Propeller Guard Test Procedure

Prepared by

American Boat & Yacht Council, Inc.

For the

United States Coast Guard

Office of Auxiliary and Boating Safety

June 3, 2013

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1. SCOPE

1.1 This procedure is intended for use by manufacturers of propeller guard devices and independent third party testing entities to evaluate propeller guard products in a consistent, repeatable manner. Propeller injury mitigation devices such as cutoff switches and propellers are not to be tested with this procedure. The procedure provides a testing method for guards installed on a specific or unique boat, with either a sterndrive or outboard configuration. Comparisons of results for different propeller guards tested using this procedure will be valid only when tests are conducted using an identical boat/engine combination.

2. PURPOSE

2.1 The purpose of this document is to determine the difference, if any, in personnel safety and boat performance characteristics resulting from the installation of a propeller guard. This test procedure provides a process by which propeller guards can be tested on a particular boat/engine combination to produce repeatable results for comparison. Other tests could be developed, subject to the requirement that they produce quantitative, repeatable results. The USCG intends that this test procedure will be reviewed by interested parties at approximately three year intervals to evaluate experience-based changes and further refine and update the test procedure. Meanwhile, a file of comments will be maintained by the USCG to serve as a basis for these reviews. To be useful comments must be detailed, and submitted together with a specific recommended change written to resolve the issue identified. Comments may be submitted by email, anytime to Eric.A.Johnson@uscg.mil using the comment form included as Appendix A to this test procedure. Reviews of this document will be announced at the discretion of the USCG.

NOTE: The addition of propeller guard to the lower unit of an engine has the potential to affect the engine's compliance with EPA exhaust regulations. This document does not address testing for emission compliance.

CAUTION: These tests may reveal unexpected handling characteristics and/or dangerous conditions before, during and after maneuvering. Care must be taken to gradually increase speed and execute the maneuvers at multiple lower speeds in order to gain a feel for the behavior. Even with extensive low-speed testing, higher speeds may result in unexpected and spontaneous reactions either with or without the device installed. Use caution and experience to determine when or if the testing should be discontinued. If, in the opinion of the operator, there is a question about the safety of test personnel or equipment, discontinue the testing.

3. REFERENCES

3.1 ABYC Standard P-17, *Mechanical Steering Systems*.

3.2 ABYC Standard P-18, *Cable Over Pulley Steering Systems for Outboard Engines*.

3.3 ABYC Standard P-22, *Steering Wheels*.

3.4 European Directive 70-311-EWG and 70-311-EEC.

3.5 NASA Man-systems Integration Standards, Chapter 4, Human Performance Capabilities.

3.6 Propeller Guard Performance Test Protocol, Propeller Guard System Evaluation by Richard Akers and Clifford A. Goudey - January 2009.

3.7 Propeller Injury Protection: An Evaluation of Commercially Available Protection Devices. A report of the Marine Technology Society by Mancil W. Milligan and Jeffrey S. Tennant - October 1998.

3.8 Propeller Injury Protection – An Evaluation of the State of the Art of Recreational Watercraft Propulsion systems A Report of the Marine Technology Society by Mancil W. Milligan and Jeffrey S. Tennant – September 1997.

3.9 SAE J1511 – Steering for Off-Road, Rubber-Tired Machines.

3.10 Summary Report of Testing Conducted July 19 – 23, 2010 and December 14 – 16, 2010 at the Center for Research and Education in Special Environments, State University of New York at Buffalo.

4. DEFINITIONS

4.1 Default Trim – With outboards or stern drives, the trim setting at which the propeller shaft is parallel to the water surface.

4.2 Fuel Consumption – Quantity of fuel consumed by the engines during operation, measured in U.S. gallons per hour.

4.3 Pitch – Periodic rotational motion about an axis running transversely (port to starboard) through the center of gravity, generally in response to waves.

4.4 Pitch Angle – Instantaneous angle between the longitudinal boat centerline and the horizontal plane, as a result of pitch, with a value of zero indicating no pitch.

4.5 Roll – Periodic rotational motion about an axis collinear with the longitudinal centerline of the boat through the center of gravity.

4.6 Roll Angle – Instantaneous angle between the longitudinal boat centerline and the vertical plane, with a value of zero indicating no roll.

4.7 RPM – Engine revolutions measured in rotations per minute.

4.8 Speed – Velocity of a boat measured in statute miles per hour (MPH), where 1 knot = 1.15 MPH.

4.9 Trim Angle –The angle between the longitudinal boat centerline and the horizontal plane, typically a result of both weight distribution and hydrodynamic effects.

