AC 2011-1755: DESIGNING AN AUV COMPETITION TO DRAW ENGINEERING STUDENTS TOWARDS OCEAN ENGINEERING

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The First International Autonomous Underwater Vehicle (AUV) Competition took place in the summer of 1998, under the sponsorship of the Office of Naval Research (ONR) and the Association for Unmanned Vehicle Systems International (AUVSI). The competition has been held every summer since then, and the fourteenth iteration (AUVSI Foundation & ONR's 14th International RoboSub Competition) will take place in July 2011, at the U.S. Navy's SSC Pacific TRANSDEC Facility in San Diego, CA. The goals of the competition is are to provide opportunities for students to experience the challenges of system engineering, to develop skill in accomplishing realistic missions with autonomous vehicles, and to foster relationships between young engineers and the organizations developing and producing autonomous systems.

There are two major aspects to designing the competition. The first is the selection of the competition site, including the body of water the AUVs will compete in. We call that body of water the *arena*. The second aspect is the design of the mission itself. Below we list the key attributes of both the competition site (including the arena) and the mission. This ordering is deliberate, as the arena will set constraints on what types are missions are either practicable or permitted. These requirements can be derived from the stakeholder analysis, which can be found in Appendix A.

Site Requirements

- Physical space and amenities for teams, judges, audience (food, drink, bathrooms, workbenches, power, shade, etc.)
- Ease of launch and recovery
- Clear water in arena
- Good acoustics in the 20-30 kHz band
- Feature-rich bathymetry
- Closed body of water
- Logistics of Locale: Close to airport with regular passenger flights; Nearby hotels for judges, staff, the teams, and their families; reliable express delivery to site and/or hotels
- Access to testing tank (e.g., 3-foot-deep inflatable swimming pool)

Mission Requirements

- Interesting, challenging task for teams
- Build relevant technical skills
- Portions of the mission must be tractable for students new to the field and competition
- Tiered success
- Easily explained to public
- Be visually engaging for audience
- Provide useful video & still imagery
- Student teams must be able to mock up the physical infrastructure on their own

Discussion of Sites Used

In reviewing the needs of the various stakeholders, we find that most of the requirements are driven by the design challenge set forth for the students or by the physical layout of the competition site. The design challenge, in turn, is critically dependent upon the characteristics (size, depth, water clarity, bottom type) of the body of water (the *arena*) in which the AUVs will operate. Therefore, the single most important choice made in designing the competition is the selection of its location and the arena.

Four different sites have been used over the years. They are:

- The U.S. Navy's Coastal System Station at Panama City, Florida. (1998, 1999) The competition arena was the P-253 Test Pond.
- Disney's Coronado Springs Resort, Orlando, Florida (2000). The competition arena was Lago Dorado, a man-made lake.
- U.S. Naval Academy, Annapolis, Maryland (2001). The competition arena was College Creek.
- Space and Warfare Systems (SPAWAR) Center, San Diego, CA. The arena is TRANSDEC, the TRANSDucer Evaluation Center at SPAWAR.

In Table 1 we present the relative strengths and weaknesses of the sites in light of the site requirements above.

Table 1. Relative Strengths of Historical AUV Competition Sites

	CSS Panama City	Coronado Springs Resort	US Naval Academy	SPAWAR TRANSDEC
Water Clarity	Fair to Good	Poor	Poor	Fair to Excellent
Acoustics	Reverberant	Reverberant	Reverberant	Reverberant
Bathymetric Features	Sloped sidewall, flat bottom	Minimal	Minimal	Feature rich, readily modified.
Ease of launch and recovery	Fair	Fair	Good	Excellent
Open area for team workspaces	Very close	Few minutes walk	Few minutes walk	Very close
Closed Body	Yes	No	No	Yes
Testing tank for student access	No	Possible	Possible	Yes
Audience access	Fair	Good	Good	Good
Audience visual appeal	Good	Fair	Fair	Good to Excellent
Amenities	Fair to Good	Excellent	Good	Good
Logistics of Locale	Fair	Good	Excellent	Excellent

Figures 1-3 show the first three arenas used (1998-2001).

