD) and other types of modeling should continue to be conducted to better assess exhaust plume configurations.
- Further research should be made to evaluate new control technologies to reduce CO concentrations on express cruisers as they continue to emerge.

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Table 1: Experiment Conditions, Boats 1 & 2

Exp #	Target Speed (mph)	Back Flaps Open	Front Flap Open	All Other Flaps Open	Front Windshield Open	Gen. on	***Into*** wind or ***With*** wind	Other Notes
1	5	y	n	n	n	y	i	Boat 1
2	5	y	y	n	n	y	i	Boat 1
3	5	y	y	n	n	y	w	Boat 1
4	5	y	n	n	n	y	w	Boat 1
5	10	y	y	n	n	y	i	Boat 1
6	10	y	y	n	n	y	w	Boat 1
7	15	y	y	n	n	y	i	Boat 1
8	15	y	y	n	n	y	w	Boat 1
9	25	y	y	n	n	y	i	Boat 1
10	25	y	y	n	n	y	w	Boat 1
11	10	y	n	n	n	y	i	Boat 1
12	25	y	n	n	n	y	i	Boat 1
13	25	y	n	n	n	y	w	Boat 1
14	5	y	y	y	n	y	i	Boat 1
15	5	y	y	y	n	y	w	Boat 1
16	10	y	y	y	n	y	i	Boat 1
17	10	y	y	y	n	y	w	Boat 1
18	15	y	y	y	n	y	i	Boat 1
19	15	y	y	y	y	y	w	Boat 1
20	25	y	y	y	y	y	i	Boat 1
21	25	y	y	y	y	y	w	Boat 1
22	15	y	y	y	n	y	n/a	Boat 1 / hatch and 2 side windows open in cabin
23	15	y	y	y	n	n	n/a	Boat 1 / hatch and 2 side windows closed in cabin
24	n/a	y	y	y	y	y	n/a	Boat 1 / at dock / generator and air conditioner on
25	5	y	y	n	n	y	n/a	Boat 2
26	10	y	y	n	n	y	n/a	Boat 2
27	5	y	n	n	n	y	n/a	Boat 2 / stopped early CO levels too high
28	15	y	y	n	n	y	n/a	Boat 2
29	25	y	y	n	n	y	n/a	Boat 2
30	5	y	y	y	n	y	n/a	Boat 2
31	10	y	y	y	n	y	n/a	Boat 2
32	15	y	y	y	n	y	n/a	Boat 2
33	15	y	y	y	y	y	n/a	Boat 2
34	25	y	y	y	y	y	n/a	Boat 2
35	15	y	y	y	n	y	n/a	Boat 2 / hatch and 2 side windows open in cabin
36	15	y	y	y	n	n	n/a	Boat 2 / hatch and 2 side windows closed in cabin
37	32	y	y	y	y	n	n/a	Boat 2
38	n/a	y	y	y	y	y	n/a	Boat 2 / at dock / generator and AC on

Table 2: Experiment Conditions, Boats 3 & 4.

Exp. #	Target Speed (mph)	Back Center Flaps Open	Back Side Flaps Open	Front Flap Open	All Other Flaps Open	Front Windshield Open	Gen. on	***Into*** wind or ***With*** wind	Other Notes
1	n/a	y	n	n	n	n	y	near dead calm	Boat 4 / AC is on /' drive engines off
2	5	y	n	n	n	n	y	near dead calm	Boat 4 / stopped short lots of alarms going off
3	25	y	n	y	n	n	y	near dead calm	Boat 4
4	15	y	n	y	n	n	y	near dead calm	Boat 4
5	10	y	n	y	n	n	y	near dead calm	Boat 4
6	25	y	n	n	n	n	y	near dead calm	Boat 4
7	15	y	n	n	n	n	y	near dead calm	Boat 4
8	25	y	y	y	n	n	y	n/a	Boat 4
9	15	y	y	y	n	n	y	n/a	Boat 4 / high levels of CO detected / opened all flaps after experiment
10	15	y	y	y	y	n	y	n/a	Boat 4
11	15	y	y	y	y	y	y	n/a	Boat 4
12	5	y	y	y	y	n	y	n/a	Boat 4
13	10	y	y	y	y	n	y	n/a	Boat 4
14	25	y	y	y	y	y	y	n/a	Boat 4
15	15	y	y	y	y	y	y	n/a	Boat 4 / 4 hatches and 2 portholes open in cabin
16	10	y	y	y	y	n	y	n/a	Boat 4 / hatches closed BUT exhaust through hub
17	5	y	y	y	y	n	y	n/a	Boat 4
18	n/a	y	y	n	n	n	y	not measured	Boat 3 / stationary at dock
19	25	y	y	n	n	n	y	not measured	Boat 3
20	15	y	y	n	n	n	y	not measured	Boat 3
21	10	y	y	n	n	n	y	not measured	Boat 3
22	5	y	y	n	n	n	y	not measured	Boat 3
23	5	y	y	y	n	n	y	not measured	Boat 3
24	10	y	y	y	n	n	y	not measured	Boat 3
25	15	y	y	y	n	n	y	not measured	Boat 3
26	25	y	y	y	n	n	y	not measured	Boat 3
27	5	y	y	y	y	n	y	not measured	Boat 3
28	10	y	y	y	y	n	y	not measured	Boat 3
29	15	y	y	y	y	n	y	not measured	Boat 3
30	15	y	y	y	y	y	y	not measured	Boat 3
31	25	y	y	y	y	y	y	not measured	Boat 3
32	15	y	y	y	y	y	y	into wind	Boat 3 / 3 hatches and 5 windows in cabin open

Table 3: Experiment Conditions, Boats 5 & 6.

Exp #	Target Speed (mph)	Aft Curtain Open	Back Side Flaps Open	Front Flap Open	All Other Flaps Open	Front Ventilation Window Open	Generator on	***Into*** **wind or** ***With*** **wind**	Other Notes
1	5	y	n	n	n	y	y	n/a	Boat 5 / Exhaust through bypass at sides above the waterline
2	5	y	n	n	n	y	y	n/a	Boat 5 / Exhaust through bypass at sides above the waterline
3	10	y	n	n	n	n	y	n/a	Boat 5 / Exhaust underwater
4	15	y	n	n	n	y	y	n/a	Boat 5 / Exhaust underwater
5	15	y	n	n	n	n	y	n/a	Boat 5 / Exhaust underwater
6	25	y	n	n	n	n	y	n/a	Boat 5 / Exhaust underwater
7	25	y	y	n	n	n	y	n/a	Boat 5 / Exhaust underwater
8	15	y	y	n	n	n	y	n/a	Boat 5 / Exhaust underwater
9	15	y	y	n	n	y	y	n/a	Boat 5 / Exhaust underwater
10	10	y	y	n	n	n	y	n/a	Boat 5 / Exhaust underwater
11	5	y	y	n	n	n	y	n/a	Boat 5 / Exhaust underwater
12	15	y	y	y	n	n	y	n/a	Boat 5 / Exhaust underwater
13	25	y	y	y	y	n	y	n/a	Boat 5 / Exhaust underwater
14	15	y	y	y	y	n	y	n/a	Boat 5 / Exhaust underwater
15	5	y	y	y	y	n	y	n/a	Boat 5 / Exhaust underwater
16	10	y	y	y	y	n	y	n/a	Boat 5 / Exhaust underwater
17	15	y	y	y	y	y	y	n/a	Boat 5 / Exhaust underwater
18	15	y	y	y	y	y	y	n/a	Boat 5 / Exhaust underwater
19	25	y	n	n	n	n	y	n/a	Boat 6 / NE 3-5 mph
20	5	y	n	n	n	n	y	n/a	Boat 6 / NE 3-5 mph
21	10	y	n	n	n	n	y	n/a	Boat 6 / NE 3-5 mph
22	15	y	n	n	n	n	y	n/a	Boat 6 / NE 3-5 mph
23	15	y	n	n	n	y	y	n/a	Boat 6 / NE 3-5 mph
24	5	y	y	n	n	n	y	n/a	Boat 6 / NE 3-3 mph
25	10	y	y	n	n	n	y	n/a	Boat 6 / NE 3-3 mph
26	15	y	y	n	n	n	y	n/a	Boat 6 / NE 3-3 mph
27	15	y	y	n	n	y	y	n/a	Boat 6 / NE 3-3 mph
28	25	y	y	n	n	n	y	n/a	Boat 6 / NE 3-3 mph
29	15	y	y	y	n	n	y	n/a	Boat 6 / E 5-10 mph
30	25	y	y	y	y	n	y	n/a	Boat 6 / E 5-10 mph
31	15	y	y	y	y	n	y	n/a	Boat 6 / E 5-10 mph
32	15	y	y	y	y	y	y	n/a	Boat 6 / E 5-10 mph
33	5	y	y	y	y	n	y	n/a	Boat 6 / E 5-10 mph
34	10	y	y	y	y	n	y	n/a	Boat 6 / E 5-10 mph
35	15	y	y	y	y	n	y	n/a	Boat 6 / Hatch open and cabin door open
36	0	y	y	y	y	n	y	n/a	Boat 6 / Idle at the dock

Table 4: Experiment Conditions, Boats 7 & 8.

Exp #	Target Speed (mph)	Aft Curtain Open	Back Side Flaps Open	Front Flap Open	All Other Flaps Open	Front Ventilation Window Open	Generator on	***Into*** wind or ***With*** wind	Other Notes
1	5	y	n	n	n	n	y	n/a	Boat 7
2	10	y	n	n	n	n	y	n/a	Boat 7
3	15	y	y	n	n	n	y	n/a	Boat 7
4	25	y	y	n	n	n	y	n/a	Boat 7
5	5	y	y	n	n	n	y	n/a	Boat 7
6	10	y	y	n	n	n	y	n/a	Boat 7
7	15	y	y	y	y	n	y	w	Boat 7
8	25	y	y	y	y	n	y	w	Boat 7
9	5	y	y	y	y	n	y	w	Boat 7
10	10	y	y	y	y	n	y	i	Boat 7
11	15	y	y	y	y	n	y	i	Boat 7
12	5	y	y	y	y	n	y	i	Boat 7
13	10	y	y	y	y	n	y	i	Boat 7
14	15	y	n	n	n	n	y	i	Boat 7
15	5	y	n	n	n	n	y	i	Boat 8
16	10	y	n	n	n	n	y	i	Boat 8
17	15	y	n	n	n	n	y	i	Boat 8
18	25	y	y	n	n	n	y	i	Boat 8
19	5	y	y	n	n	n	y	i	Boat 8
20	10	y	y	n	n	n	y	i	Boat 8
21	15	y	y	n	n	n	y	w	Boat 8
22	25	y	y	y	y	n	y	w	Boat 8
23	5	y	y	y	y	n	y	w	Boat 8
24	10	y	y	y	y	n	y	w	Boat 8
25	15	y	y	y	y	n	y	w	Boat 8
26	25	y	y	y	y	y	y	i	Boat 8
27	5	y	y	y	y	y	y	w	Boat 8
28	5	y	n	n	n	n	y	n/a	Boat 8
29	5	y	n	n	n	n	y	n/a	Boat 8

Table 5: Experiment Conditions, Boats 9 & 10.

Exp #	Target Speed (mph)	Aft Curtain Open	Back Side Flaps Open	Front Flap Open	All Other Flaps Open	Front Ventilation Window Open	Generator on	***Into*** wind or ***With*** wind	Other Notes
1	5	yes	no	no	no	no	yes	n/a	Boat 9
2	10	yes	no	no	no	no	yes	n/a	Boat 9
3	15	yes	no	no	no	no	yes	n/a	Boat 9
4	20	yes	no	no	no	no	yes	n/a	Boat 9
5	25	yes	no	no	no	no	yes	n/a	Boat 9
6	5	yes	yes	no	no	no	yes	n/a	Boat 9
7	10	yes	yes	no	no	no	yes	n/a	Boat 9
8	15	yes	yes	no	no	no	yes	n/a	Boat 9
9	25	yes	yes	no	no	no	yes	n/a	Boat 9
10	10	yes	yes	yes	yes	no	yes	n/a	Boat 9
11	5	yes	yes	yes	yes	no	yes	n/a	Boat 9
12	At Dock	yes	no	no	no	no	yes	n/a	Boat 9
13	5	yes	no	no	no	no	yes	n/a	Boat 10
14	10	yes	no	no	no	no	yes	n/a	Boat 10
15	15	yes	no	no	no	no	yes	n/a	Boat 10
16	25	yes	no	no	no	no	yes	n/a	Boat 10
17	5	yes	yes	no	no	no	yes	n/a	Boat 10
18	10	yes	yes	no	no	no	yes	n/a	Boat 10
19	15	yes	yes	no	no	no	yes	n/a	Boat 10
20	25	yes	yes	no	no	no	yes	n/a	Boat 10
21	10	yes	yes	yes	yes	no	yes	n/a	Boat 10
22	5	yes	yes	yes	yes	no	yes	n/a	Boat 10
23	At Dock	yes	no	no	no	no	yes	n/a	Boat 10

Table 6: Average ToxiUltra CO Values, Boats 1 & 2.

All measurements are expressed in parts per million (ppm)

Experiment #	TU1	TU2	TU3	TU4	TU5	TU6	TU8	TU10	TU11	TU12
1	209	303	75	204	61	220	183	85		
2	46	274	118	39	49	27	32	51		
3	14	24	41	18	48	19	18	24		
4	37	61	98	28	48	30	22	15		
5	537	912	215	316	52	71	94	52		
6	437	919	69	100	64	171	111	80		
7	285	798	193	159	49	43	76	36		
8	40	177	46	22	47	18	14	15		
9	45	191	49	29	46	12	14	7		
10	1	45	25	7	46	7	2	1		
11	334	423	130	333	69	306	252	87		
12	48	62	33	65	51	62	64	54	54	
13	15	38	20	38	49	28	27	22	32	
14	37	34	17	9	47	23	30	18	41	13
15	117	351	17	12	50	25	19	10	296	140
16	11	22	28	8	47	13	10	6	24	20
17	31	58	6	10	47	18	17	6	59	32
18	228	294	176	111	55	157	141	80	321	188
19	170	537	45	15	53	22	3	37	511	224
20	52	177	6	6	47	7	0	4	179	65
21	26	220	17	10	47	6	-1	3	193	94
22	334	521	176	167	62	87	110	0	460	281
23	197	257	50	105	60	156	136	50	221	206
24	3	5	3	5	47	15	7	0	6	9
25	48	595	247	14	48	17	39	34	591	193
26	20	497	213	18	48	13	21	12	470	118
27	388	682	372	438	82	139	156	28	689	240
28	69	1084	57	45	47	16	24	12	1143	154
29	8	821	22	12	47	7	7	1	850	68
30	161	474	281	91	55	53	67	20	438	190
31	106	120	33	126	47	21	36	25	118	77
32	241	371	440	178	64	195	220	135	334	144
33	324	675	797	89	83	143	7	107	621	217
34	83	152	125	35	50	16	0	26	153	58
35	154	199	307	124	62	18	16	0	197	87
36	214	401	434	345	68	245	221	205	346	131
37	121	277	250	95	56	16	2	13	259	92
38	35	24	21	19	47	19	10	10	24	51

Table 7: Maximum ToxiUltra CO Values, Boats 1 & 2.

(light shading)	Above 50 ppm
(medium shading)	Above 200 ppm
(dark shading)	Above 1000 ppm

Experiment #	TU1	TU2	TU3	TU4	TU5	TU6	TU8	TU10	TU11	TU12
1	257	469	120	265	65	273	221	89	0	0
2	133	347	227	69	50	39	61	76	0	0
3	38	74	197	39	49	32	26	25	0	0
4	91	246	166	52	49	39	31	17	0	0
5	997	1091	496	550	58	143	154	78	0	0
6	708	1091	139	152	72	271	167	83	0	0
7	590	1080	348	426	51	77	174	53	0	0
8	106	382	103	49	50	38	22	19	0	0
9	69	340	167	48	47	17	27	15	0	0
10	5	300	163	23	47	14	3	2	0	0
11	406	488	203	351	71	328	281	135	0	0
12	78	173	111	88	52	83	89	76	126	0
13	26	181	81	152	55	39	39	35	100	0
14	124	114	28	19	48	41	72	34	150	20
15	438	709	45	25	56	78	44	23	631	327
16	17	34	39	11	47	14	13	8	36	26
17	55	110	27	17	51	26	28	7	103	92
18	487	584	255	235	59	270	251	173	554	323
19	512	860	131	33	75	54	5	67	789	379
20	105	237	13	14	47	11	1	8	287	88
21	65	329	40	47	48	18	1	22	317	146
22	744	730	321	221	79	303	175	0	736	431
23	684	649	147	329	81	519	401	101	556	604
24	5	13	5	62	54	103	72	0	9	32
25	57	1081	741	21	52	23	75	46	1011	250
26	33	722	665	114	56	21	22	18	668	194
27	529	879	515	603	104	241	248	33	839	274
28	132	1084	136	92	49	22	36	21	1143	288
29	12	1086	106	35	49	16	8	2	1145	111
30	318	973	594	312	64	166	142	21	831	267
31	142	142	45	187	47	30	54	26	146	81
32	522	865	1095	272	83	369	368	176	652	231
33	595	1086	1071	153	101	179	15	181	1049	433
34	159	310	305	56	53	25	-1	55	296	106
35	309	606	767	301	86	34	50	-1	508	161
36	883	1084	1056	1020	109	623	587	502	1096	259
37	453	1089	929	348	98	57	9	27	1147	250
38	199	274	98	107	50	100	42	16	290	140

Table 8: Average ToxiUltra CO Values, Boats 3 & 4.