4.10 Trimmed-In-Setting – Outboard or sterndrive trim condition such that the engine is fully trimmed in or under.

4.11 Trimmed –Out Setting – Outboard or sterndrive trim condition for a specific boat and load condition, such that the engine is trimmed as far out as possible without causing excessive porpoising, propeller ventilation, or other undesired behaviors.

4.12 Yaw – Periodic rotational motion about an axis of the boat running vertically through the center of gravity.

4.13 Yaw Angle – The instantaneous angle between the longitudinal boat centerline and a vertical plane through the longitudinal boat axis, with a value of zero indicating no yaw.

5. TEST CONDITIONS FOR ALL ON-WATER TESTING

5.1 Testing shall be conducted on calm water (wave or wake height <6-in.) with the wind speed below 10 MPH.

5.2 The wind speed, direction and the wave conditions shall be recorded.

5.3 The current, if any, shall not exceed 0.25 MPH.

5.4 The procedures in the following sections shall be executed six times, over a range of three propulsion system trim settings, and with and without the propeller guard system installed (**Figure 1**).

Table 1 – Test Conditions

	Propeller Guard	
Propulsion Trim Setting	**Not Installed**	**Installed**
Trim Setting 1 (“In”)	Test 1	Test 4
Trim Setting 2 (“Default”)	Test 2	Test 5
Trim Setting 3 (“Out”)	Test 3	Test 6

5.5 Trim settings displayed above are defined as follows:

5.5.1 A "default" trim setting would have the propeller shaft parallel to the keel line.

5.5.2 A trimmed -in setting has the lower unit pulled in toward the transom 6˚ from default. If the outboard / outdrive trim system hits a built-in stop before reaching 6˚ in from "default", then the stop will determine the trimmed - in setting.

5.5.3 A trimmed-out condition has the lower unit pushed out 6˚ from the "default" condition.

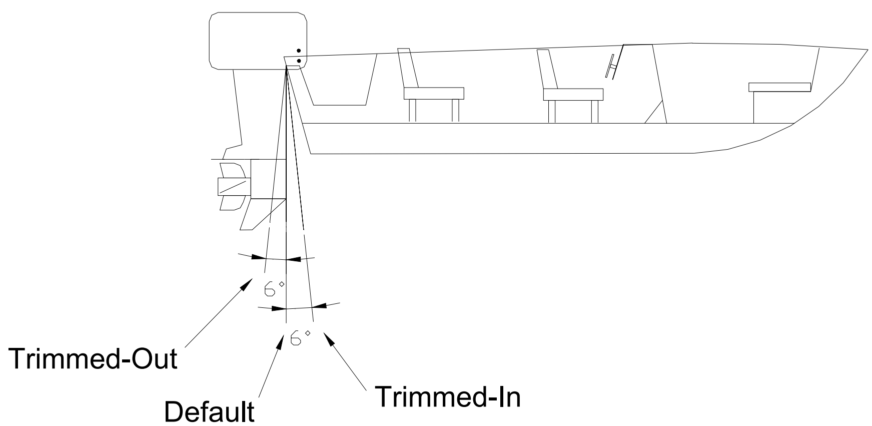
NOTES:

1. Determining the proper trim settings is critical in the execution of the test procedure. An error in these measurements and the inability to repeat the trim angles will result in faulty data and an invalid test.

2. In determining these trim settings, measure the angular difference between the keel line and the propeller shaft in degrees. The use of an electronic level or a dial angle indicator is suggested. In the case of boats with multiple engines, the trim indicators shall be calibrated on each outboard or sterndrive.

3. If the boat is not equipped with a trim indicator, manual adjustments shall be made prior to each test. Precise visual markings may be used to provide a repeatable trim position. Alternatively, suitably sized gage blocks can be fabricated in plastic or wood to act as stops to ensure the "<u>in</u>", "<u>out</u>", and "<u>default</u>" conditions are consistent throughout the test series.

Figure 1 - Trim Settings



6. PREPARATION AND CONDITION

6.1 The following aspects of the boat shall be considered:

NOTE: It is recognized that operator skill and familiarity with a particular boat and engine combination may affect the test results. It is, therefore, considered permissible to make a number of practice runs for each test. Since the testing may result in unexpected maneuvering issues experienced operators are required for these tests.

6.1.1 Fuel Tank(s) – There shall be an accurate way of measuring the fuel on board. The same amount of fuel shall be aboard at the beginning of each series of tests. The method used to determine fuel level, and the amount on board shall be documented.