The fourth arena, TRANSDEC, at SPAWAR, has been used since 2002. An aerial view is given in Figure 4, while Figure 5 (and Table 2) present its unique depth profile. (The facility was designed for characterizing acoustic sources, and the profile is essentially anechoic for an acoustic source placed at the correct point in the deep bowl.) Another advantage of TRANSDEC is its physical size and the bridge which provides a natural division of the arena. This allows us to set up two separate competition areas, and place two vehicles in the water for testing at all times. Even during the competition, the other half of the arena is in use for trials.

Figure 4 shows the wide, flat space around the arena, ideal for setting up work tents for teams, food and drink concessions, a shaded dining and rest area, and a trailer/office for the judges. The space is easily large enough that we can set up 2 inflatable swimming pools for simple in-water testing. Because the work tents, judges, and amenities are all on the open, level area around the arena, interactions between teams (and between team members and the judges, press, and audience) arise naturally. It is quite common for teams to loan each other test equipment, tools, and parts, as well as sharing war stories and suggestions for solving technical problems. The sponsors have stated in very clear terms that this atmosphere of collegial competition is critical to the success of the program, and they have been pleased with the outcome.

The Evolution of the Mission

We open this section with a description of the evolution of the mission over the first several years of the program, where we were exploring what sensor modalities and tasks fit the needs of the various stakeholders as well as learning the range technical capabilities of the students. We follow that discussion with a description of the 2010 competition, where we used the knowledge gained over the preceding twelve years to create an exciting, engaging, audience-friendly competition that challenged even the most skilled teams, yet allowed those new to the competition the chance to achieve their own successes.

Evolution: 1998-2003

We had, of course, no experience in running competitions to draw upon for the initial mission design. However, we did have our experience in designing and building AUVs and our experience as educators to draw upon. We realized the need for tiered levels of success, and recognized that a team of engineering students (with limited experience in underwater systems) would find it a sizable challenge to simply make a submersible that could

1. Keep water out of its hull
2. Dive and maintain a depth, and
3. Swim in a more-or-less straight line.

We also realized that the teams would likely be integrating mission sensors into a working vehicle very close to the competition, so we wanted the sensor suite to be a simple as possible. Given the primacy of acoustics for underwater systems we felt some acoustically based payload was required. Finally, we were skeptical of vision-based algorithms for two reasons. First, vision is far less useful than acoustics for most AUV missions. Second, given the state of computing power at that time, we doubted the ability of students to make a working vision-based payload for their AUVs.

Therefore, for the first competition, we made the mission to circumnavigate the pond along the 10-foot-depth contour, travelling counterclockwise. This task exploited the simple geometry of the pond (Figure 1), which has a steeply (45°) sloped bottom around its perimeter. The task required no navigational capability and a single, downward-looking, pencil-beam sonar (along with a pressure gauge) was the only payload required. The algorithm is simple -- if the water is getting too shallow, turn to port, if it is getting to deep, turn to starboard. (In the competition, the sharp point at each end of the pond posed a challenge for the vehicles.)

The task then raised the question of assessment: How were the judges to assess how well the AUV performed its mission? We chose to place six U-shaped validation gates (Figure 6) at roughly equal angular intervals around the pond. Each gate straddled the 10-foot depth contour. If a vehicle passed through each validation gate in order, is was presumed to have followed the depth contour.

Scoring was based on (in order of increasing value)

- Quality of a technical paper describing that design
- Static judging of the vehicle
- Successfully diving, holding depth, and travelling in a straight line
- Completing the tasks of the mission

By the third year we were adding pingers and underwater strobes, and requiring teams to record the ping- and flash-rates, and to home in on those beacons. Man-made objects (2-foot-square tables of various heights) were placed on the bottom near the beacons and the teams had to determine the heights of these objects (or the depth of their tops below the water's surface).