All measurements are expressed in parts per million (ppm)

Experiment #	TU 1	TU 2	TU 3	TU 4	TU 5	TU 6	TU 7	TU 8	TU 10	TU 12
1	42	42	46	31	39	33	33	32	13	45
2	502	485	720	417	501	337	356	315	108	168
3	28	48	74	28	34	27	24	41	86	48
4	96	256	428	46	151	69	44	71	34	63
5	287	361	356	121	196	129	114	122	68	114
6	121	131	166	88	97	68	86	60	66	91
7	223	350	449	237	437	241	241	219	66	157
8	167	150	140	118	114	96	81	91	67	92
9	314	397	476	237	386	286	218	255	135	187
10	15	21	76	18	33	49	36	51	76	52
11	13	18	49	7	28	19	16	18	15	21
12	73	81	178	16	58	28	25	24	11	25
13	18	50	12	9	9	21	12	15	5	17
14	18	50	12	9	9	21	12	15	5	17
15	25	43	27	8	15	20	16	16	3	15
16	23	241	235	14	103	48	31	36	5	24
17	225	128	173	68	72	59	57	44	9	54
18	79	97	37	36	39	54	41	33	10	16
19	150	167	50	62	50	81	85	64	45	53
20	68	137	33	41	62	78	81	46	21	28
21	186	277	35	76	74	116	99	70	25	35
22	253	430	103	127	98	152	144	93	36	59
23	381	338	63	207	66	151	206	139	54	74
24	329	321	49	158	67	162	176	147	52	61
25	74	57	16	55	18	67	71	48	39	39
26	59	60	14	31	29	59	45	39	16	26
27	52	62	52	29	122	103	58	84	27	39
28	150	43	37	32	92	111	83	95	58	49
29	13	11	8	11	16	36	30	27	27	28
30	7	10	9	7	17	23	18	14	8	19
31	5	5	8	5	16	16	9	11	5	16
32	65	72	31	6	31	17	9	10	5	35

Table 9: Maximum ToxiUltra CO Values, Boats 3 & 4.

	Above 50 ppm
	Above 200 ppm
	Above 1000 ppm

Experiment #	TU 1	TU 2	TU 3	TU 4	TU 5	TU 6	TU 7	TU 8	TU 10	TU 12
1	84	102	96	63	59	54	55	57	20	64
2	624	598	975	546	630	414	460	409	140	237
3	76	99	194	51	88	51	41	68	132	73
4	215	449	669	107	279	148	79	143	45	111
5	751	535	552	187	367	175	168	164	85	139
6	381	305	437	167	163	96	123	89	79	138
7	368	556	531	318	449	316	315	282	93	198
8	339	293	431	269	333	226	140	220	110	161
9	622	658	638	409	543	433	343	365	166	297
10	17	30	136	34	59	68	56	67	157	101
11	14	24	63	8	36	25	20	19	19	25
12	242	173	374	62	209	36	39	29	12	32
13	40	102	23	28	10	28	16	19	8	34
14	40	102	23	28	10	28	16	19	8	34
15	56	78	56	10	26	25	26	22	3	17
16	35	645	404	24	176	70	38	53	7	34
17	358	318	440	164	138	71	71	55	11	74
18	143	180	81	54	53	76	58	47	16	25
19	658	581	190	158	207	197	235	180	59	117
20	199	285	84	103	139	154	147	101	27	44
21	233	324	46	99	81	130	113	81	30	41
22	405	614	199	167	126	172	172	110	42	67
23	527	453	114	234	73	180	239	174	56	79
24	385	413	94	181	79	191	198	176	56	68
25	206	158	58	149	39	121	156	107	51	64
26	100	97	27	43	42	78	55	55	20	30
27	166	107	81	39	200	150	101	125	34	44
28	283	53	46	41	115	138	93	114	63	52
29	19	16	13	21	20	48	45	40	52	42
30	9	13	12	8	21	26	22	17	11	21
31	6	7	13	6	17	19	11	13	6	18
32	87	128	58	11	75	32	13	15	6	45

Table 10: Average ToxiUltra CO Values, Boats 5 & 6.

All measurements are expressed in parts per million (ppm)

Experiment #	TU 1	TU 2	TU 3	TU 4	TU 5	TU 7	TU 8	TU 9	TU 10	TU 11	TU 12
1	59	56	70	48	40	41	37	17	20	1	34
2	56	50	56	39	17	23	9	17	18	1	10
3	122	56	73	39	35	32	32	16	16	1	32
4	27	26	38	14	15	10	7	16	16	1	13
5	58	43	50	38	34	38	37	15	15	1	32
6	0	5	4	8	3	7	7	15	14	1	0
7	2	5	6	5	2	5	5	13	13	1	0
8	13	11	25	14	11	14	15	12	12	0	10
9	77	47	30	25	25	18	11	12	11	1	21
10	110	58	38	28	18	24	26	12	11	1	14
11	28	12	9	12	2	9	9	11	11	1	1
12	125	89	82	59	10	33	37	11	10	1	9
13	20	2	4	9	0	4	7	10	9	1	0
14	27	1	2	9	0	4	6	9	8	1	0
15	44	8	5	10	0	4	7	8	7	1	0
16	23	5	5	11	0	5	8	8	7	1	0
17	36	3	3	9	1	5	7	8	8	1	0
18	11	3	2	7	0	4	4	3	2	1	0
19	10	2	3	8	0	3	6	22	23	0	0
20	105	190	168	39	49	38	43	21	20	0	41
21	256	225	325	44	51	46	51	20	20	0	21
22	98	83	103	51	33	46	50	19	19	0	47
23	171	118	142	60	68	29	20	19	19	0	60
24	24	5	13	13	3	5	7	18	18	0	6
25	223	83	228	27	45	23	28	18	18	0	17
26	19	16	41	14	8	16	18	18	18	0	10
27	20	26	55	17	13	9	14	17	18	0	12
28	9	55	37	7	3	6	8	17	17	0	1
29	9	1	3	6	0	4	5	16	16	0	0
30	6	7	1	3	0	2	4	14	14	0	0
31	4	0	1	2	0	2	4	14	14	0	0
32	5	0	1	3	0	2	4	13	13	0	0
33	47	12	7	8	1	3	6	10	10	0	1
34	116	9	2	5	0	2	4	10	10	0	1
35	17	3	2	6	0	3	6	3	3	0	0
36	79	57	59	24	14	8	11	2	2	0	26

Table 11: Maximum ToxiUltra CO Values, Boats 5 & 6.

(light shading)	Above 50 ppm
(medium shading)	Above 200 ppm
(dark shading)	Above 1000 ppm

Experiment #	TU 1	TU 2	TU 3	TU 4	TU 5	TU 7	TU 8	TU 9	TU 10	TU 11	TU 12
1	88	71	89	54	43	46	42	18	21	1	38
2	105	91	106	58	52	36	13	18	19	1	36
3	293	144	131	54	59	54	51	17	17	1	53
4	40	31	49	17	19	17	10	16	17	1	17
5	122	71	62	53	44	49	48	15	15	1	41
6	0	23	12	11	9	19	16	15	15	1	4
7	4	14	15	7	3	9	8	14	14	1	1
8	29	16	41	20	19	22	22	13	13	1	17
9	108	129	44	36	39	26	12	13	12	1	26
10	138	252	132	43	49	70	88	12	12	1	21
11	76	35	33	25	13	20	17	12	12	1	8
12	153	111	106	73	14	43	46	12	11	1	12
13	28	5	6	12	0	5	7	10	10	1	0
14	43	1	3	12	0	4	6	9	9	1	0
15	54	12	8	12	0	5	8	9	8	1	0
16	32	6	10	12	0	6	9	8	8	1	0
17	73	4	3	10	1	5	9	8	8	1	0
18	12	5	3	7	0	4	4	7	6	1	0
19	12	4	5	10	1	4	7	23	24	1	1
20	184	385	282	66	72	58	63	21	21	1	76
21	433	412	513	63	77	69	74	20	20	1	39
22	237	148	168	80	57	76	80	20	20	1	84
23	410	211	219	96	142	51	32	20	19	1	108
24	30	13	28	15	6	9	9	19	19	1	8
25	386	270	320	39	83	38	45	19	18	0	29
26	30	58	128	26	16	24	26	18	19	1	21
27	41	68	133	29	31	16	23	18	18	0	24
28	37	466	306	21	28	31	28	17	17	1	7
29	26	10	6	8	0	8	10	17	17	1	2
30	24	67	4	4	0	4	5	15	15	1	0
31	4	0	1	2	0	3	5	14	14	0	0
32	9	0	1	4	0	3	5	14	14	1	0
33	87	51	18	14	3	4	7	10	10	0	4
34	166	19	3	6	0	3	5	11	10	1	2
35	52	22	3	8	0	5	7	7	6	1	3
36	200	197	139	51	31	17	21	3	3	0	52

Table 12: Average ToxiUltra CO Values, Boats 7 & 8.

All measurements are expressed in parts per million (ppm)

Experiment #	TU 1	TU 2	TU 3	TU 4	TU 5	TU 6	TU 7	TU 8	TU 9	TU 10	TU 11
1	3	259	90	33	34	22	27	29	11	9	6
2	31	264	78	26	29	24	25	24	17	15	6
3	133	245	127	30	28	25	28	31	20	19	4
4	134	166	175	17	17	13	16	10	16	21	4
5	59	20	329	3	5	2	2	1	10	15	3
6	40	11	160	2	0	0	1	1	5	9	1
7	12	9	28	2	0	0	1	1	4	6	38
8	127	6	36	1	0	0	1	0	2	4	30
9	395	3	2	1	0	0	0	1	3	3	8
10	35	7	9	2	1	0	1	2	3	3	6
11	72	37	56	2	1	1	1	1	2	3	2
12	74	181	160	1	0	0	1	0	2	3	2
13	48	185	108	1	0	0	3	0	1	2	1
14	102	250	140	1	0	0	1	0	1	2	15
15	52	130	167	1	0	0	0	1	1	1	2
16	269	317	402	113	133	72	93	123	7	8	69
17	364	346	355	244	270	251	222	182	58	55	42
18	93	39	43	50	52	52	54	65	52	57	71
19	139	110	157	80	73	78	84	75	50	52	72
20	189	149	178	92	94	102	111	106	48	50	14
21	273	176	210	140	150	155	161	129	58	58	9
22	12	20	31	8	8	12	15	5	45	52	14
23	3	3	5	3	2	4	7	1	26	30	12
24	1	2	3	2	0	2	3	4	18	21	4
25	20	20	34	6	8	6	6	1	15	17	6
26	7	7	16	3	0	1	3	2	11	13	14
27	19	7	12	5	3	6	7	8	8	9	67
28	45	25	76	14	7	15	15	14	7	8	5
29	8	8	15	3	2	2	1	1	5	7	18

Table 13: Maximum ToxiUltra CO Values, Boats 7 & 8.

(light shading)	Above 50 ppm
(medium shading)	Above 200 ppm
(dark shading)	Above 1000 ppm

Experiment #	TU 1	TU 2	TU 3	TU 4	TU 5	TU 6	TU 7	TU 8	TU 9	TU 10	TU 11
1	12	376	132	39	53	29	39	38	14	11	7
2	53	463	113	38	52	35	37	34	17	18	7
3	345	560	358	50	47	43	47	56	27	21	5
4	341	395	304	56	59	50	47	41	26	24	5
5	101	51	432	15	45	19	5	2	15	17	6
6	69	11	379	2	1	0	1	1	6	11	2
7	38	11	145	7	1	1	3	2	5	8	82
8	544	8	410	3	1	1	2	1	4	5	71
9	723	6	3	2	1	0	1	2	3	4	18
10	67	21	31	8	3	3	4	6	3	4	41
11	448	372	404	6	8	4	2	5	3	4	3
12	115	370	248	2	1	0	3	1	2	4	5
13	73	243	172	2	0	0	3	1	2	3	2
14	132	343	230	2	1	0	2	1	1	2	80
15	110	338	265	3	0	2	3	4	1	2	7
16	423	520	697	251	288	131	204	286	21	20	143
17	501	552	569	377	376	350	350	346	69	69	72
18	122	55	70	70	76	71	71	105	56	65	84
19	264	219	380	125	135	137	134	134	55	57	82
20	307	183	214	101	107	108	119	143	48	51	29
21	448	270	339	244	283	276	270	271	66	66	14
22	29	47	93	15	18	26	24	12	57	64	32
23	11	12	15	8	8	8	11	6	34	39	28
24	4	2	12	5	1	3	7	23	21	24	8
25	64	42	59	21	25	22	16	3	16	18	11
26	24	15	80	14	2	9	10	11	13	15	19
27	71	35	34	12	9	19	20	22	9	11	169
28	68	62	159	25	11	20	21	23	8	9	31
29	45	56	104	10	9	12	5	5	7	9	31

Table 14: Average ToxiUltra CO Values, Boats 9 & 10.

All measurements are expressed in parts per million (ppm)

Experiment #	**TU 1**	**TU 2**	**TU 3**	**TU 4**	**TU 5**	**TU 6**	**TU 7**	**TU 8**	**TU 9**	**TU 10**	**TU 11**	**TU 12**	**TU 13**	**TU 14**
1	249	224	206	24	19	34	19	21	4	5	35	49	62	36
2	344	398	192	50	28	37	32	34	10	7	33	65	81	58
3	103	127	65	31	20	25	20	25	10	10	16	25	32	26
4	59	75	40	24	14	15	14	13	8	9	8	21	24	21
5	30	20	16	11	12	13	8	12	7	7	7	8	5	12
6	149	164	141	54	23	29	31	28	7	7	3	41	51	32
7	212	229	178	85	35	43	43	43	7	7	3	54	66	44
8	97	116	102	45	26	32	26	33	7	7	14	42	36	31
9	26	11	50	10	8	7	2	5	6	7	7	8	3	2
10	207	254	136	24	9	7	7	9	6	7	6	53	62	45
11	183	203	156	32	12	9	15	13	8	7	2	38	69	52
12	16	10	17	10	15	15	9	13	6	7	24	6	2	1
13	252	331	218	68	64	72	81	69	33	35	254	115	111	97
14	375	540	315	126	117	97	119	87	44	43	116	229	227	227
15	208	237	164	120	126	67	77	44	46	38	60	167	161	170
16	136	162	73	21	22	12	8	8	23	21	85	35	30	36
17	113	145	58	9	10	7	7	5	18	21	165	23	23	8
18	353	540	292	82	113	61	68	63	21	22	117	126	122	134
19	165	174	166	66	80	61	58	46	18	18	88	96	86	97
20	25	14	33	10	11	7	5	6	11	10	53	11	6	16
21	525	944	561	11	24	11	6	10	8	9	88	19	21	14
22	422	740	525	15	20	8	8	11	8	8	113	37	26	18
23	27	13	27	10	9	9	4	8	5	8	173	6	3	1

Table 15: Maximum ToxiUltra CO Values, Boats 9 & 10.

	Above 50 ppm
	Above 200 ppm
	Above 1000 ppm

Experiment #	TU 1	TU 2	TU 3	TU 4	TU 5	TU 6	TU 7	TU 8	TU 9	TU 10	TU 11	TU 12	TU 13	TU 14
1	446	421	321	40	40	68	41	38	5	6	76	106	106	86
2	488	489	227	85	34	46	42	40	12	9	61	83	138	99
3	389	529	230	83	37	52	41	44	11	10	31	80	115	96
4	253	389	133	56	25	23	31	20	9	10	10	60	97	111
5	187	165	69	31	25	26	21	23	8	8	10	20	25	89
6	216	315	224	72	34	44	38	43	9	8	5	51	66	40
7	284	336	216	98	42	53	51	53	8	8	4	103	123	61
8	292	376	316	65	44	50	43	49	7	8	19	91	72	74
9	144	60	258	22	21	18	12	15	7	7	19	25	13	13
10	257	327	169	48	12	9	10	12	7	7	14	63	84	54
11	226	286	177	56	18	17	28	19	9	8	5	49	85	67
12	118	49	106	51	72	62	58	60	7	8	100	26	22	33
13	553	1112	736	100	99	123	157	135	41	42	462	227	207	171
14	533	720	393	158	156	146	163	127	51	44	169	246	245	251
15	334	519	334	157	166	113	135	76	54	43	108	235	232	238
16	450	547	267	70	81	70	62	57	41	35	131	122	120	121
17	361	601	283	23	42	23	30	18	20	22	224	136	174	69
18	391	610	367	146	205	94	112	108	22	24	189	155	165	206
19	320	408	244	104	128	124	94	83	21	21	141	195	192	203
20	89	43	94	21	31	22	18	20	13	12	89	27	17	51
21	683	1111	761	33	60	38	29	44	9	11	153	54	66	43
22	615	882	594	47	68	27	31	43	10	9	139	65	56	44
23	235	76	45	30	18	37	22	37	9	10	217	22	10	13

Table 16: Evacuated Container Concentrations, Boats 1 & 2.

Boat	Container ID #	Condition	Concentration (ppm)
Boat 1	D9426	5 mph, all canvas closed, aft panel open, front screen opened	1027
Boat 1	D9413	10 mph, canvas closed, aft panel open, front screen opened	657
Boat 1	D9427	25 mph into wind, canvas closed, aft panel open, front screen opened	109
Boat 1	D9425	25 mph with wind, canvas closed, aft panel open, front screen opened	120
Boat 1	D9441	10 mph, all panel opened	4
Boat 2	D9453	5 mph, no wind, all canvas closed, aft panel open	341
Boat 2	D9432	10 mph, no wind, all canvas closed, aft panel open	102
Boat 2	D9434	15 mph, no wind, all canvas closed, aft panel open	1516

Table 17: Evacuated Container Concentrations, Boats 3 & 4.

Boat	Container ID #	Condition	Concentration (ppm)
Boat 4	D9428	5 mph, all canvas installed, aft panel opened	340
Boat 4	D9429	25 mph, all canvas installed, aft panel opened, opening front screen	10
Boat 4	D9431	25 mph, partial canvas installed	232
Boat 4	D9882	15 mph, all canvas opened, center windshield opened	5
Boat 4	D9881	15 mph, all canvas opened, center windshield opened	26
Boat 4	D9877	5 mph, all canvas opened, center windshield opened	7
Boat 3	D9875	25 mph. all canvas installed, aft panel opened	8
Boat 3	D9609	10 mph. all canvas installed, aft panel opened	242
Boat 3	D9608	10 mph, back fully opened, and center of windshield opened	129
Boat 3	D9879	5 mph, all canvas removed	21
Boat 3	D9870	15 mph, all canvas removed	1
Boat 3	D9430	15 mph, all canvas removed, center of windshield opened	2
Boat 3	D9880	25 mph, all canvas removed, center of windshield opened	1

Table 18: Evacuated Container Concentrations, Boats 5 & 6.