6.1.2 Capacity – The boat shall not be overloaded or in its lightest condition. One test operator and one data technician shall be on board during underway testing unless otherwise indicated in the procedures that follow. Equipment and personnel shall be located consistently on board for each of the six test conditions. Document the load and its positioning.

6.1.3 Water Tanks/Live Wells/Bilge shall be empty.

6.1.4 Equipment – Bimini tops, fire extinguishers, fish finders, anchors, dock lines, fenders etc. shall be in their normal positions for underway operation, and shall remain consistent throughout the testing.

6.1.5 If the boat is fitted with trim tabs that are not required for normal operation, they shall remain in the up (unused) position for all tests. If a boat requires trim tabs for acceptable performance (e.g. planing) then that position shall be used throughout the test and the position shall be documented. ***NOTE: Trim tabs may not be used to compensate for any condition that occurs when a device is installed.***

7. TEST EQUIPMENT

7.1 Various manufacturers provide equipment suitable for performing on-water testing. A suggested instrumentation package is contained in **Table 2** below.

Table 2 - Test Equipment

Parameter	**Desired Units**	**Digitally Logged**	**Suggested Sensor**	**Desired Accuracy**	**Max. Time between Samples**
Speed	MPH	Yes	Differential GPS	+/- 0.25 MPH	1 second
Engine	RPM	No	Tachometer	+/- 10 RPM	N.A.
Acceleration	Gs	Yes	Accelerometers	+/- 0.01 G	0.1 seconds (with 10Hz, 2nd order low-pass filter)
Turning radius	Feet	Yes	Tracking GPS	+/- 8 inches	Post processing based on 1-second position track
Pitch	Degrees	Yes	3-Axis Inclinometer	+/- 2 degrees	0.1 seconds
Yaw	Degrees	Yes	3-Axis Inclinometer	+/- 2 degrees	0.1 seconds
Roll	Degrees	Yes	3-Axis Inclinometer	+/- 2 degrees	0.1 seconds
Steering angle	Degrees	Yes	Angle sensor	+/- 1 degrees	0.1 seconds

Parameter	Desired Units	Digitally Logged	Suggested Sensor	Desired Accuracy	Max. Time between Samples
Steering torque	Foot pounds	Yes	Strain gage load cell	+/- 1% full scale	0.1 seconds (with 10Hz, 2nd order low-pass filter)
Outboard/ sterndrive Trim	Degrees	No	Protractor, digital level or dial angle indicator	+/- 1 degrees	N/A

8. TEST METHOD

8.1 Rating Scale

8.1.1 A rating scale of 0 to 3 has been established for the four rating categories discussed in this procedure. Test procedures for each category are outlined below.

8.2 Performance - Speed

8.2.1 This is a straight-line speed test used to quantify any change in speed as a result of adding the propeller guard. The specific steps to be taken to determine the effect of the propeller guard on the boat's speed shall be in accordance with the procedures listed below

8.2.2 Procedure

8.2.2.1 Prior to commencing this test, verify that the installed propeller is consistent with the engine manufacturer's recommendation for the boat make/model to be tested.

8.2.2.2 With the outboard/sterndrive in forward, head directly into the wind at idle in-gear RPM. Once the speed has stabilized, note the RPM and the speed.

8.2.2.3 Increase outboard/sterndrive RPM to the first multiple of 500 RPM, achieve stabilization and again, note RPM and the speed.

8.2.2.4 Repeat 8.2.2.3 in 500-RPM increments until the outboard/sterndrive reaches maximum RPM. Run a final test at maximum RPM.

8.2.2.5 If the wind speed is greater than 5 MPH, repeat Steps 8.2.2.2, 8.2.2.3 and 8.2.2.4 heading directly downwind.

8.2.2.6 Should the engine fail to achieve the manufacturer's rated maximum rpm during Step 8.2.2.4 above, install a propeller with a pitch allowing full rated rpm to be achieved with the guard installed and then repeat the steps in 8.2.2.

8.2.3 Required Data

8.2.3.1 The following data shall be recorded:

8.2.3.1.1 Engine RPM (noted for each increment).

8.2.3.1.2 Boat speed.

8.2.3.1.3 Boat trim angle at static floating position (displayed or logged values from the test instrumentation, taken at the beginning of the test). Boat trim angle at each RPM.