We discovered that, thanks to the then-booming web-cam industry, teams were actually quite adept at implementing vision systems into their vehicles. Vision has the added advantage that part of a team can work on the vision system in air in the lab while the rest of the team is getting the vehicle assembled and working, allowing them a faster path to success. Finally, since we need to use venues with clear water for other reasons (particularly to keep the event interesting to the audience), the limitations of vision in real-world applications do not apply in the competition. Therefore, we embraced vision as a sensing modality, and added tasks to the missions that exploit the students' substantial capabilities in this arena. The first such task (in the fifth year) required students to read 2-foot-wide bar codes printed on structures on the bottom of the arena and report back the height of each specific structure off of the bottom. In the sixth year we added a task that required students to locate an array of bins on the bottom and drop a marker (of their own design) into a designated bin.

By this point the mission had met our goals of requiring the vehicle to travel autonomously, sense its environment, change its actions based on that sensing, and interact physically with the environment.

Today's mission

As discussed above, while underwater acoustics makes the most sense for the environment, pingers and hydrophones can be expensive. Creating circuitry to perceive the echo and then determine its bearing from the vehicle is difficult at best. Because of this, over the years, visual targets have also been included. In comparison, cameras are cheap and a large amount of information can be gathered using open source software and time. A forum was established to promote a free flow of information between the technical director and all the teams. Preliminary rules are released approximately 8 months before the competition, to give the teams a heads up on what to expect, and to also allow the teams to help guide the design and colors of the tasks. To this end, the 13th annual underwater competition (with a Friday the 13th theme), held in 2010, has tasks laid out to take advantage of all of this (Figure 7).

At the beginning of the day, the correct buoy colors, the correct window color, and first and second silhouette where give to the teams (more on this later). There are "path segments" which are placed directly after each task and point toward the next task to help the vehicle find the next task. The tasks can be completed in any order except for the first; the vehicle must submerge and pass under the gate. Twenty-one teams took on this undertaking:

- Find and touch 2 of 3 buoys. Points are awarded for touching any, while a large amount of points are awarded for touching the correct 1st, and then the correct 2nd buoy.
- Pass over a "U" shaped obstacle. No points are awarded if the vehicle doesn't break the top plane of the "U". Some points are awarded for ½, or more, of the vehicle being above the top of the "U", more points for the vehicle being ½ or more below the "U".
- Find 4 bins (2-ft x 1-ft black box with a 6" white border around). Inside each bin is a silhouette of an axe, hedge clippers, hammer or machete. The vehicle has 2 markers. Points are awarded for dropping markers in any bin, with a large amount of points awarded for dropping a marker in the correct 1st silhouette and a marker in the 2nd silhouette.
- Find the "window" (an open square in each of 4 quadrants with either a green, red, yellow or blue border) and fire a torpedo through it. Points are awarded for the torpedo passing through any square, more points for the correct square
- Find the active pinger. There are two pingers in the water, with one active (which can be switched at dockside. This was necessary, because teams became very good a dead reckoning). Located just above the pinger is a pvc structure. The vehicle may attempt to grab the structure and lift it to an octagon floating above the pinger. Once on the surface, the vehicle may also attempt to drop the structure. Points are awarded for completing any part of this task.

The tiered structure of points, and positive reinforcement of obtaining points if you try and succeed, but without penalty if you don't, harbors the positive thinking of, "I might as well try" which pushes the competitors to attempt more. There continues to be a challenge for well established teams, while encouraging new teams to join the competition.

Assessment

The prime sponsors have enthusiastically continued to back the competition despite the variations in the economy and changes in defense priorities since 1998, as well as turnover in the responsible program manager at both ONR and AUVSI. We have a cadre of teams that compete each year, and new teams taking part essentially every year. The number of teams competing is 20 to 30 each year, with an average of about 14 students per team. So, the competition brings between 250 to 400 students each year to the excitement and challenges of Ocean Engineering. We look forward to many more years of competitions to come.

Figures

Figure 1. The first arena used. This is the P-253 Test Pond at the US Navy's Coastal Systems Station in Panama City, Florida. The pond itself is 300 feet long by 200 feet wide and is concrete lined. The sidewalls slope in at a 45-degree angle until they reach a depth of ~20 feet, at which point the bottom is flat.