Boat	Container ID #	Condition	Concentration (ppm)
Boat 5	D9442	5 mph, canvas fully closed, aft panel open	24
Boat 5	D9433	25 mph, canvas fully closed, aft panel open, center window opened	1
Boat 5	D9443	15 mph, canvas fully closed, aft panel open, center window opened	45
Boat 5	D9444	5 mph, all canvas removed, bimini top only	2
Boat 6	D9448	5 mph, canvas fully closed, aft panel open	112
Boat 6	D9447	15 mph, canvas fully closed, aft panel open	65
Boat 6	D9446	25 mph, canvas fully closed, center vent open	1

Table 19: Evacuated Container Concentrations, Boats 7 & 8.

Boat	Container ID #	Condition	Concentration (ppm)
Boat 7	D9449	10 mph, all canvas installed, aft panel open, with the wind	142
Boat 7	D9450	5 mph, all canvas installed, fully removed rear panels, with the wind	12
Boat 7	D9452	10 mph, all canvas removed, bimini top only, into the wind	7
Boat 7	D9451	25 mph, all canvas removed, bimini top only, into the wind	10
Boat 8	D9416	5 mph, all canvas installed, aft panel open, into the wind	217
Boat 8	D9414	5 mph, partial canvas, rear and side panels removed, into wind	89
Boat 8	D9415	25 mph, partial canvas, rear and side panels removed, with wind	2
Boat 8	D9417	5 mph, all canvas removed, bimini top only, with the wind	2

Table 20: Evacuated Container Concentrations, Boats 9 & 10.

Boat	Container ID #	Condition	Concentration (ppm)
Boat 9	D9418	10 mph, all canvas installed, aft panel open, wind difficult to describe	346
Boat 9	D9419	25 mph, all canvas installed, aft panel open	Non Detected
Boat 9	M6789	25 mph, partial canvas	1

Table 21: Detector Tube Readings, Boats 1 & 2.

Boat	Condition	Concentration (ppm)
Boat 1	5 mph, all canvas closed, aft panel open, front screen opened	20
Boat 1	10 mph, canvas closed, aft panel open, front screen opened	700
Boat 1	10 mph, all panel opened	40
Boat 1	15 mph, into the wind, all canvas opened	350
Boat 1	25 mph, with the wind, all canvas opened	290
Boat 2	5 mph, no wind, all canvas closed, aft panel open	500
Boat 2	10 mph, no wind, all canvas closed, aft panel open	400
Boat 2	5 mph, all canvas removed, no wind	700
Boat 2	15 mph, all canvas removed, no wind	300

Table 22: Detector Tube Readings, Boats 3 & 4.

Boat	Condition	Concentration (ppm)
Boat 4	15 mph, all canvas installed, aft panel opened	>100
Boat 4	10 mph, all canvas installed, aft panel opened	160
Boat 4	5 mph, all canvas opened, center windshield opened	100
Boat 3	15 mph, all canvas closed, aft panel open	120
Boat 3	5 mph, all canvas closed, aft panel open	200
Boat 3	10 mph, all canvas removed, bimini top only	75

Table 23: Detector Tube Readings, Boats 5 & 6.

Boat	Condition	Concentration (ppm)
Boat 5	5 mph, all canvas installed, aft panel open	50
Boat 5	25 mph, all canvas installed, aft panel open	0
Boat 5	5 mph, partial canvas, no apparent wind	20
Boat 5	10 mph, all canvas removed, bimini top only	0

Table 24: Detector Tube Readings, Boats 7 & 8.

Boat	Condition	Concentration (ppm)
Boat 7	5 mph, all canvas closed, aft panel open, with the wind	120
Boat 7	15 mph, all canvas closed, aft panel open, with the wind	200
Boat 7	10 mph, all canvas installed, fully removed rear panels, with the wind	30
Boat 7	25 mph, all canvas installed, fully removed rear panels, into the wind	10
Boat 7	10 mph, all canvas removed, bimini top only, with the wind	20
Boat 7	5 mph, all canvas removed, bimini top only, into the wind	60
Boat 8	15 mph, all canvas installed, aft panel open, into the wind	50
Boat 8	5 mph, partial canvas, into the wind	140
Boat 8	10 mph, all canvas removed, bimini top only, with the wind	30

Table 25: Detector Tube Readings, Boats 9 & 10.

Boat	Condition	Concentration (ppm)
Boat 9	5 mph, all canvas installed, aft panel open	150
Boat 9	15 mph, all canvas installed, aft panel open	10
Boat 9	15 mph, partial canvas, no apparent wind	60
Boat 9	10 mph, all canvas removed, bimini top only	150

Table 26: Relative Wind Velocities, Boats 1 & 2.

Boat	Condition	Velocity (mph)
Boat 1	5 mph, all canvas closed, aft panel opened	9.37
Boat 1	5 mph, all canvas closed, aft panel opened, front screen opened	11.06
Boat 1	10 mph, canvas closed, aft panel open, front screen opened, into wind	11.5
Boat 1	10 mph, canvas closed, aft panel open, front screen opened, with wind	0.37
Boat 1	15 mph, canvas closed, aft panel open, into the wind	17.5
Boat 1	15 mph, canvas closed, aft panel open, with the wind	12.12
Boat 1	25 mph, canvas closed, aft panel open, into the wind	27.5
Boat 1	25 mph, canvas closed, aft panel open, with the wind	20
Boat 1	10 mph, canvas closed, aft panel open, into the wind	12.5
Boat 1	25 mph, canvas closed, aft panel open, with the wind	20
Boat 1	5 mph, canvas opened, into the wind	6.56
Boat 1	5 mph, canvas opened, no wind	0
Boat 1	10 mph, canvas opened, no wind	9
Boat 1	15 mph, canvas opened, with the wind	16.87
Boat 1	15 mph, canvas opened, into the wind	11.87
Boat 1	25 mph, all canvas opened, into the wind	15.62
Boat 1	25 mph, all canvas opened, with the wind	22.5
Boat 1	15 mph, all canvas opened, side windows opened	18.75
Boat 2	5 mph, all canvas closed, aft panel opened, no wind	1.62
Boat 2	10 mph, all canvas closed, aft panel opened, no wind	3.68
Boat 2	15 mph, all canvas closed, aft panel opened, no wind	15
Boat 2	25 mph, all canvas closed, aft panel opened, no wind	26.25
Boat 2	5 mph, all canvas removed, bimini top only, no wind	4.5
Boat 2	10 mph, all canvas removed, bimini top only, no wind	2
Boat 2	15 mph, all canvas removed, bimini top only, no wind	11.5
Boat 2	25 mph, all canvas removed, bimini top only, no wind	22.5
Boat 2	15 mph, all canvas removed, bimini top only, no wind, side windows	12.31

Table 27: Relative Wind Velocities, Boats 3 & 4.

Boat	Condition	Velocity (mph)
Boat 4	5 mph, all canvas installed, aft panel opened	2.73
Boat 4	15 mph, all canvas installed, aft panel opened	11.02
Boat 4	10 mph, all canvas installed, aft panel opened	3.12
Boat 4	25 mph, all canvas installed, aft panel opened	39.99
Boat 4	25 mph, all canvas installed, aft panel opened	33.97
Boat 4	15 mph, all canvas opened, bimini top only	25.56
Boat 4	15 mph, all canvas opened, bimini top only, center windshield opened	21.58
Boat 4	10 mph, all canvas opened, bimini top only, center windshield opened	7.27
Boat 4	25 mph, all canvas opened, bimini top only, center windshield opened	35.61
Boat 4	15 mph, all canvas opened, bimini top only, center windshield opened	14.77
Boat 4	5 mph, all canvas opened, bimini top only, center windshield opened	2.50
Boat 3	25 mph, all canvas installed, aft panel opened	34.42
Boat 3	15 mph, all canvas installed, aft panel opened	28.97
Boat 3	10 mph, all canvas installed, aft panel opened	14.88
Boat 3	5 mph, all canvas installed, aft panel opened	10.68
Boat 3	5 mph, back fully open, center of windshield opened	10.45
Boat 3	10 mph, back fully open, center of windshield opened	14.20
Boat 3	15 mph, back fully open, center of windshield opened	20.33
Boat 3	15 mph, back fully open, center of windshield opened	18.18
Boat 3	5 mph, all canvas removed, bimini top only	6.82
Boat 3	10 mph, all canvas removed, bimini top only	16.98
Boat 3	15 mph, all canvas removed, bimini top only	20.16
Boat 3	15 mph, all canvas removed, bimini top only, center windshield opened	21.75
Boat 3	25 mph, all canvas removed, bimini top only, center windshield opened	25.16
Boat 3	15 mph, all canvas removed, bimini top only, 2 side windows open	27.26

Table 28: Relative Wind Velocities, Boats 5 & 6.

Boat	Condition	Velocity (mph)
Boat 5	5 mph, all canvas installed, aft panel open, with the wind	7.90
Boat 5	10 mph, all canvas installed, aft panel open, with the wind	9.66
Boat 5	15 mph, all canvas installed, aft panel open, with the wind	16.47
Boat 5	25 mph, all canvas installed, aft panel open, into the wind	26.13
Boat 5	5 mph, partial canvas, rear and side panels removed, into wind	9.37
Boat 5	10 mph, partial canvas, rear and side panels removed, into wind	14.77
Boat 5	25 mph, all canvas installed, fully removed rear panels, with the wind	29.54
Boat 5	5 mph, all canvas removed, bimini top only, with the wind	7.60
Boat 5	10 mph, all canvas removed, bimini top only, with the wind	10.52
Boat 5	15 mph, all canvas removed, bimini top only, with the wind	16.20
Boat 5	5 mph, all canvas removed, bimini top only, into the wind	10.30
Boat 5	10 mph, all canvas removed, bimini top only, into the wind	17.00
Boat 5	15 mph, all canvas removed, bimini top only, into the wind	22.30
Boat 6	5 mph, all canvas installed, aft panel open, into the wind	5.68
Boat 6	10 mph, all canvas installed, aft panel open, into the wind	10.22
Boat 6	15 mph, all canvas installed, aft panel open, into the wind	18.18
Boat 6	25 mph, all canvas installed, aft panel open, into the wind	27.26
Boat 6	5 mph, partial canvas, into the wind	10.22
Boat 6	10 mph, partial canvas, into the wind	10.79
Boat 6	15 mph, partial canvas, with the wind	16.76
Boat 6	25 mph, partial canvas, with the wind	17.61
Boat 6	5 mph, all canvas removed, bimini top only, with the wind	4.54
Boat 6	10 mph, all canvas removed, bimini top only, with the wind	10.25
Boat 6	15 mph, all canvas removed, bimini top only, with the wind	14.13
Boat 6	25 mph, all canvas removed, bimini top only, into the wind	25.30
Boat 6	5 mph, all canvas removed, bimini top only, into the wind, side vents open	6.52
Boat 6	5 mph, all canvas removed, bimini top only, with the wind, side vents open	7.85

Table 29: Relative Wind Velocities, Boats 7 & 8.

Boat	Condition	Velocity (mph)
Boat 7	5 mph, all canvas installed, aft panel open, with the wind	11.90
Boat 7	10 mph, all canvas installed, aft panel open, with the wind	13.90
Boat 7	15 mph, all canvas installed, aft panel open, with the wind	19.20
Boat 7	25 mph, all canvas installed, aft panel open, into the wind	45.00
Boat 7	5 mph, partial canvas, rear and side panels removed, into wind	23.00
Boat 7	10 mph, partial canvas, rear and side panels removed, into wind	24.00
Boat 7	25 mph, all canvas installed, fully removed rear panels, with the wind	7.80
Boat 7	5 mph, all canvas removed, bimini top only, with the wind	4.70
Boat 7	10 mph, all canvas removed, bimini top only, with the wind	8.20
Boat 7	15 mph, all canvas removed, bimini top only, with the wind	2.10
Boat 7	5 mph, all canvas removed, bimini top only, into the wind	16.80
Boat 7	10 mph, all canvas removed, bimini top only, into the wind	23.00
Boat 7	15 mph, all canvas removed, bimini top only, into the wind	25.00
Boat 8	5 mph, all canvas installed, aft panel open, into the wind	8.00
Boat 8	10 mph, all canvas installed, aft panel open, into the wind	14.70
Boat 8	15 mph, all canvas installed, aft panel open, into the wind	23.00
Boat 8	25 mph, all canvas installed, aft panel open, into the wind	36.00
Boat 8	5 mph, partial canvas, into the wind	16.40
Boat 8	10 mph, partial canvas, into the wind	21.00
Boat 8	15 mph, partial canvas, with the wind	6.50
Boat 8	25 mph, partial canvas, with the wind	8.00
Boat 8	5 mph, all canvas removed, bimini top only, with the wind	10.60
Boat 8	10 mph, all canvas removed, bimini top only, with the wind	4.00
Boat 8	15 mph, all canvas removed, bimini top only, with the wind	4.10
Boat 8	25 mph, all canvas removed, bimini top only, into the wind	27.00
Boat 8	5 mph, all canvas removed, bimini top only, into the wind, side vents open	16.00
Boat 8	5 mph, all canvas removed, bimini top only, with the wind, side vents open	5.70