8.2.3.2 The summary metrics for the Speed vs. RPM tests are:

8.2.3.2.1 The average of the percent differences in speed over the full range of RPM settings.

8.2.3.2.2 The percent difference between top speeds with and without the propeller guard.

8.2.3.2.3 The percent difference in maximum boat trim angle over the full range of RPM settings.

8.2.4 Data Evaluation

8.2.4.1 Following the procedures above, a speed rating can be determined. When determining the rating for speed, a degradation greater than or equal to 25% relative to an unguarded propeller shall be assigned a rating of '1', a degradation of between 10% and 25% shall be assigned a rating of '2', and a degradation less than or equal to 10% (or an increase in speed) shall be assigned a rating of '3'. Since there are a large number of combinations of potential hull forms and power, the test report shall state that the rating was based on testing using a particular hull form and engine.

8.3 Performance - Maneuverability

8.3.1 This test measures the difference between maneuvering with and without a propeller guard. The test measures the ability of the boat to turn in response to specified helm inputs.

8.3.2 Procedure

8.3.2.1 Determine three test speeds as follows:

8.3.2.1.1 High speed - 90% of the top speed, determined from the straight line testing (see 8.2) both with and without a propeller guard for each trim setting.

8.3.2.1.2 Low speed - shall correspond to a "no-wake" speed with positive steering control.

8.3.2.1.3 Medium speed - the average of the high and low speeds.

NOTE: Should medium speed fall in the transition range between non-planing and planing operation, increase the test medium speed slightly above the calculated average to achieve low-speed planing operation.

8.3.2.2 For each selected speed setting, identify the corresponding RPM setting for each trim setting with and without a propeller guard. That RPM setting shall be used throughout each serpentine run (see **Figure 2**). The steering position sensor is recorded during these tests for the purpose of verifying that the helm commands were properly executed within the specified time limit. If low test speeds result in the crossing of the test boat's earlier wake, disregard any roll data from that run.

8.3.2.3 Set the engine RPM for the first low-speed setting. Steer a course (initial heading) in the intended direction of the test sequence. Identify the helm position that provides a constant heading. Mark that helm position with a piece of tape or other means.

NOTE: The "amidships" mark is likely to change at different engine speeds and should be determined for each test speed setting.

8.3.2.4 Once at a steady speed, turn the steering wheel 360˚/one full turn to starboard or the limit of rotation, whichever is less. The helm turn shall be completed in less than 1 second.

8.3.2.5 Hold the wheel at that position until the boat has turned 90° relative to its initial heading.

NOTE: It may be necessary to adjust the throttle setting during the turn in order to maintain the specified engine RPM.

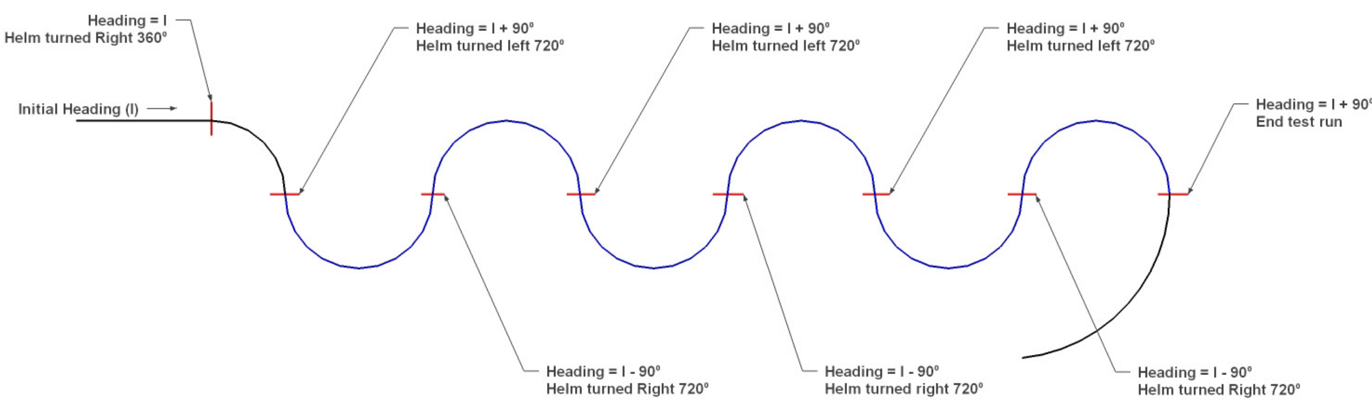
8.3.2.6 Once at 90˚ from the initial heading quickly turn the wheel to port 720˚/two full turns or until the limit of rotation is reached, whichever is less. The helm turn shall be completed in less than 2 seconds.