The launching point (L) for the competition was the dock by the roadway. The competition was to circumnavigate the pond on the 10-foot-depth contour. Six gates (shaped as inverted "U"s) were placed around the pond on that contour, and a vehicle that passed through each gate (as determined by a diver tracking the AUV) was considered to have succeeded.

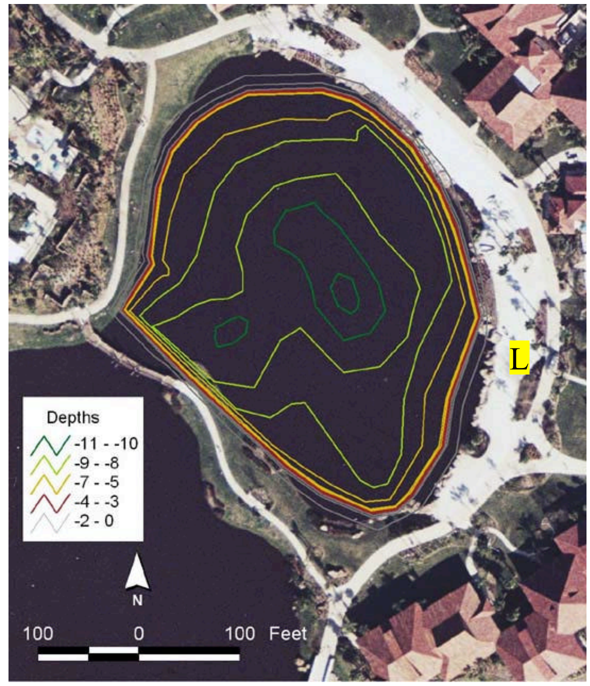

Figure 2. The second arena used, at the Coronado Springs Resort, Orlando, Florida. The arm of this man-made lake that we used is a rough oval, 200 feet by 300 feet. The bottom is mud and silt, and the depth is no greater than 11 feet. The arm used for the competition is almost, but not completely, enclosed. There is a bridge on the east side which opens into the larger body of the lake proper.

The launching point (L) for the competition was from the western beach. Four stations were placed in the pond some 75-100 feet from the launching point. Each station was equipped with a pinger (20-30 kHz band), an underwater strobe, and a 1-foot-diameter ring. When an AUV was launched, one of the stations was turned on. The mission was to report back the ping rate, the strobe flash rate, and recover the ring.

Figure 3 (Left). The third arena used, College Creek, on the grounds of the US Naval Academy (Annapolis, Maryland). The launching point (L) was on the boat dock. The competition was for the AUV to locate one of four stations located SSW of the dock, towards the King George St. bridge. Each station carried an acoustic beacon and an underwater strobe. Once the AUV was launched, one station was powered on. The vehicle had to i) return the ping rate (or flash rate) of the beacons, ii) pick up a 1-foot-tall marker from the station, and iii) give the depth of the shallowest of a series of 2-foot-square structures placed before the station.

Figure 4: Aerial photo of the TRANSDEC facility. The water clarity shown is typical. The bridge structure has no piers or supports in the pond and does not obstruct the water. The oval is approximately 200 feet wide and 300 feet long.