Figure 1: Typical Sample Locations

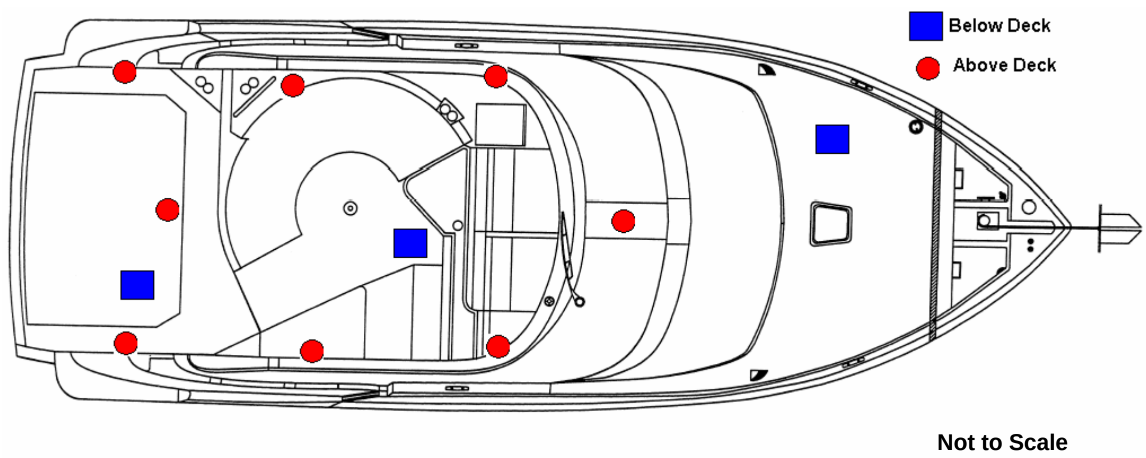


Figure 2: Typical Recirculation Patterns / 5 and 10 mph

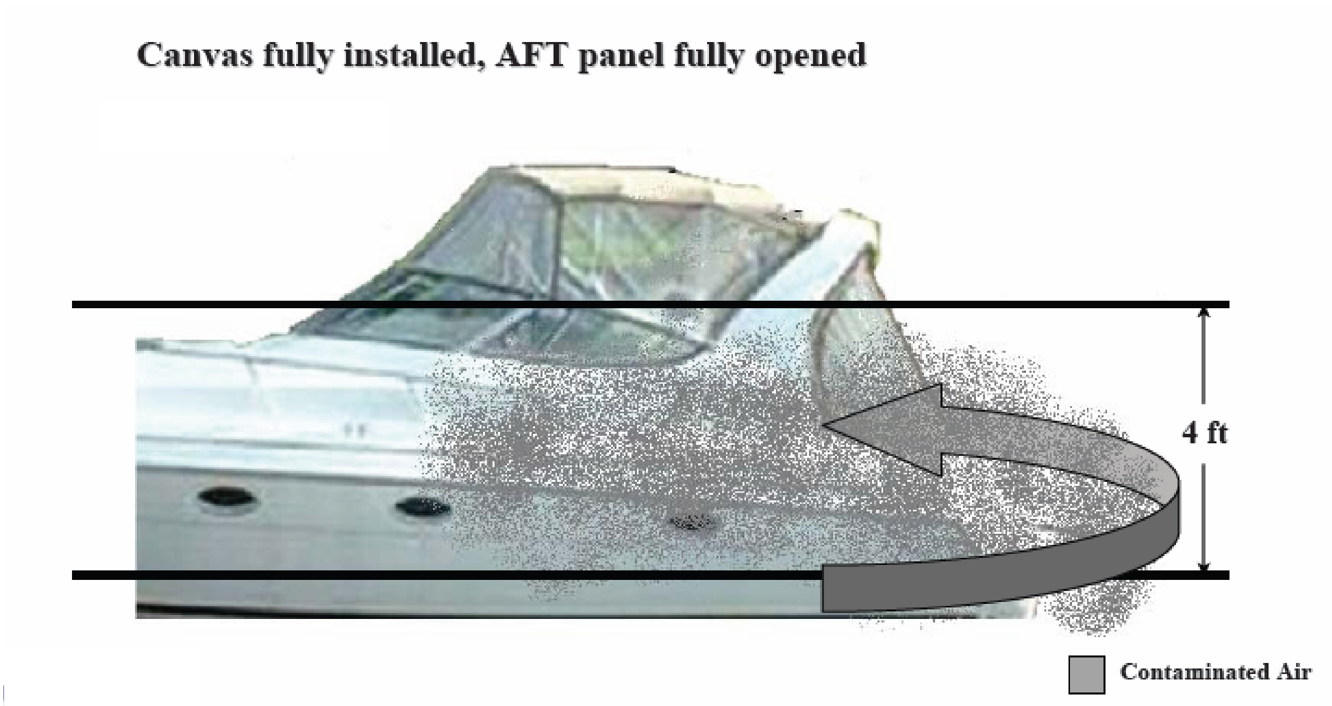


Figure 3: Typical Recirculation Patterns / 15 mph

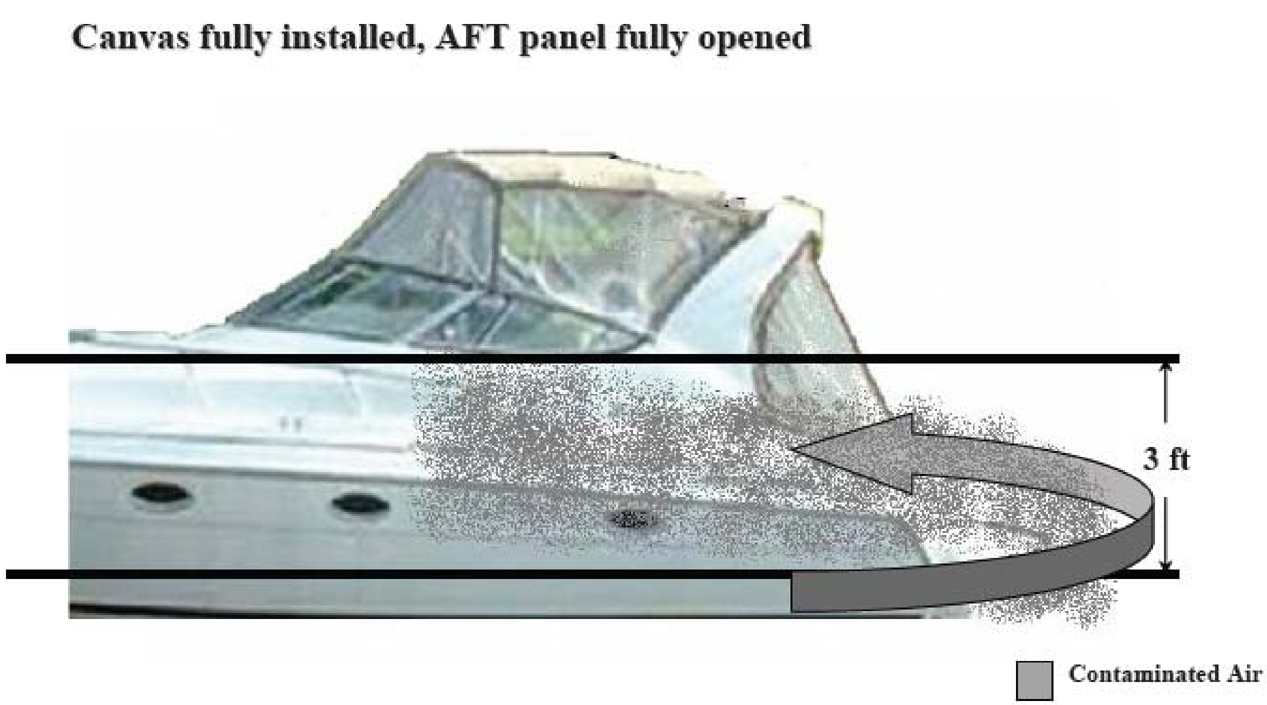


Figure 4: Typical Recirculation Patterns / 25 mph

Canvas fully installed, AFT panel fully opened

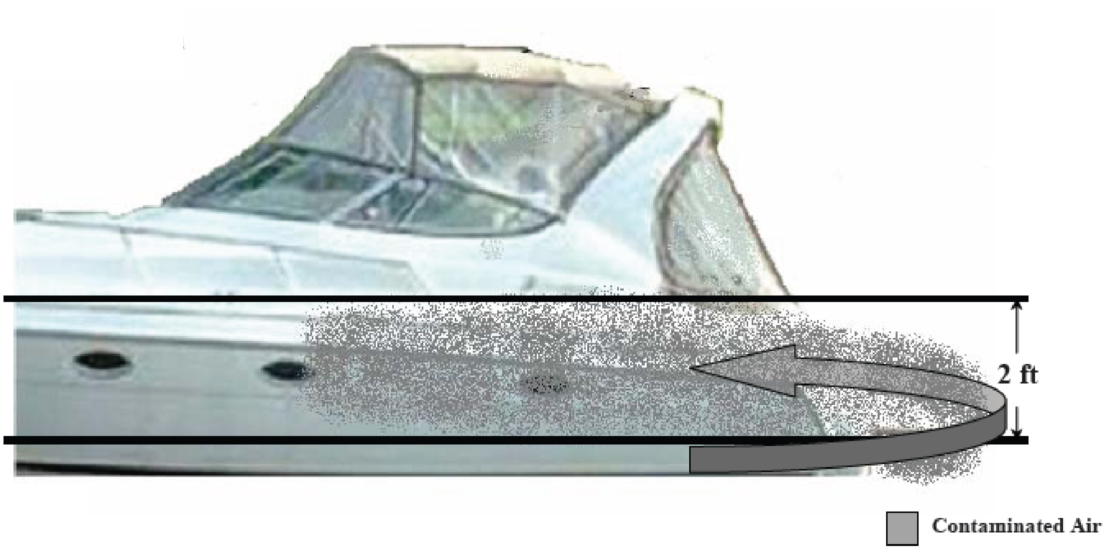
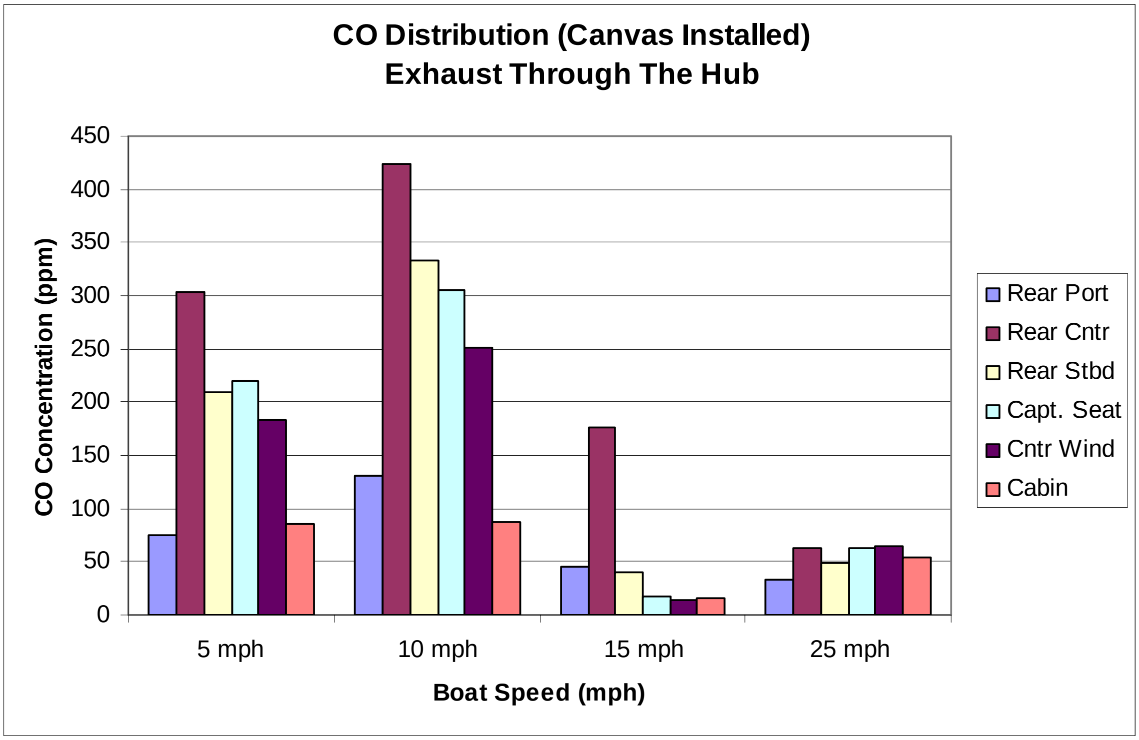
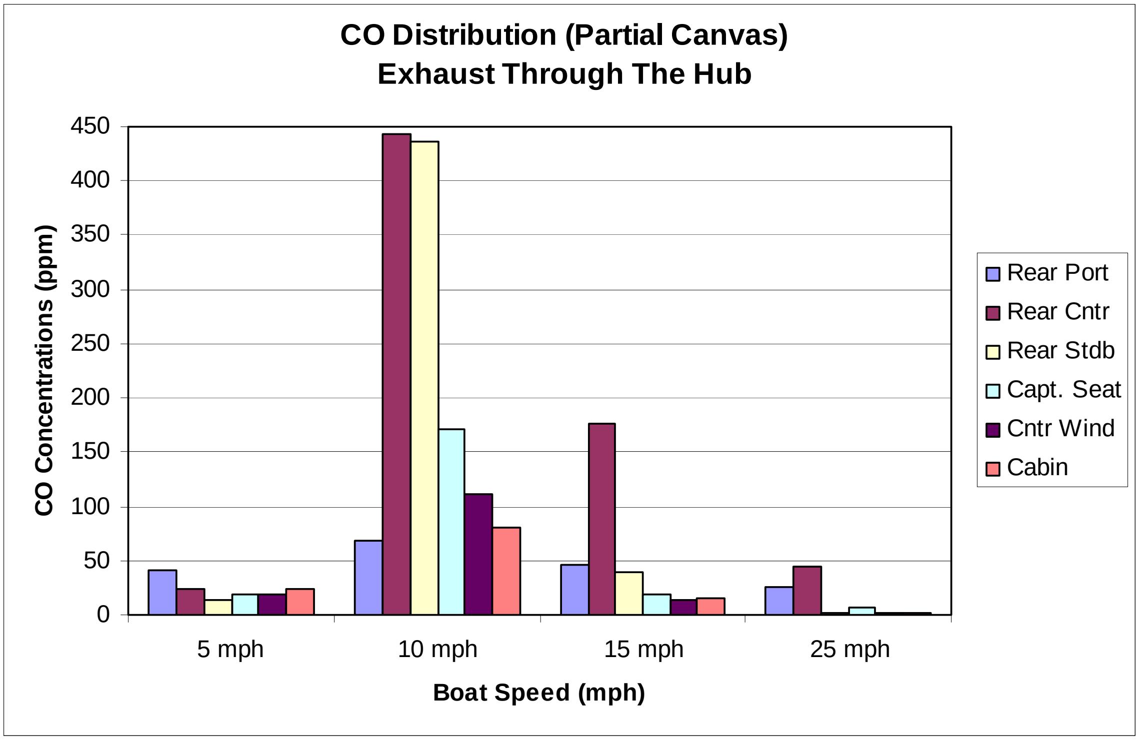
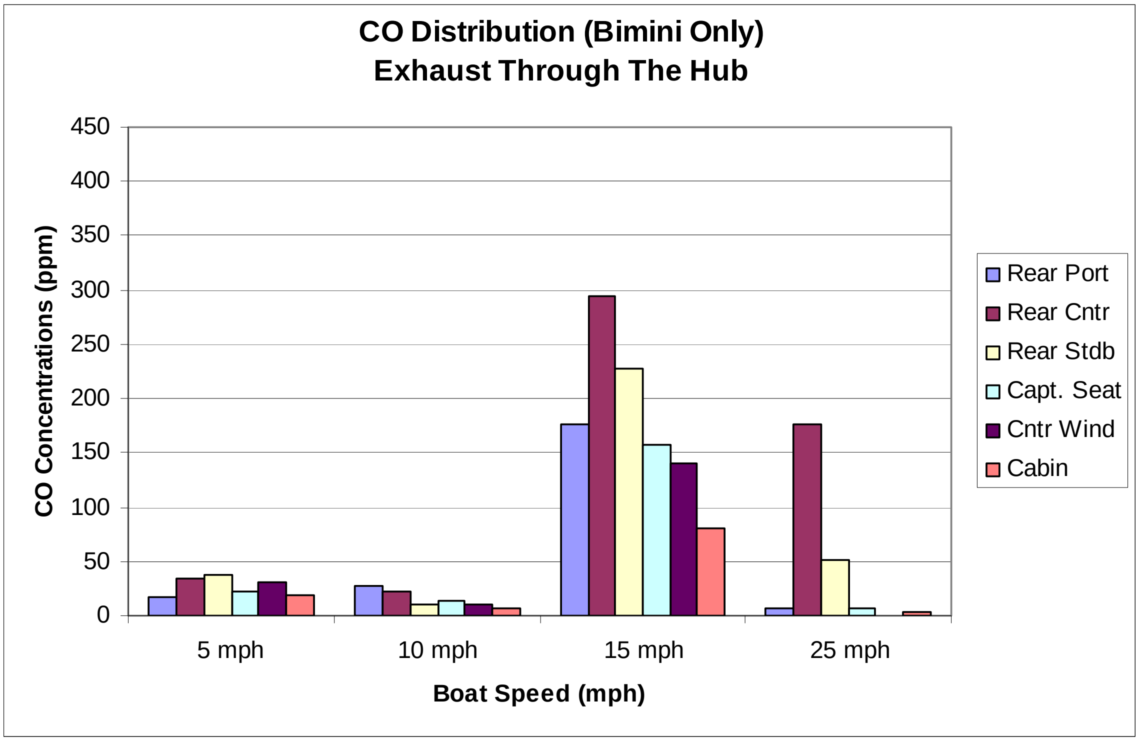


Figure 5: Boat 1 (33') Twin Volvo Penta 5.7L Exhausting Through the Hub.

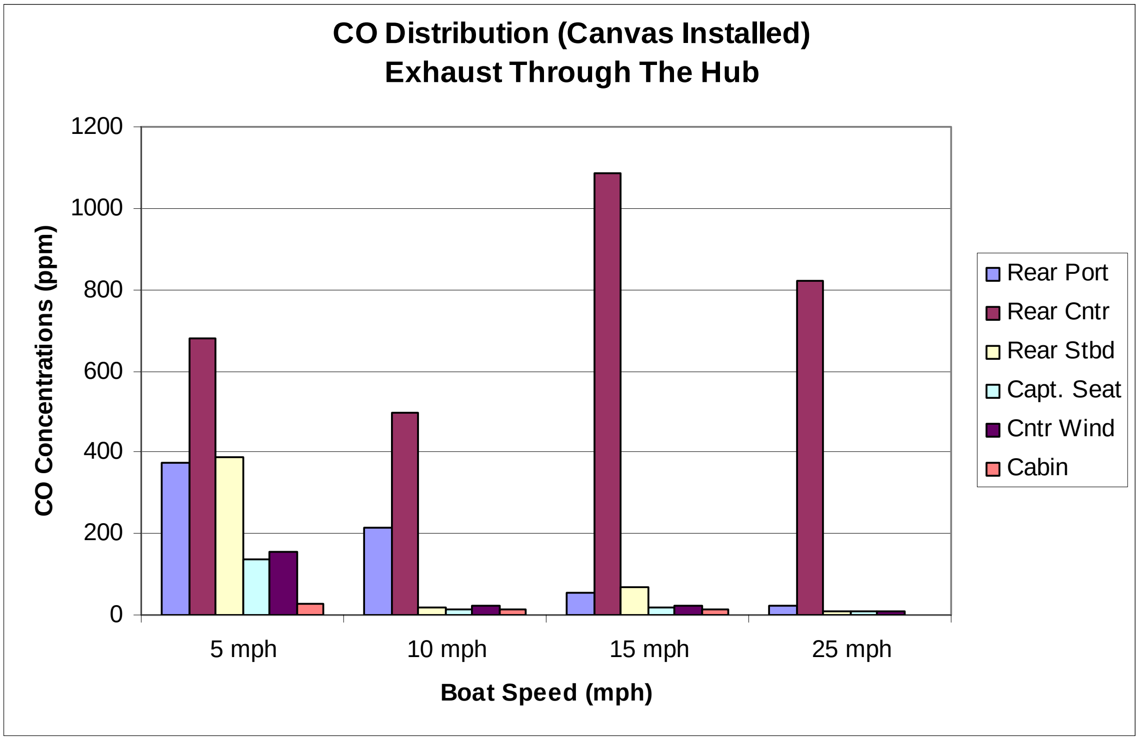


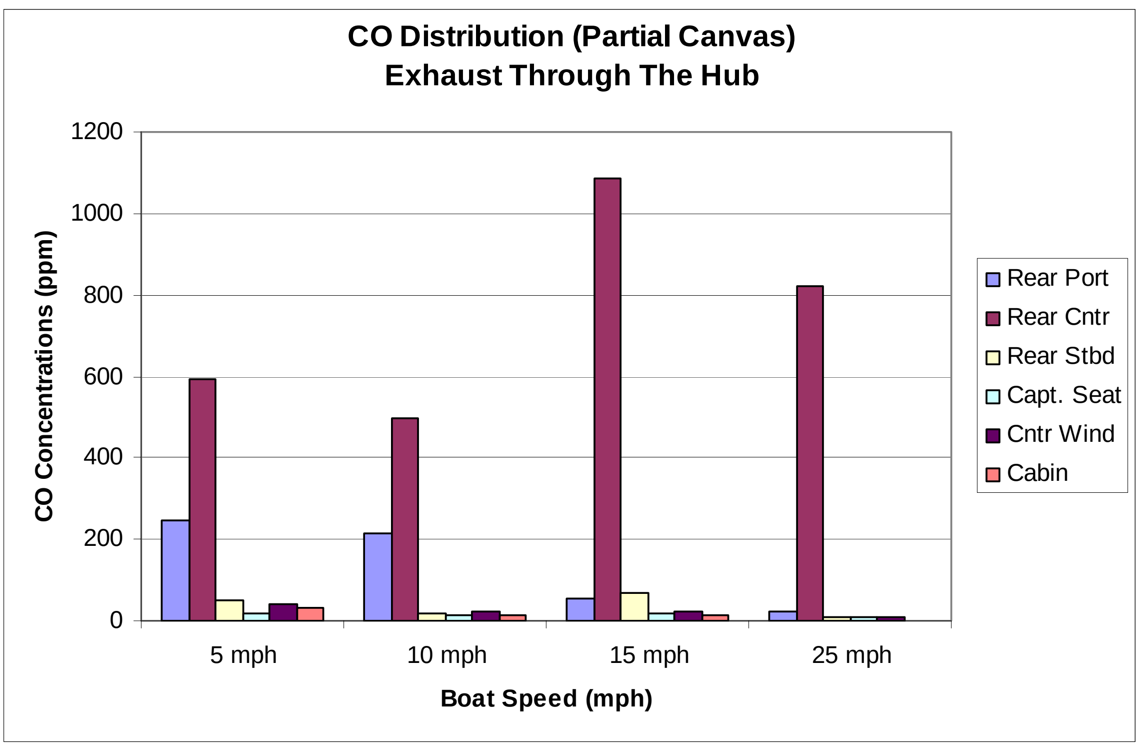




CO Distribution (Bimini Only)
Exhaust Through The Hub
CO Concentrations (ppm)
450
400
350
300
250
200
150
100
50
0
5 mph
10 mph
15 mph
25 mph
Boat Speed (mph)
Rear Port
Rear Cntr
Rear Stdb
Capt. Seat
Cntr Wind
Cabin

Figure 6: Boat 2 (30') Twin Mercruiser 5.0L Exhausting Through the Hub.