8.3.2.7 Complete a 180˚ course change and once at 90˚ from the initial heading quickly turn the wheel to starboard 720˚/two full turns or until the limit of rotation is reached, whichever is less. The helm turn shall be completed in less than 2 seconds..

8.3.2.8 Repeat steps 8.3.2.6 and 8.3.2.7 until the boat has gone through six complete half-turns. During the entire series of turns, adjust the throttle to maintain the specified outboard/sterndrive RPM. A diagram of the desired track is presented in **Figure 2.**

8.3.2.8.1 Document any anomalies such as propeller ventilation during turns. If any instabilities or difficulty in controlling the boat is experienced, the test shall be aborted, and the anomalies recorded.

Figure 2 - A diagram of the desired track for the maneuvering test.



8.3.3 Required Data

8.3.3.1 Pitch and roll angle data recorded during the 180˚ turns (blue portion of **Figure 2**), edited to remove the data recorded when the boat encounters its' own wake.

8.3.3.2 Speed and position from GPS.

8.3.3.3 Steering Wheel torque data recorded during the series of 180˚ turns.

8.3.4 Data Evaluation

8.3.4.1 Calculate the following metrics for each trim condition and speed:

8.3.4.1.1 The extreme and the average of the port and starboard roll angles during the serpentine run.

8.3.4.1.2 The maximum and the average of the port and starboard steering wheel torques during the serpentine run.

8.3.4.1.3 Plot the track of each serpentine run and graphically determine the turning radius for each of the 180˚ turns (blue portion shown in **Figure 2**).

8.3.4.1.4 Calculate the steering position for each of the turns and the time required to execute the helm shift. This is defined as the time from the start of the steering event to the finish of the steering event. The steering position data shall be reviewed to ensure that helm positions during the 180˚ turns are held to within 1˚ of the prescribed position and that the helm is shifted within the prescribed time constraints.

8.3.4.2 The following metrics shall be calculated to evaluate maneuverability performance.

8.3.4.2.1 The percent difference in extreme port and starboard roll angle over the three 180° changes in boat direction.

8.3.4.2.2 The percent difference in average port and starboard roll angle over the three 180° changes in boat direction.

8.3.4.2.3 The percent difference in extreme port and starboard steering wheel torques over the three 180° changes in boat direction.

8.3.4.2.4 The percent difference in average port and starboard steering wheel torques over the three 180° changes in boat direction.

8.3.4.2.5 The percent difference in port and starboard turning radii averaged over the three 180° changes in boat direction.

8.3.5 Statistically compare the average of these peak torque measurements recorded above for a guarded versus unguarded condition to determine whether the addition of a guard significantly alters steering effort. A simple two-group comparison test will suffice (an independent t-test or Mann-Whitney test, depending on whether the data is normally distributed). Any peak torque measurement under the guarded condition exceeding 27 Nm shall result in a rating of “0” for this test. If no peak readings greater than 27 Nm are recorded, determine evaluation scores from **Table 3** below.

Table 3 - Maneuverability Evaluation

Comparison Result “p” value	Evaluation Score
$p \leq 0.05$	1
$0.05 < p \leq 0.15$	2
$p > 0.15$	3

8.4 Ease of Installation

8.4.1 In determining the rating criterion for ease of installation the time required for installation and installation difficulty (represented by the need to use a power tool) shall determine the rating. **Figure 3** represents the rating criterion for ease of installation.

8.4.2 Procedure

8.4.2.1 Begin with the guard as packaged for sale.

8.4.2.2 Unpack guard, instructions and any included hardware.

8.4.2.3 Identify basic guard type as cage, ring, or concentric ring. See example photos below

Cage Guard

Ring guard

Concentric Ring guard

8.4.2.4 Install guard as directed in manufacturer's installation instructions.

8.4.3 Required Data

8.4.3.1 Record guard type and whether or not power tools were required for installation.

8.4.3.2 Note elapsed time from unpacking to completion of installation.

8.4.4 Data Evaluation

8.4.4.1 Assign evaluation rating obtained from **Figure 3**.

<u>Figure 3 – Installation Rating Criteria</u>

		Power tool required?	
		No	Yes
Installation time	< 1hour	3	2
	> 1 hour	2	1

8.5 Effectiveness

8.5.1 Testing conducted at Center for Research and Education in Special Environments (CRESE) located at the State University of New York at Buffalo, New York explored three principle speeds: (1) planing – 15mph, (2) wake speed/trawling – 5mph, and (3) boarding – idle and reverse. The CRESE testing was analyzed to determine the number of test sample strikes or impacts during each speed presentation. A profile was developed based on the observed characteristics of an unguarded propeller and the percentage ranges of injury producing events was assigned ratings to indicate improvement or degradation over an unguarded propeller.