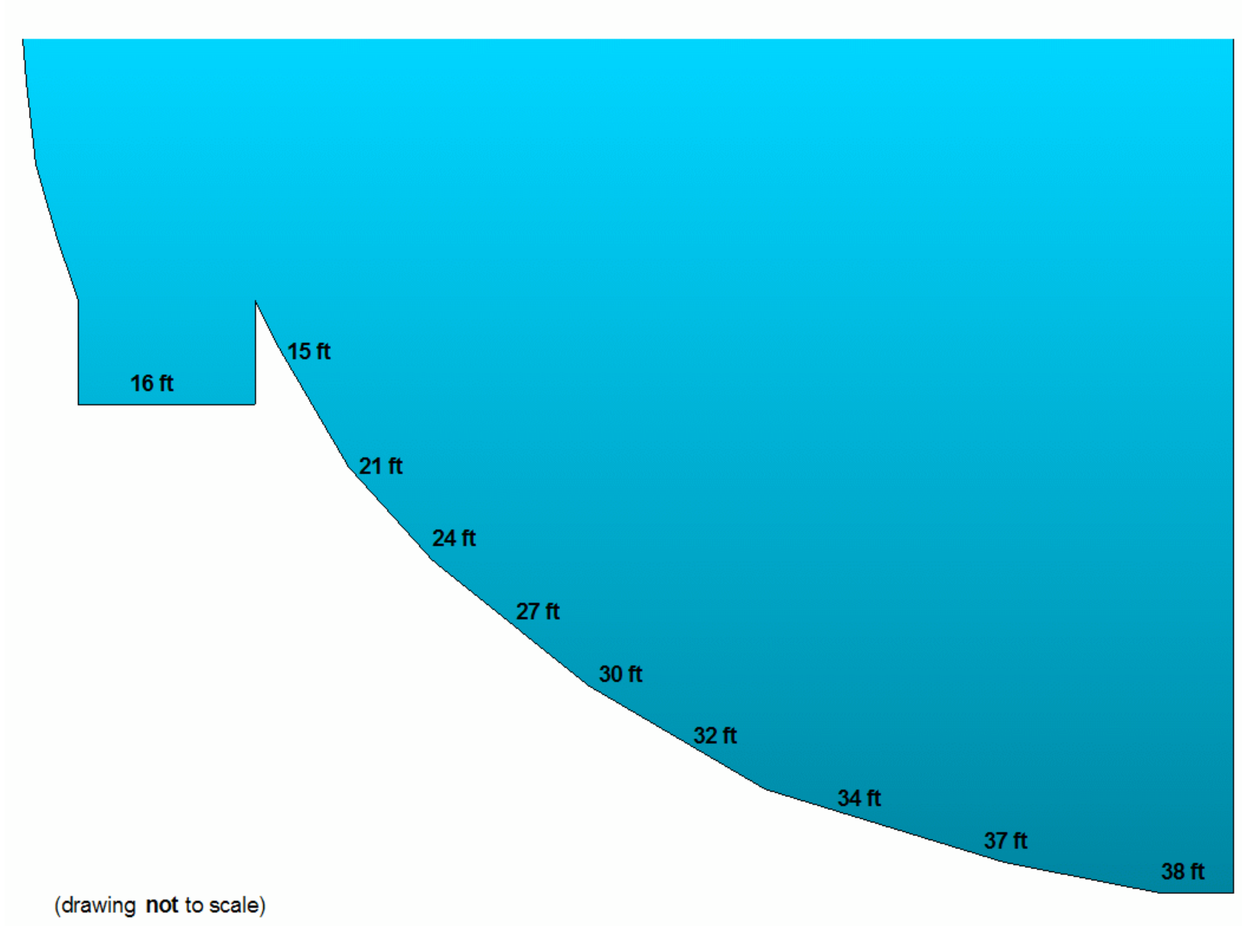

Figure 5: Cross section of arena showing the depth profile. Note that the acoustic trap (the 16-foot-deep section around the perimeter) varies in width around the pond (Figure 4). Table 2, below, lists the numbers from this Figure for the bowl dimensions.

Table 2: Depth of bowl at various radii from its center.

Radius	0	22	32	41.5	47.5	52.8	59.5	64.9	69.5	77.4
Depth	38	37	35	34	32	30	27	24	21	15