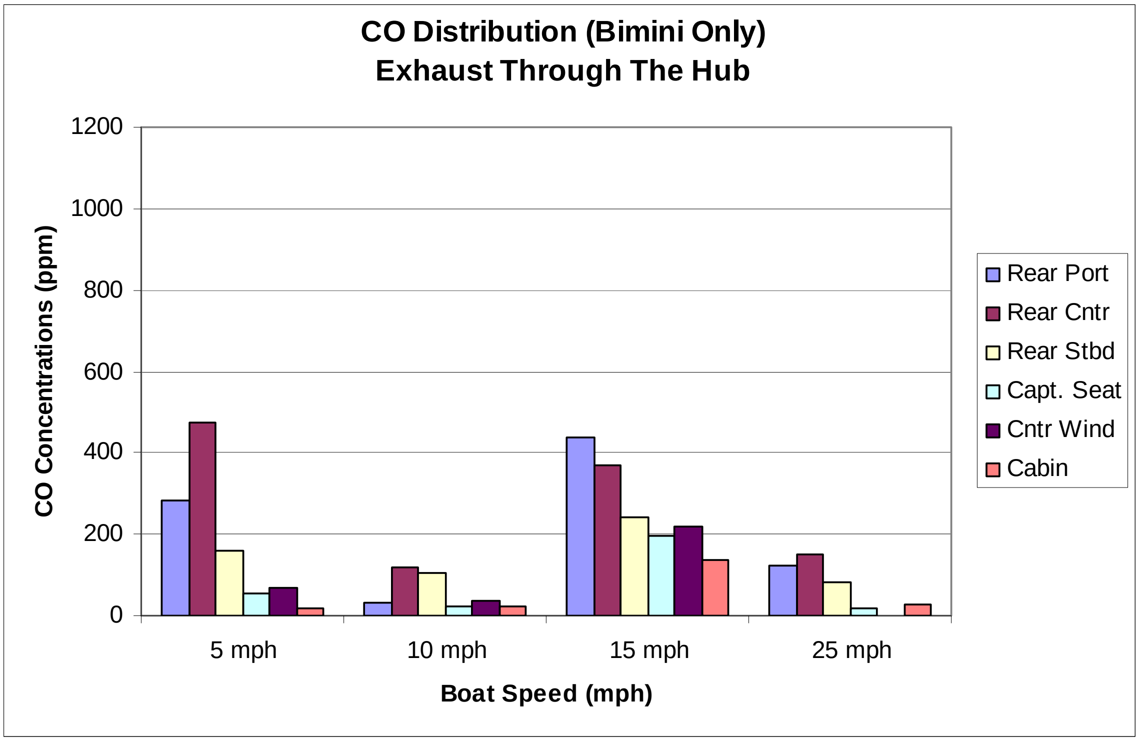
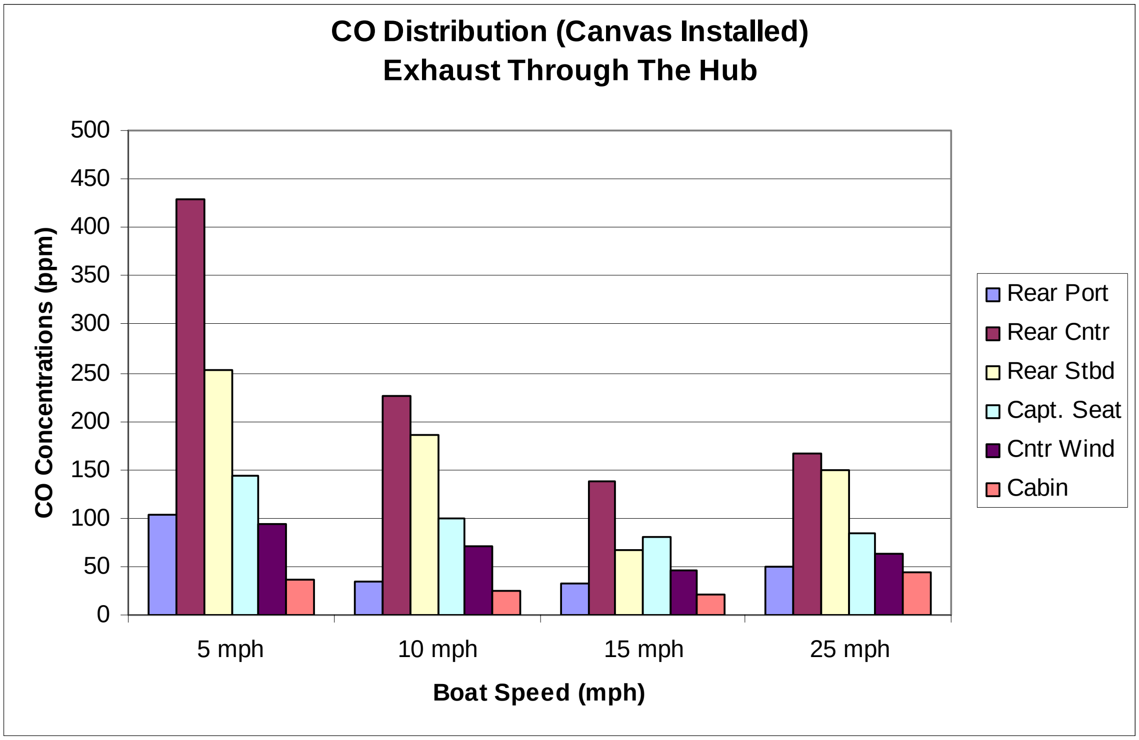
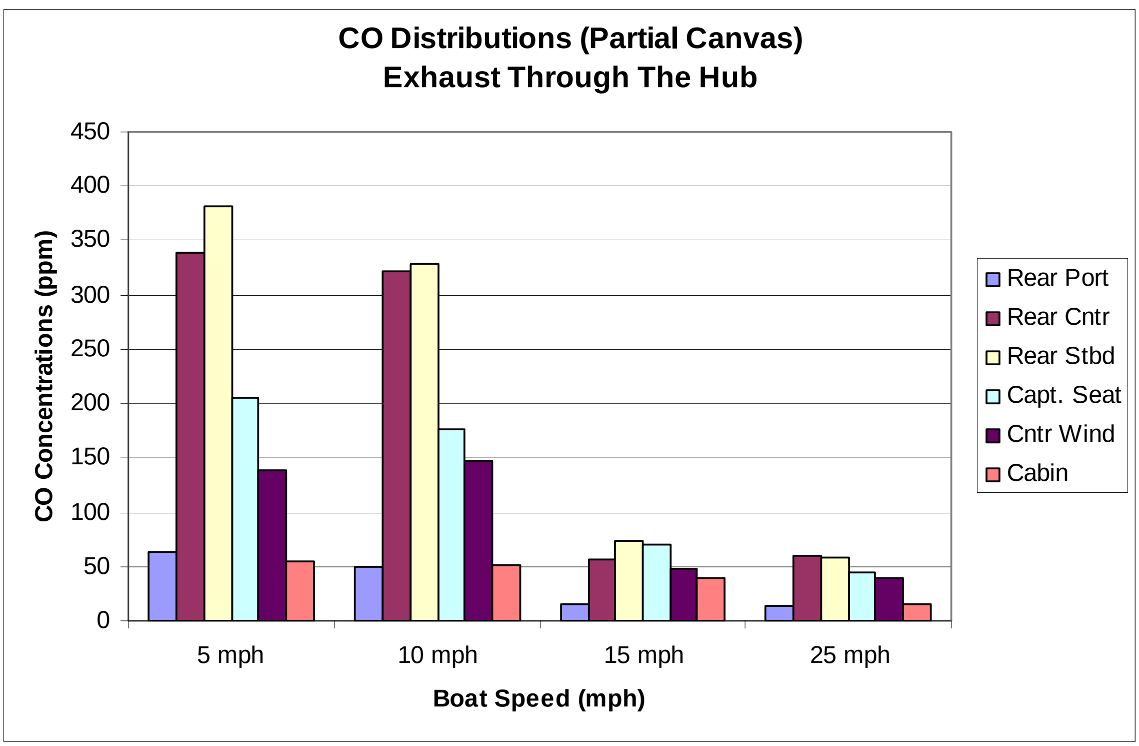

CO Distribution (Bimini Only)
Exhaust Through The Hub
CO Concentrations (ppm)
1200
1000
800
600
400
200
0
5 mph
10 mph
15 mph
25 mph
Boat Speed (mph)
Rear Port
Rear Cntr
Rear Stbd
Capt. Seat
Cntr Wind
Cabin

Figure 7: Boat 3 (31') Twin Volvo Penta 8.1L Exhausting Through the Hub.





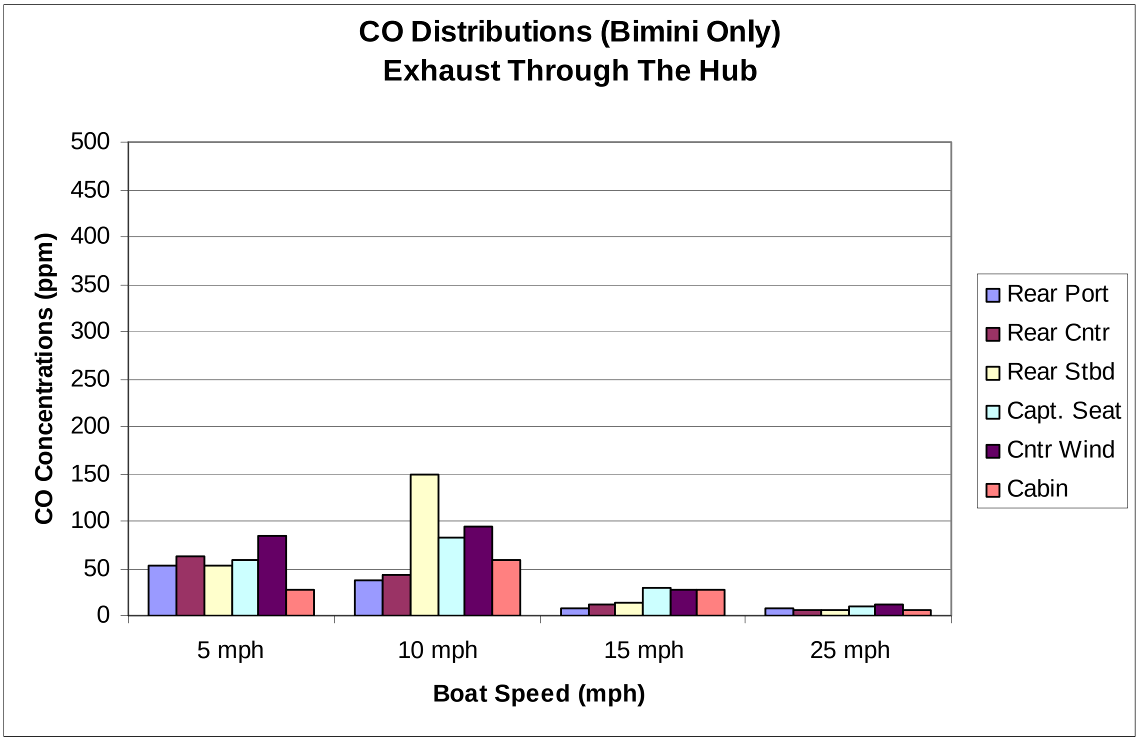
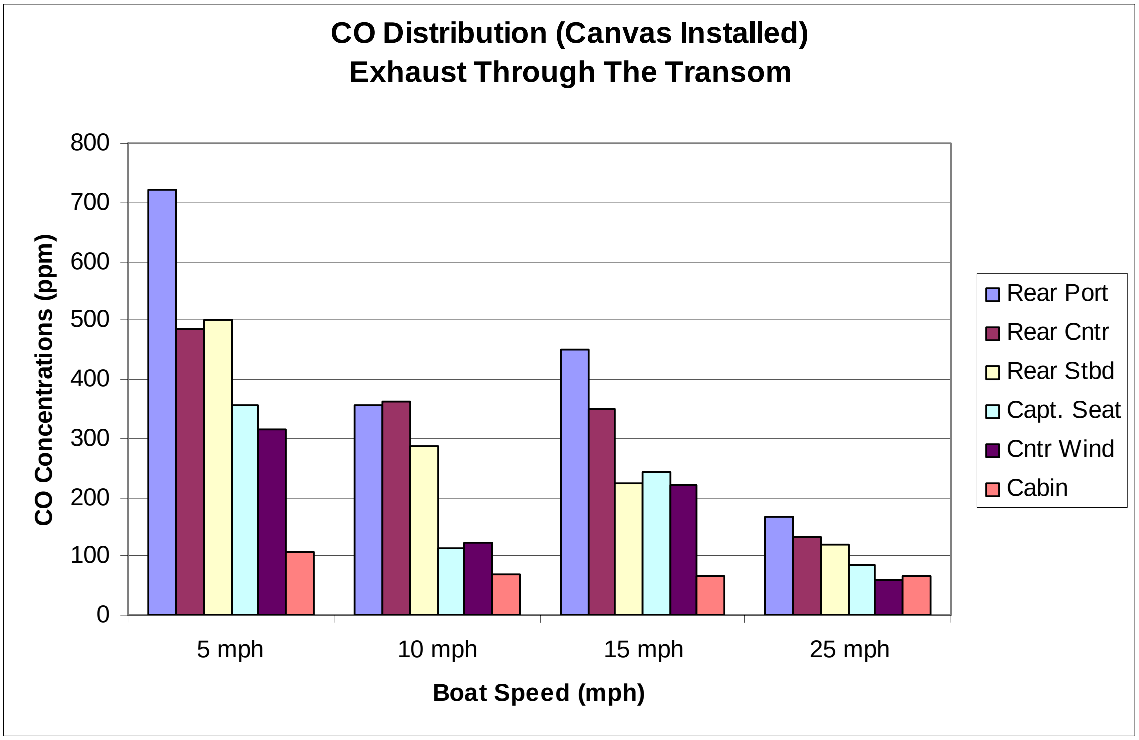
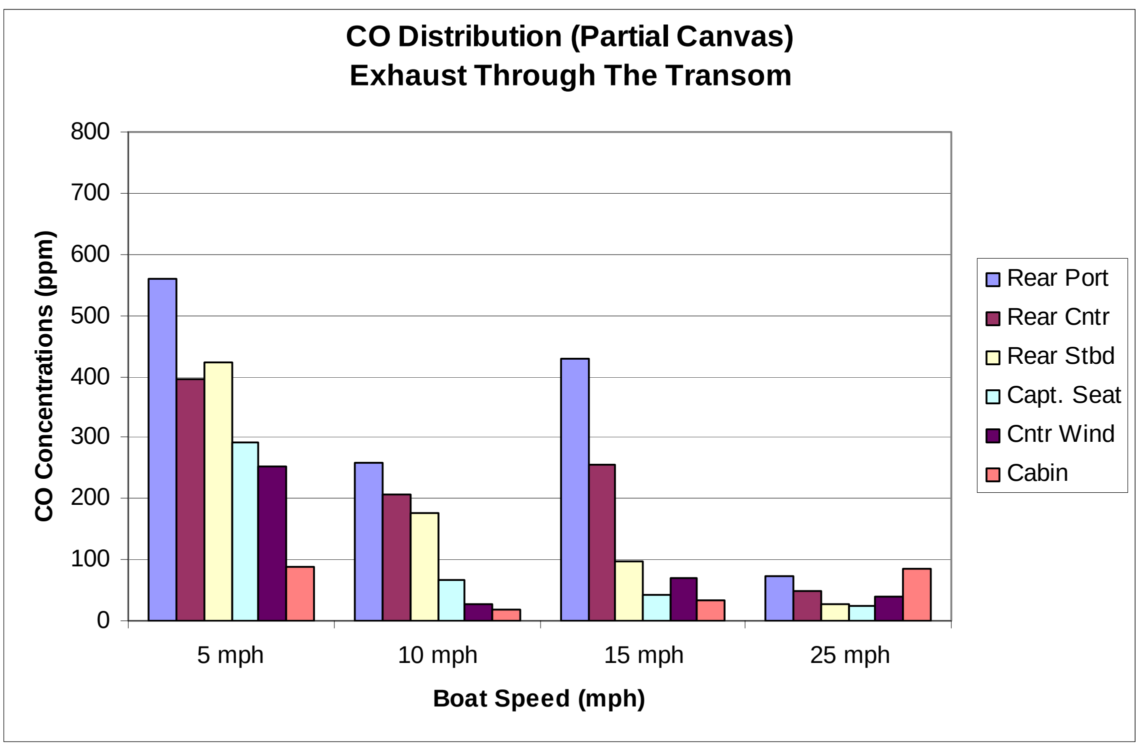
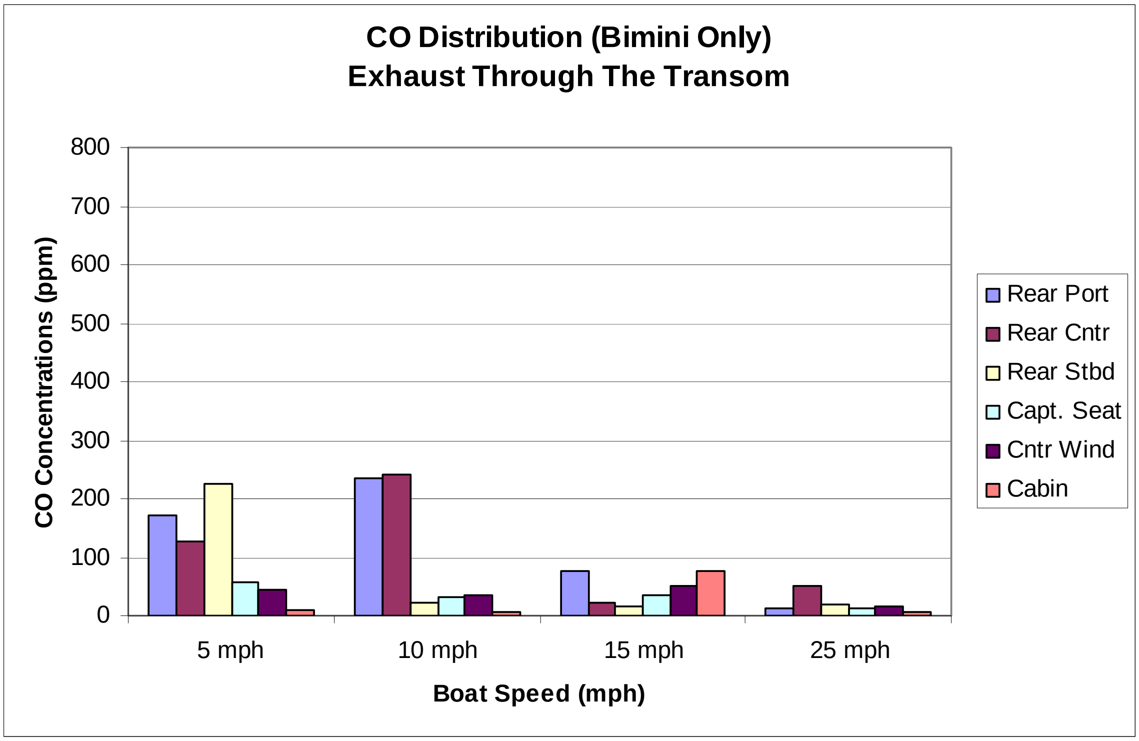