Percentage of injury producing events	Rating
0% to 25%	3
26% to 50%	2
51% to 75%	1
76% to 100%	0

8.5.1.1 In lieu of expensive tank testing for each new guard, the ratings based on the CRESE results, and shown in **Table 4** below, may be used. Should one desire to perform the actual tests used in developing Table 4, the test setup and procedures from the CRESE tank tests are included as Appendix B to this test procedure.

Table 4 – Effectiveness Rating Criteria

Guard Type	**BOARDING**	**WAKE ZONE/TRAWLING (5 mph)**	**PLANING (15 MPH)**
Cage	3	3	0
Concentric	1	3	0
Ring	1	1	0
Unguarded	0	2	3

Appendix A

Comment Form

COMMENT FORM

This form is to be used to comment on the document. Each comment is to be entered on a separate line (including your name on each line). The referenced section number must have the paragraph number (e.g. 8.21.1). This will allow the comments to be sorted and make the review work much more efficient. If you have more comments than the number of lines included in this form, press tab once you have reached the last bottom right row and a new row will be created.

Please E-mail this comment form as an attachment to Eric.A.Johnson@uscg.mil ***with the document title followed by comment in the E-mail subject line.***

For example "Propeller Guard Test Protocol Comment"

Date:	**Document Name**: Propeller Guard Test Procedure	**Document Date**:

Your Name:	**Comment Type- Technical/ Editorial**	**Section, Figure or Table #**	**Statement of Problem**	**Proposed Change**

Appendix B

Effectiveness Test Setup and Procedure

Effectiveness Test Set-up and Procedure

Effectiveness Testing Protocol

This Appendix summarizes the equipment and test methods employed for testing propeller guard effectiveness that resulted in Section 8.5.5.1, Table 4 of this Test procedure. Appendix B may be used to develop the data required for evaluating effectiveness if desired.

In order to study the effectiveness of propeller guards, engine speeds of 15 miles per hour (mph), 5 mph, parked-in-gear and reverse were tested. These speeds represented planing speed, no-wake speed and maneuvering. Test samples were placed at distances of 30 inches (in.), 24-in., 12-in. and 6-in. measured horizontally from the centerline of the propeller. Using these speed presentations and the test sample distances, five different test scenarios: (1) unguarded, (2) cage guard (Figure 1), (3) round ring guard (Figure 2), (4) octagonal ring guard (Figure 3), and (5) concentric ring guard (Figure 4) were studied.