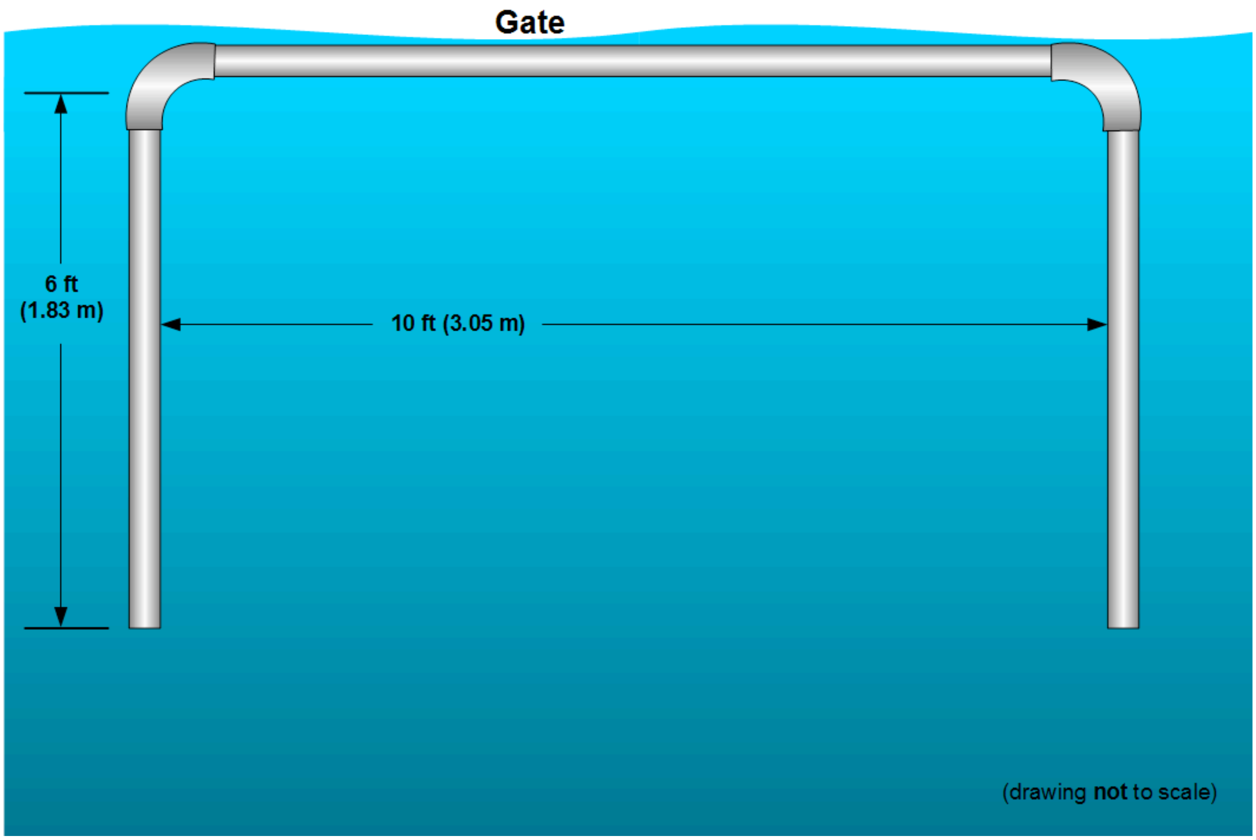

Figure 6: Validation gate. It is constructed of 4-inch-diameter white PVC pipe. It is 10 feet wide and each leg is six feet long. It is buoyant and anchored to the bottom by lines.