CO Distributions (Bimini Only)
Exhaust Through The Hub
CO Concentrations (ppm)
500
450
400
350
300
250
200
150
100
50
0
5 mph
10 mph
15 mph
25 mph
Boat Speed (mph)
Rear Port
Rear Cntr
Rear Stbd
Capt. Seat
Cntr Wind
Cabin

Figure 8: Boat 4 (37') Twin Mercruiser 8.1L Exhausting Through the Transom.

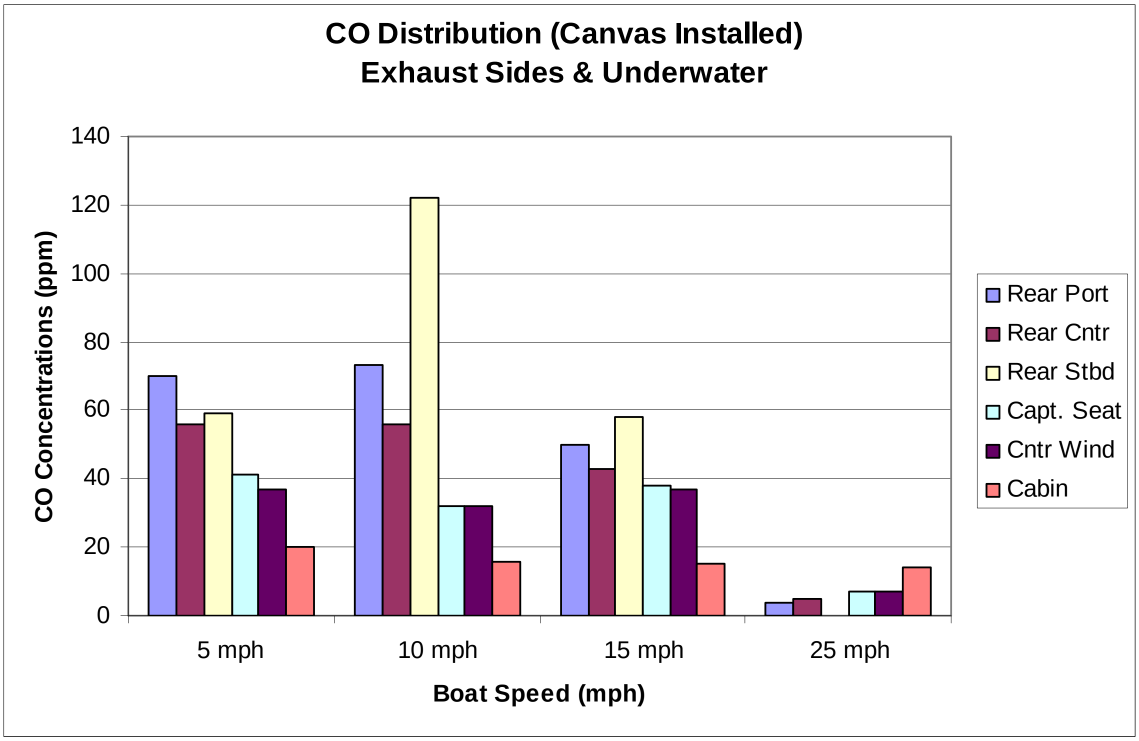


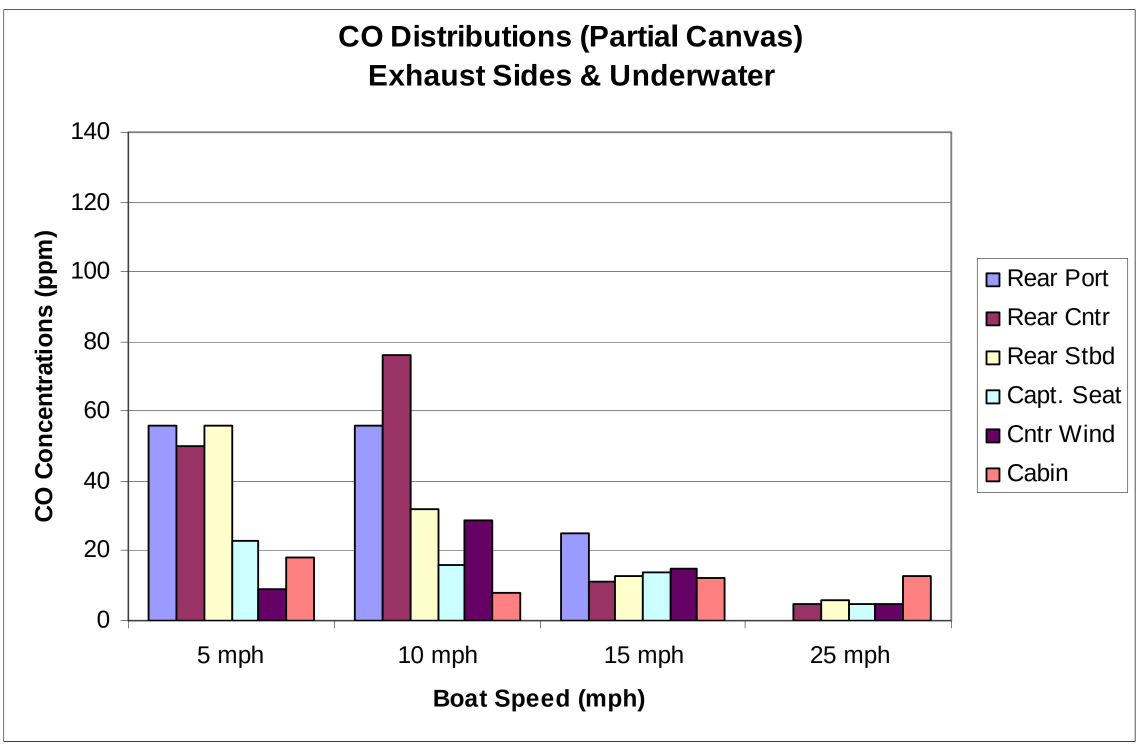




CO Distribution (Bimini Only)
Exhaust Through The Transom
CO Concentrations (ppm)
800
700
600
500
400
300
200
100
0
5 mph
10 mph
15 mph
25 mph
Boat Speed (mph)
Rear Port
Rear Cntr
Rear Stbd
Capt. Seat
Cntr Wind
Cabin

Figure 9: Boat 5 (36') Twin Mercruiser 8.1L Combined Exhaust Through the Sides and Underwater.





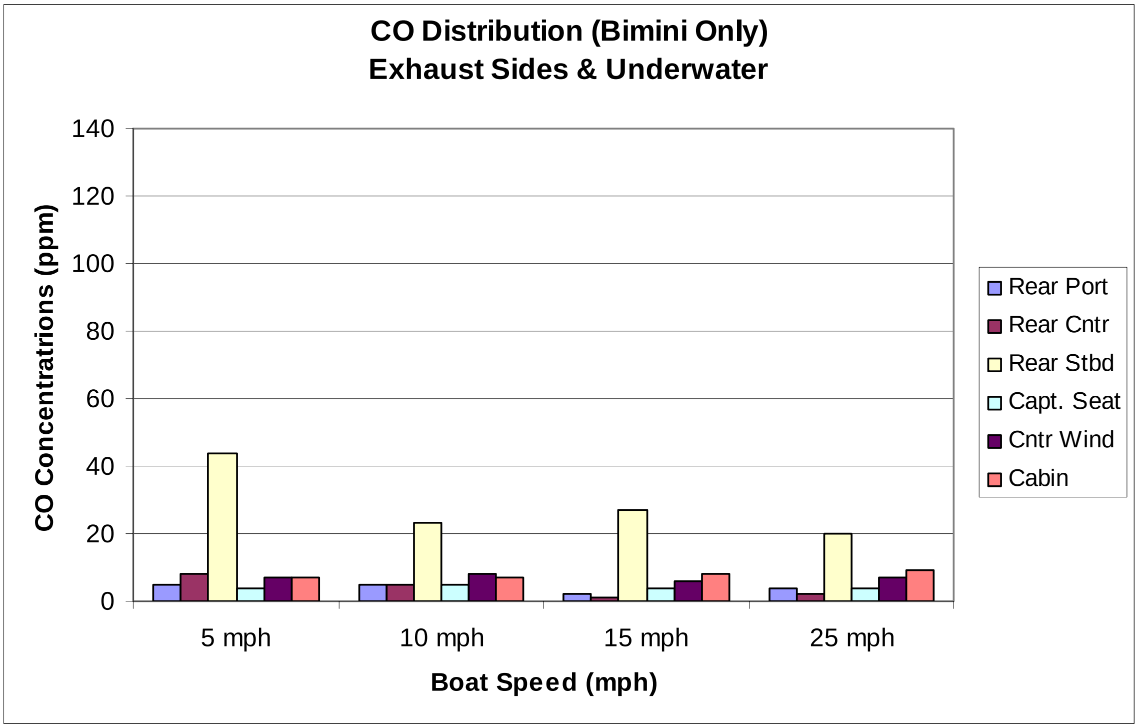
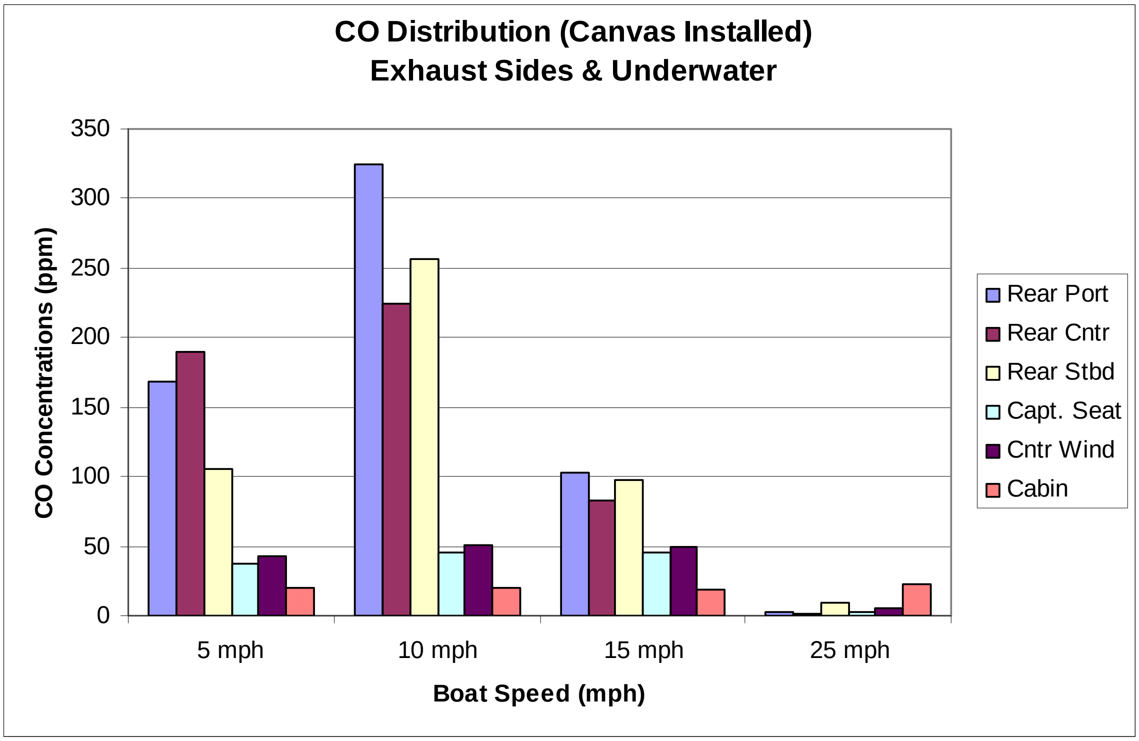
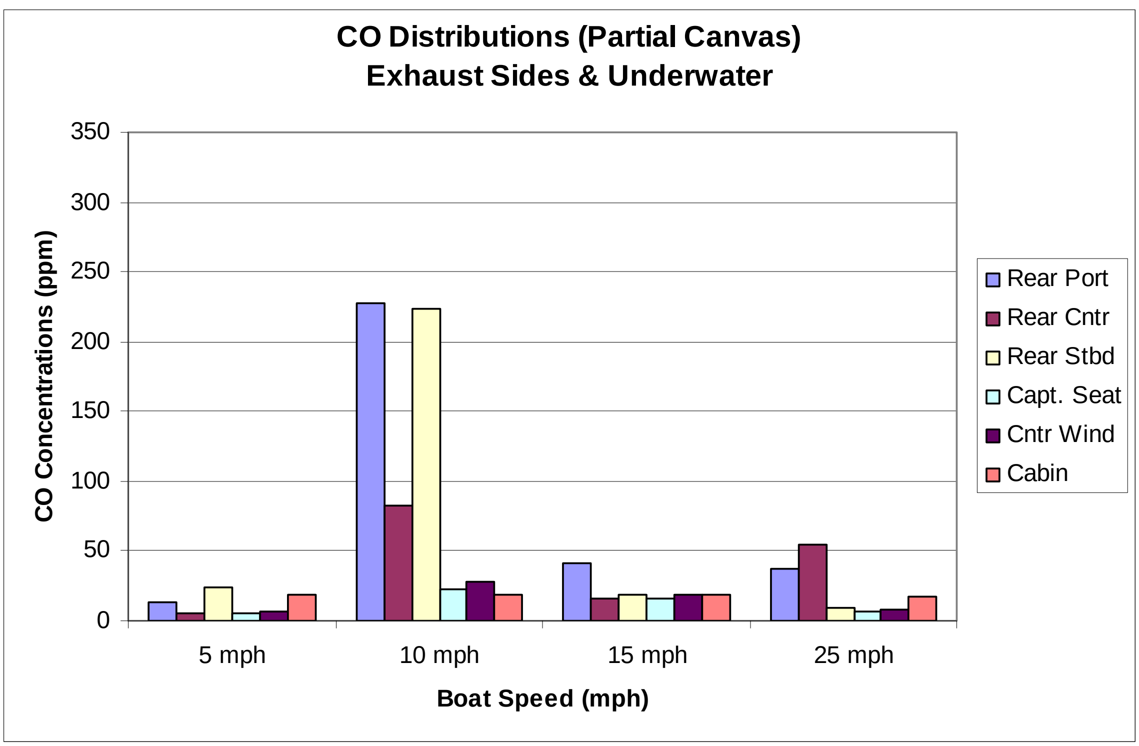

CO Distribution (Bimini Only)
Exhaust Sides & Underwater
140
120
100
80
60
40
20
0
CO Concentratrions (ppm)
5 mph
10 mph
15 mph
25 mph
Boat Speed (mph)
Rear Port
Rear Cntr
Rear Stbd
Capt. Seat
Cntr Wind
Cabin

Figure 10: Boat 6 (40') Twin Mercruiser 8.1L Combined Exhaust Through the Sides and Underwater.