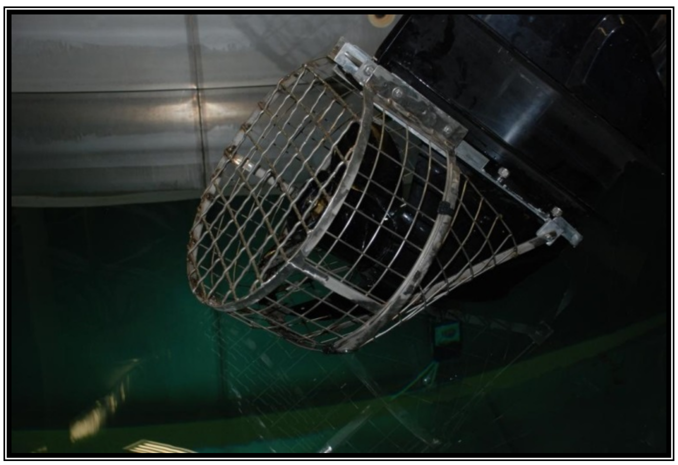


Figure 1 – Cage guard

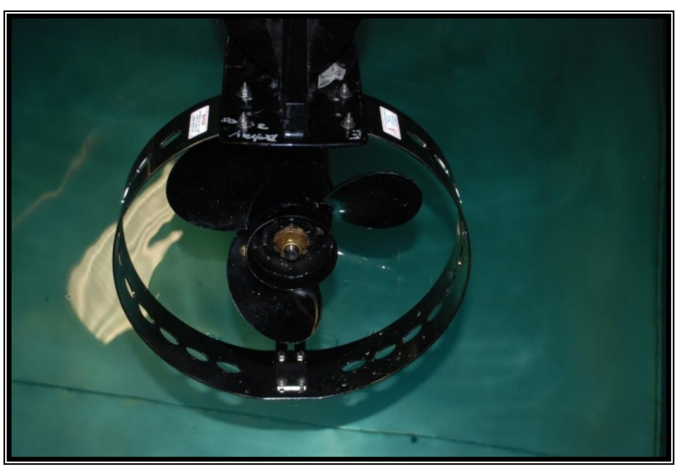


Figure 2 – Round ring guard

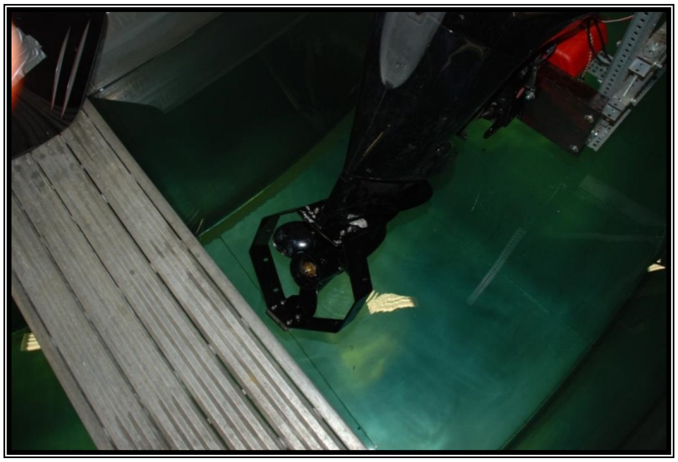


Figure 3 – Octagonal ring guard

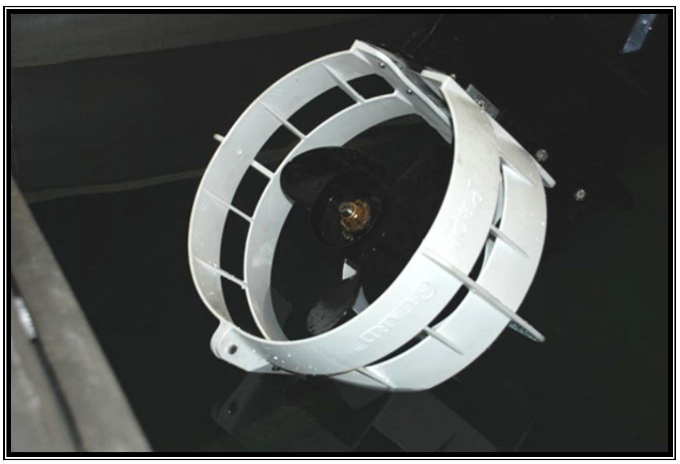


Figure 4 – Concentric ring guard

Data was recorded using video as described below. The results of each of the test runs were described in notes and photographs were used to record the results of any contact between the engine and the test samples.

Test Apparatus

Originally configured as part of a human rated centrifuge, the CRESE circular pool was eight feet deep and eight feet wide and was fitted with a rotating arm; a 175 horsepower (hp) outboard engine was mounted on the rotating arm (Figure 5). Two Deep Blue Pro color underwater video cameras were suspended underwater and mounted on an extruded aluminum frame on the outside diameter of the circular pool. Additionally, an Olympus iSpeed high speed camera was mounted adjacent to an observation window located below the pool's waterline (Figure 6). The two Deep Blue Pro video cameras captured the approaching and departing engine, while the high speed video camera recorded video at 90 degrees horizontally to the path of the engine. High intensity lighting illuminated the circular pool from locations above and below the pool's waterline.

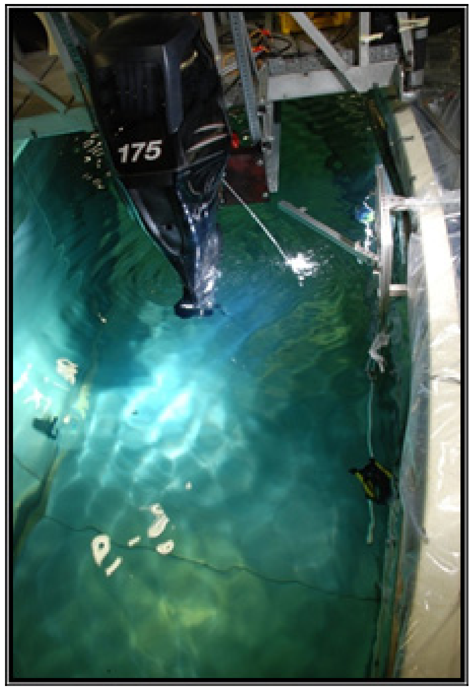


Figure 5 – Engine mounted on the rotating arm

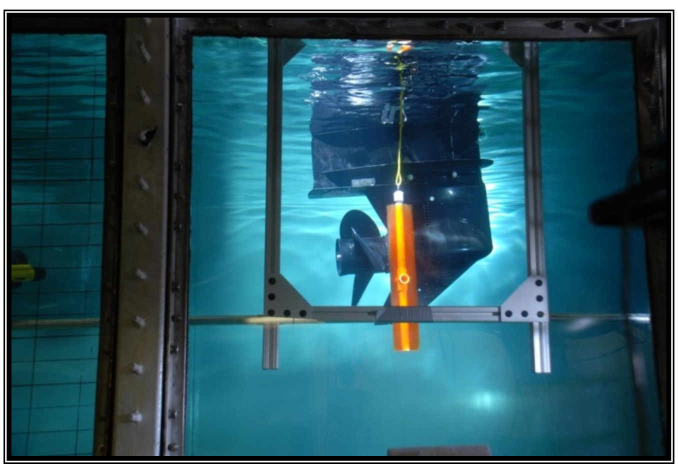


Figure 6 – Observation window. One of two Deep Blue Pro underwater cameras shown on the left. Test sample shown suspended from extruded aluminum frame

Test samples consisted of Gelatin Innovations VYSE professional ballistic and ordnance gelatin (ballistic gel). As depicted in Figure 6, cured ballistic gel samples used during the July 2010 testing and a portion of the December 2010 testing were 16-in. long with a 3-in. diameter, cored with ½-in. schedule 40 PVC piping, and with a 4-way cross fitting centered within the sample. These test samples were hung from the extruded aluminum frame as depicted in Figure 6. Cured ballistic gel samples used during the

December 2010 testing had a 10-in. diameter and were either 16-in. or 30-in. long, cored in a similar manner with PVC piping, and with a 4-way cross fitting centered within the sample. In order to study the relationship between the location of the test sample and the interaction with the propeller, the design of the frame permitted movement of the sample along a line perpendicular to the centerline of the propeller.

A summary of the test apparatus is depicted in Figure 7 below.

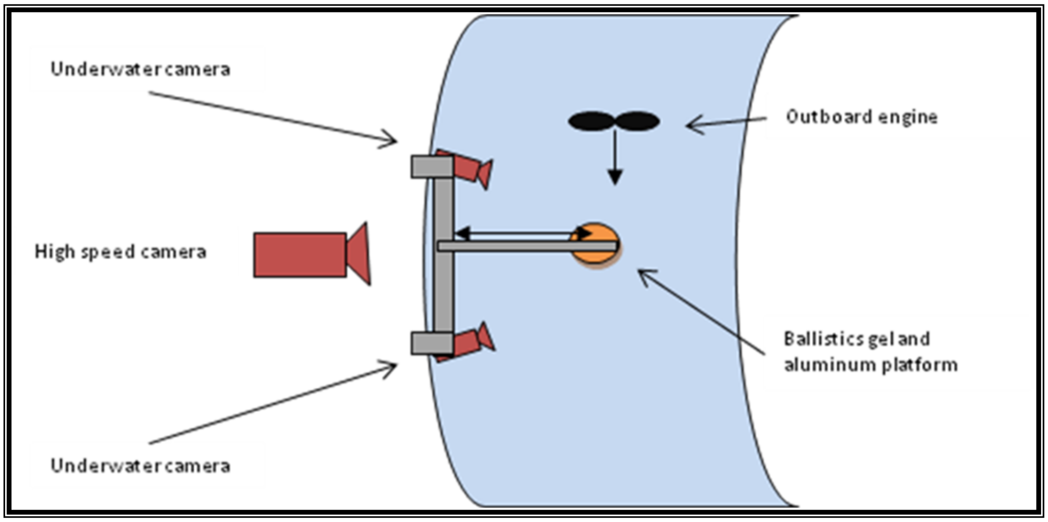


Figure 7 – Test apparatus representation

Testing Analysis

Following the test runs, analyze the number of test sample strikes during each speed run to develop a profile as described in Paragraph 8.5.1 of the Propeller Guard Test procedure. Propeller Impacts with test samples are considered as injury producing events, and the percent of injury producing events relates to the effectiveness ratings, 0 – 3.