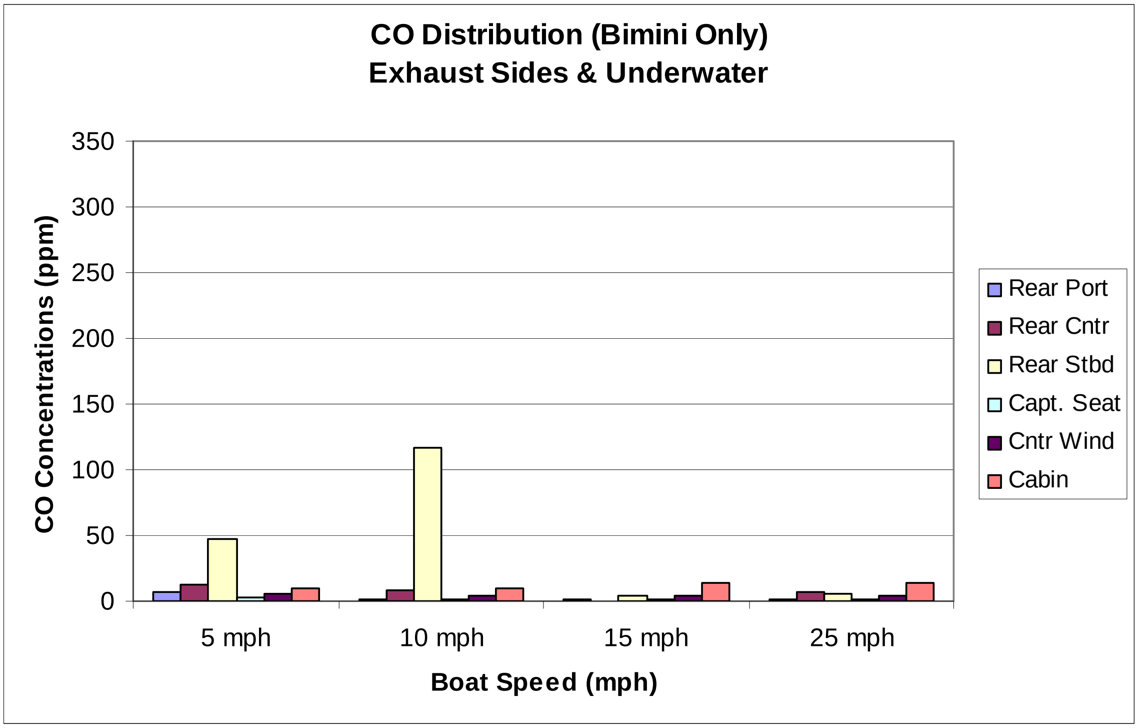
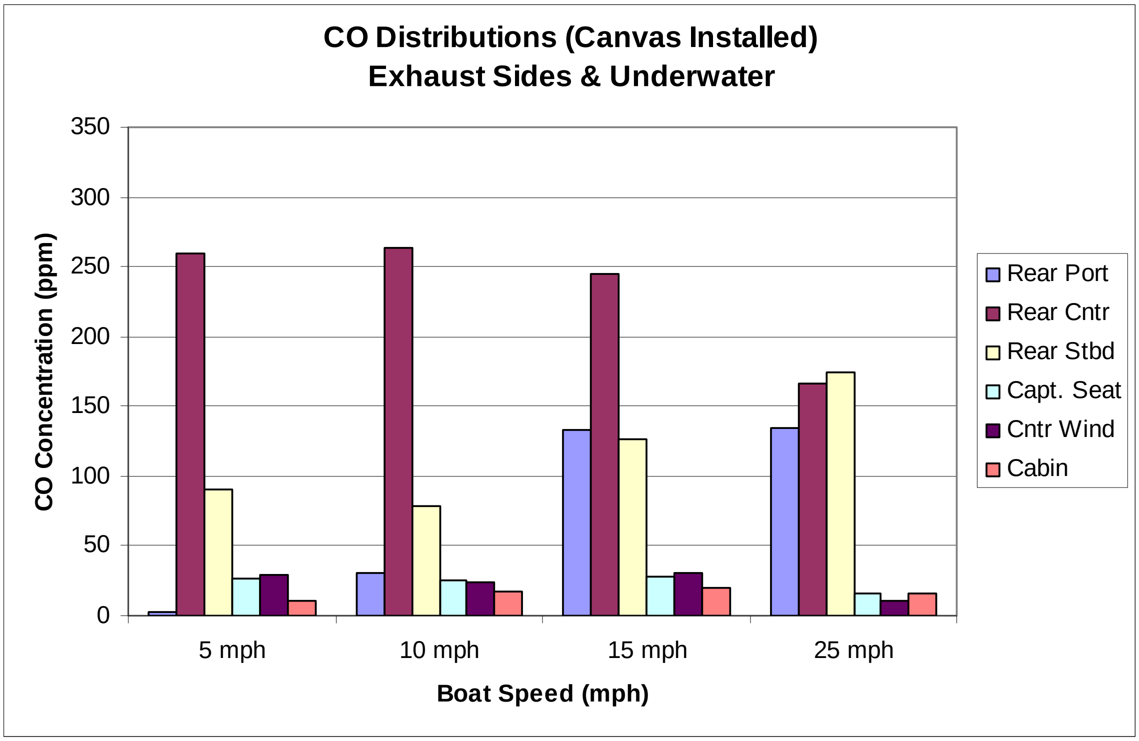
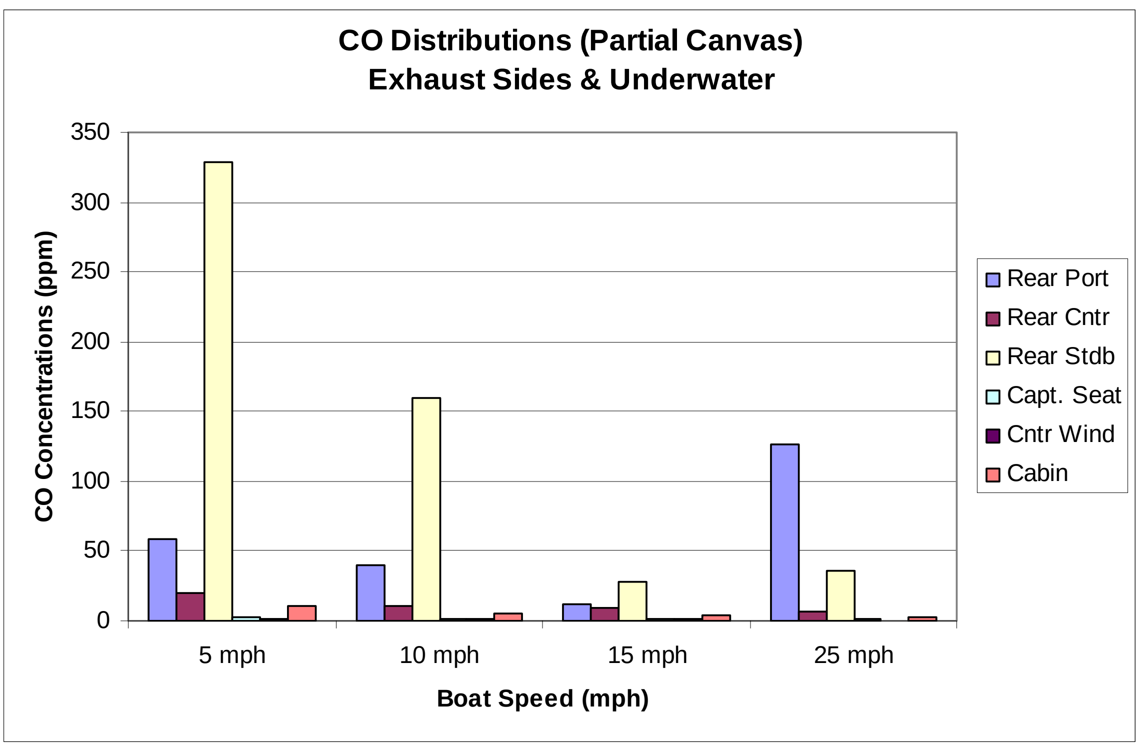

CO Distribution (Bimini Only)
Exhaust Sides & Underwater
350
300
250
200
150
100
50
0
CO Concentrations (ppm)
5 mph
10 mph
15 mph
25 mph
Boat Speed (mph)
Rear Port
Rear Cntr
Rear Stbd
Capt. Seat
Cntr Wind
Cabin

Figure 11: Boat 7 (41') Motor Yatch Twin Mercruiser 8.1L Combined Exhaust Through the Sides and Underwater.





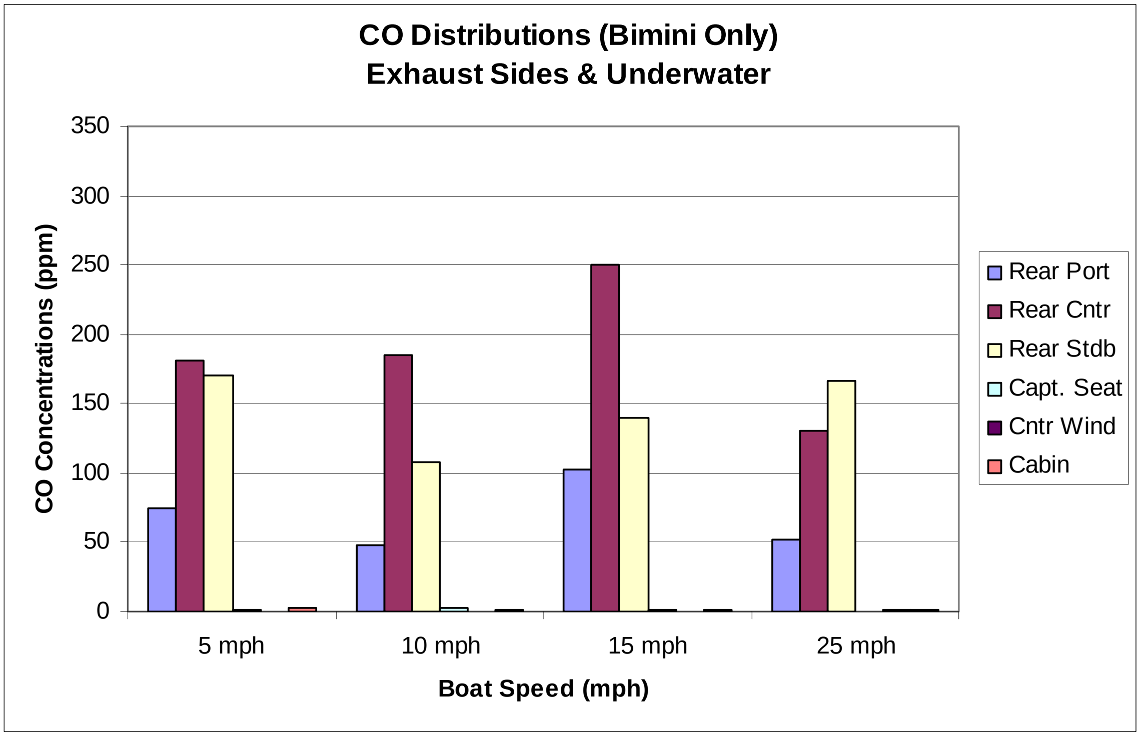
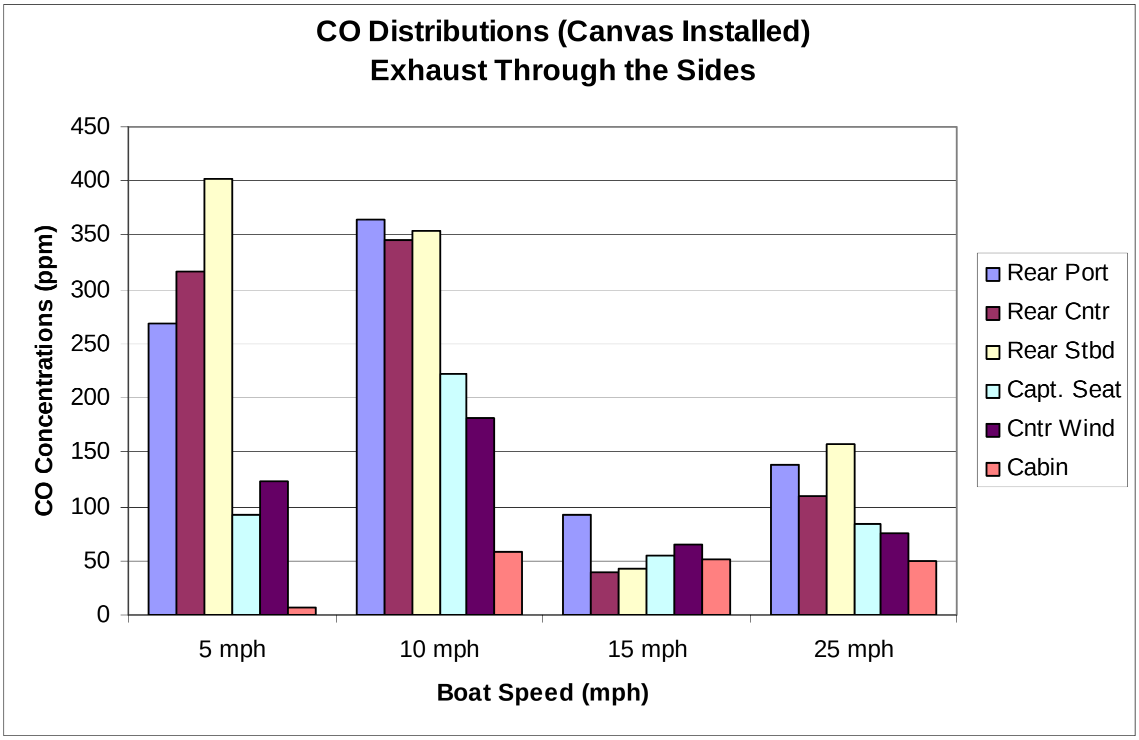
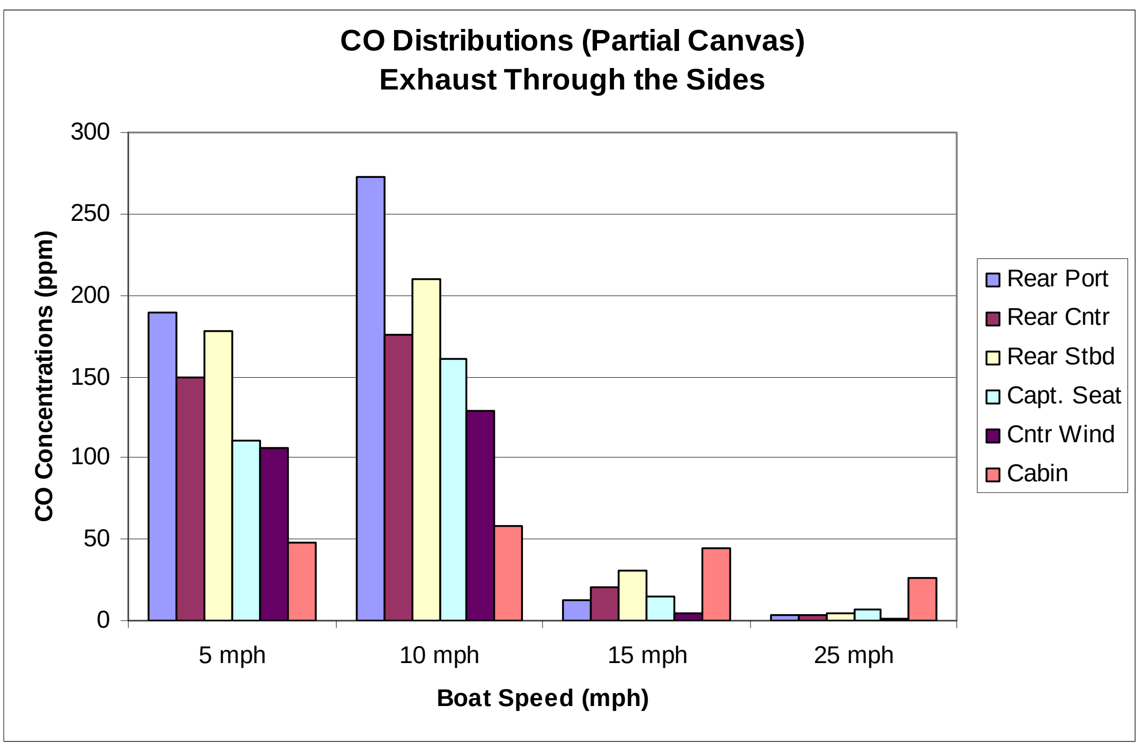

CO Distributions (Bimini Only)
Exhaust Sides & Underwater
CO Concentrations (ppm)
350
300
250
200
150
100
50
0
5 mph
10 mph
15 mph
25 mph
Boat Speed (mph)
Rear Port
Rear Cntr
Rear Stdb
Capt. Seat
Cntr Wind
Cabin

Figure 12: Boat 8 (34') Twin Mercruiser 8.1L Exhaust Through the Sides.





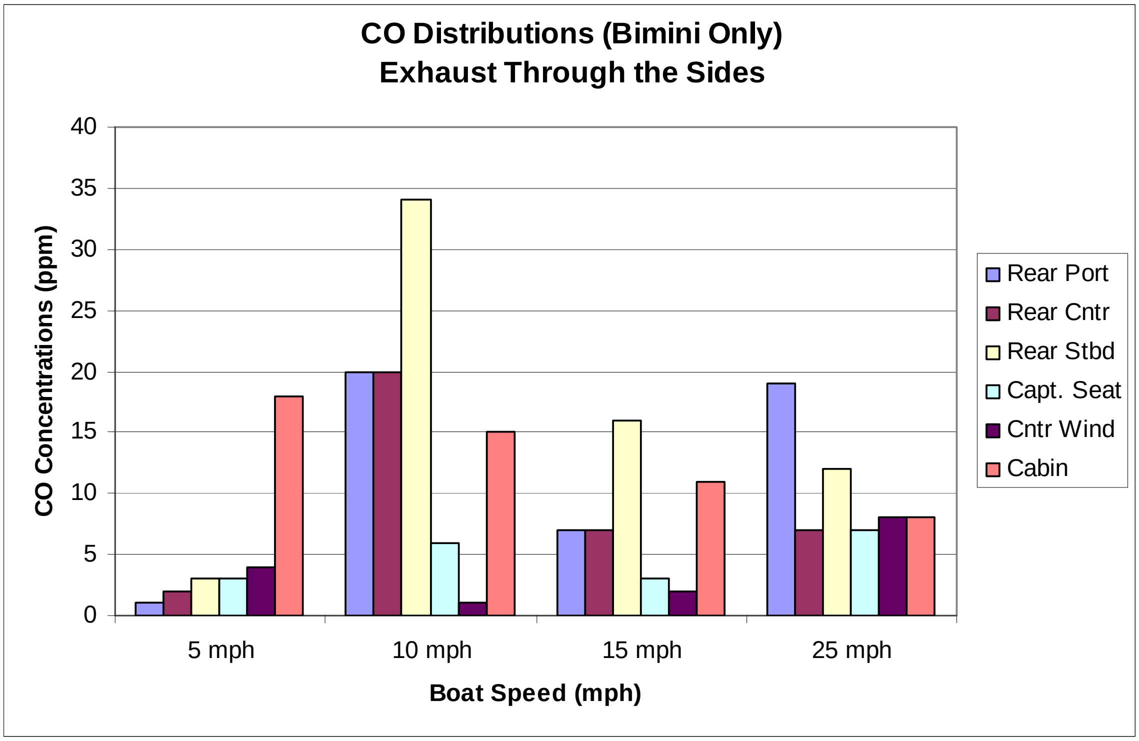
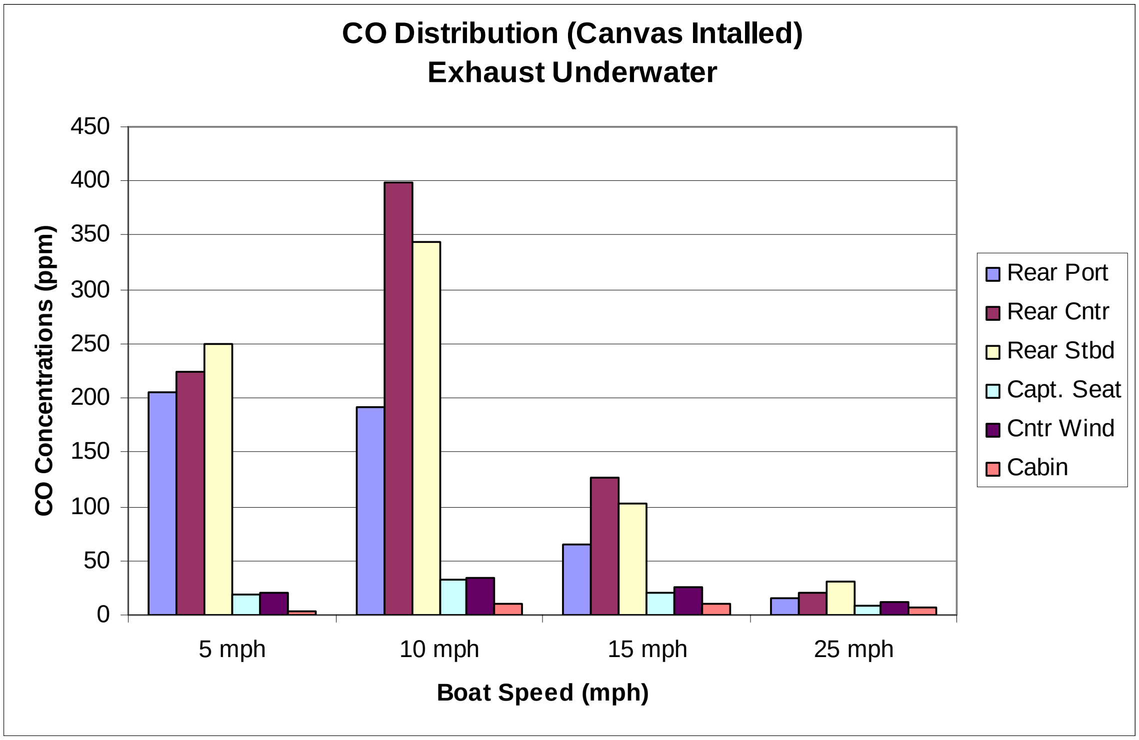
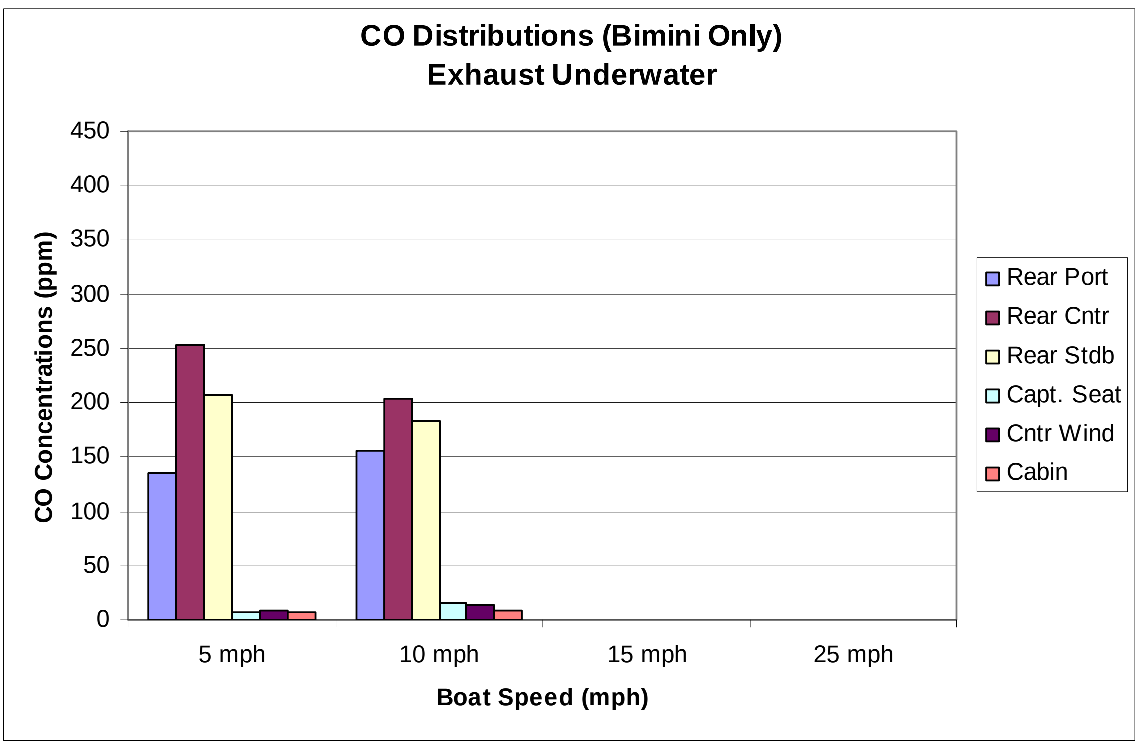

CO Distributions (Bimini Only)
Exhaust Through the Sides
CO Concentrations (ppm)
0
5
10
15
20
25
30
35
40
5 mph
10 mph
15 mph
25 mph
Boat Speed (mph)
Rear Port
Rear Cntr
Rear Stbd
Capt. Seat
Cntr Wind
Cabin

Figure 13: Boat 9 (38') Twin Crusaders 8.1L Exhaust Underwater.





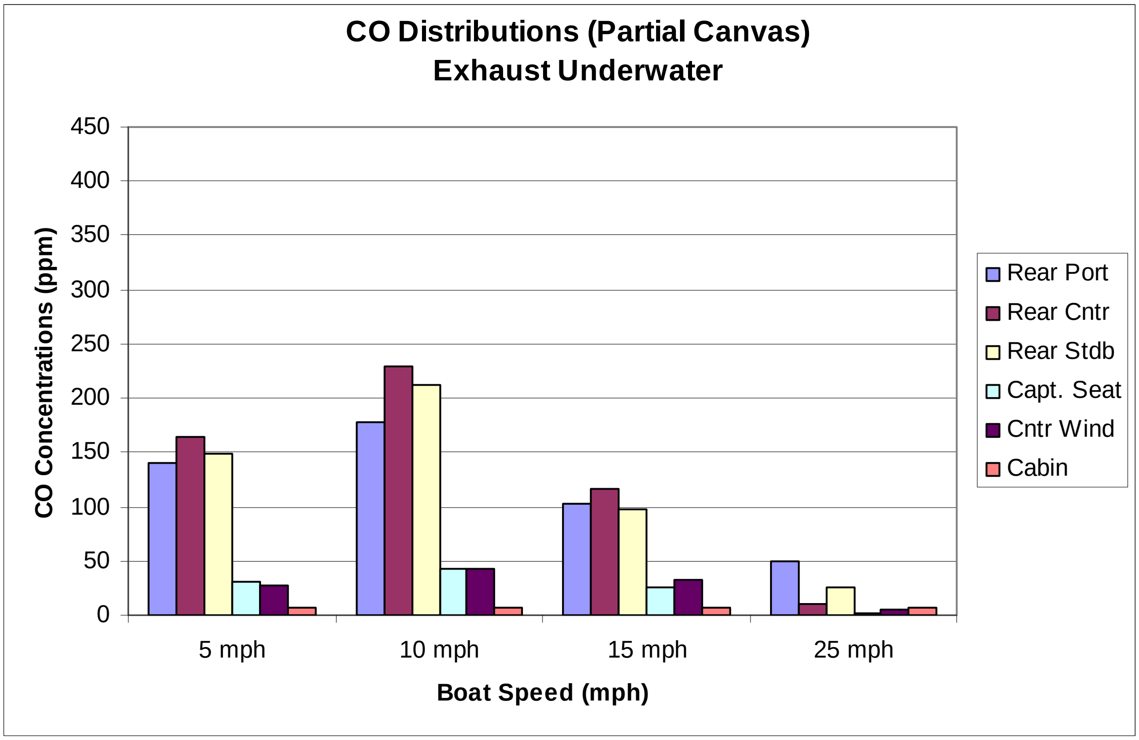
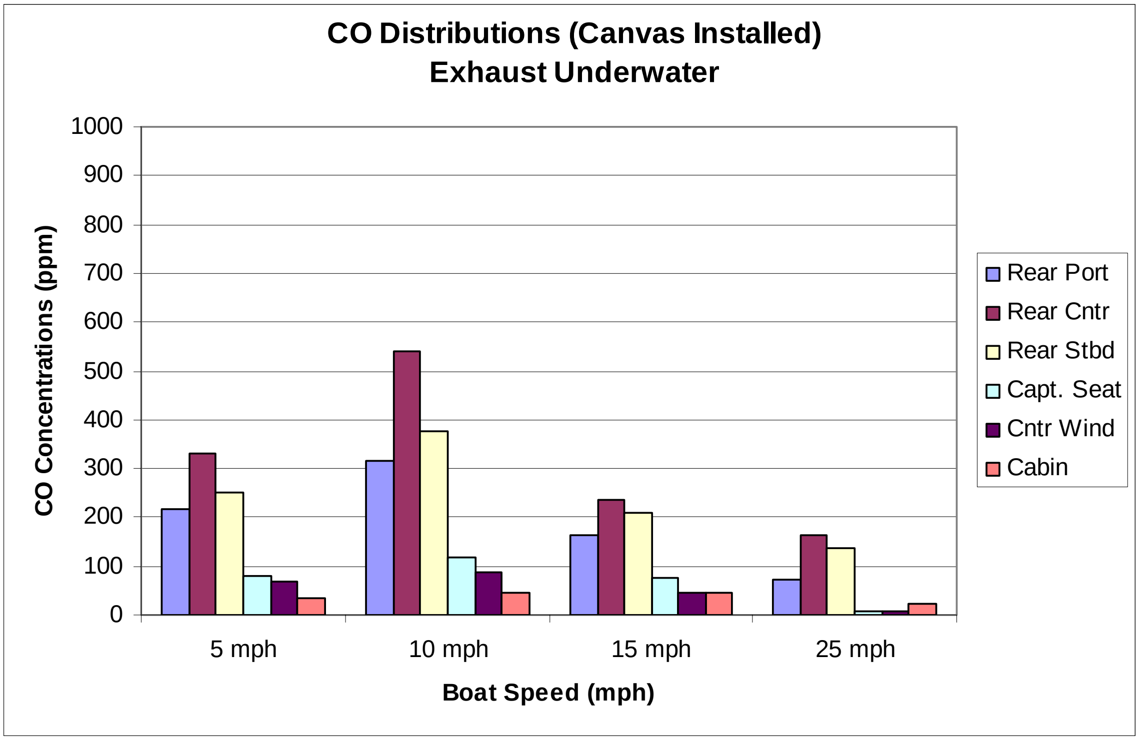
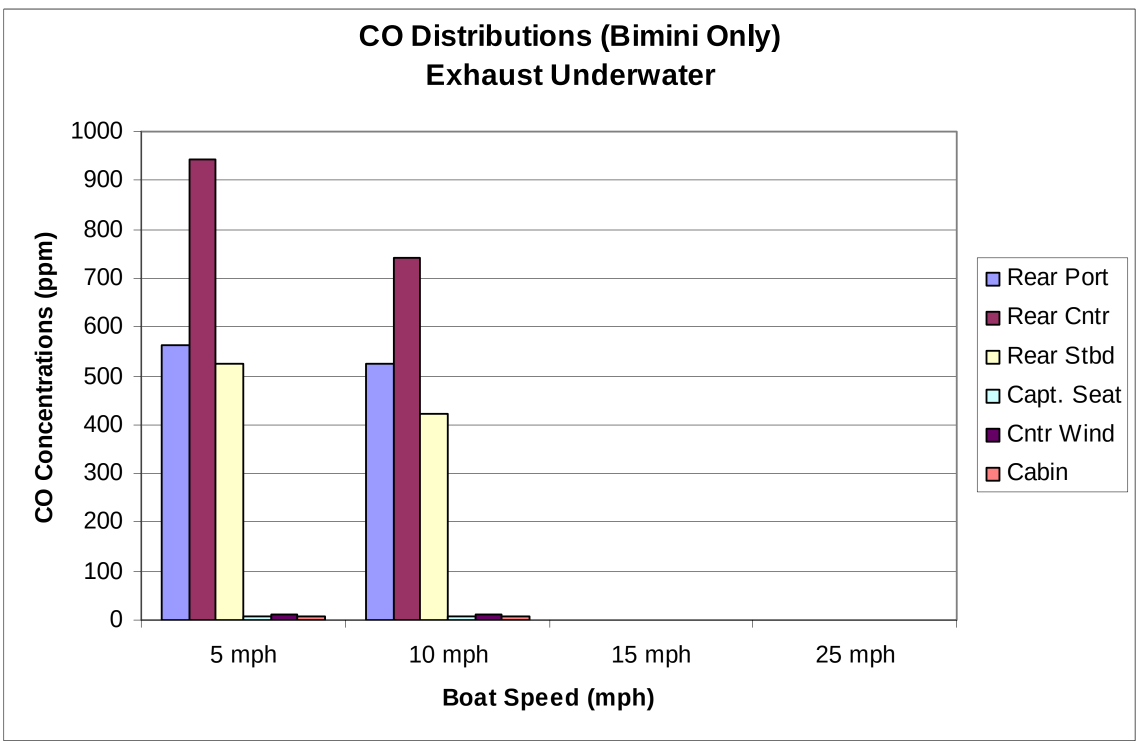
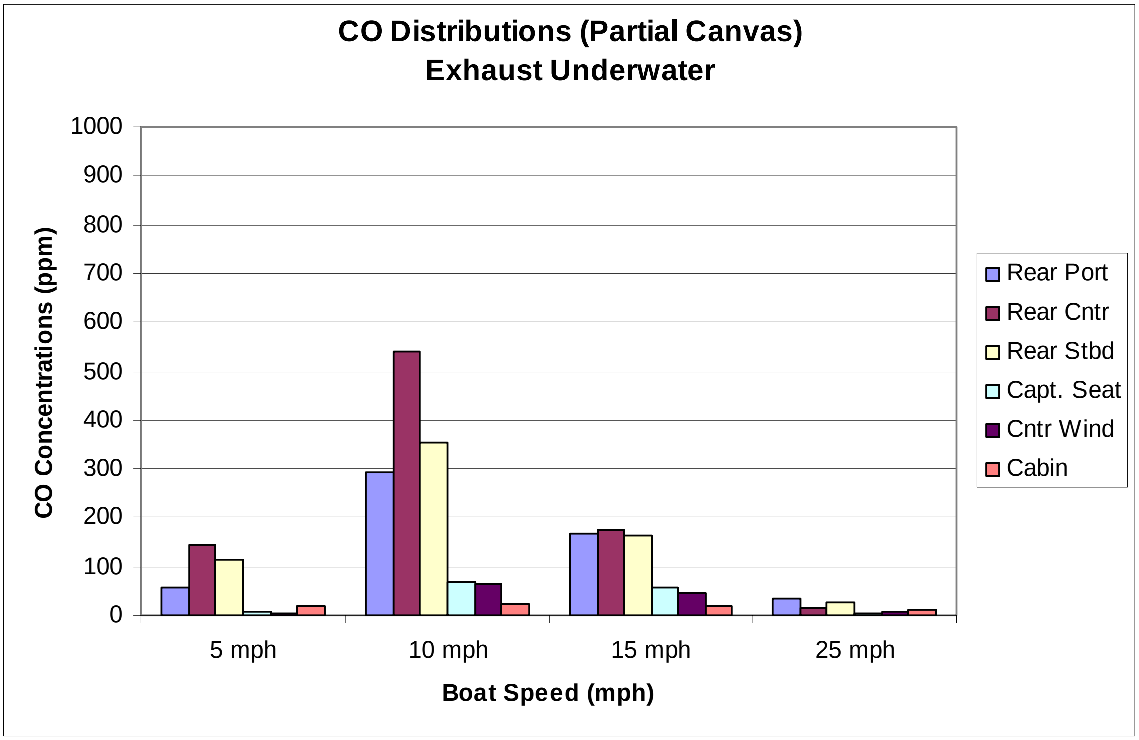

CO Distributions (Partial Canvas)
Exhaust Underwater
450
400
350
300
250
200
150
100
50
0
CO Concentrations (ppm)
5 mph
10 mph
15 mph
25 mph
Boat Speed (mph)
Rear Port
Rear Cntr
Rear Stdb
Capt. Seat
Cntr Wind
Cabin

Figure 14: Boat 10 (35') Motor Yacht Twin Crusaders 8.1L Exhaust Underwater.






CO Distributions (Partial Canvas)
Exhaust Underwater
CO Concentrations (ppm)
1000
900
800
700
600
500
400
300
200
100
0
5 mph
10 mph
15 mph
25 mph
Boat Speed (mph)
Rear Port
Rear Cntr
Rear Stbd
Capt. Seat
Cntr Wind
Cabin