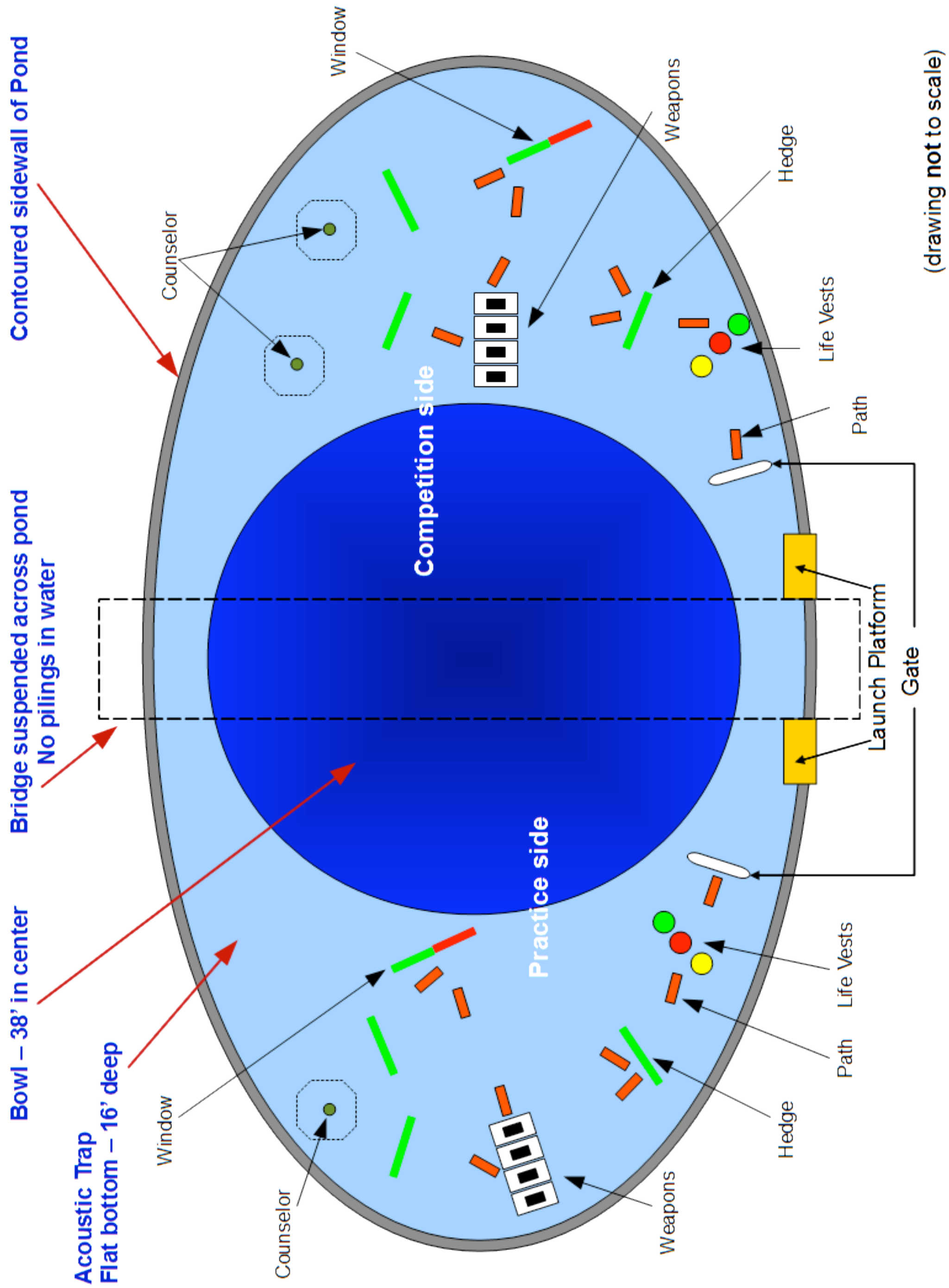

Figure 7. Layout of the TRANSDEC arena for the 2010 competition. As it was the thirteenth instance of the competition, the mission had a "Friday the 13th" theme. Yet the core of the mission was creating a fully autonomous underwater vehicle capable of propelling itself through the water, sensing its environment, acting on the data it collects, and interacting with that environment.

Appendix A: Stakeholder Analysis

In creating the competition we recognized the need to balance the requirements of the several stakeholders in the event. We start with a list of the key stakeholders and their requirements. The key stakeholders are:

- Prime Sponsors (AUVSI/AUVSI Foundation and ONR)
- Competition Site
- Student Participants
- Judges
- Industry
- Academic Institutions
- The Audience

The Prime Sponsors: The prime sponsoring organizations (AUVSI/AUVSI Foundation, ONR) need to see substantial numbers of students engaged in the competition, including a significant number who would not otherwise have been exposed to the design of underwater systems. Over the long term, they need to conclude that the competition is bringing more young engineers into the filed. The prime sponsors need to obtain images, video, audio, and text suitable for promoting their organizations, as well as favorable media coverage of the event itself.

The prime sponsors want the event to promote professional skills among the young engineers competing, particularly their communication, team building, management, and project planning skills. While the event is a competition, the sponsors want the general atmosphere to be collegial rather than adversarial. Finally, long-term success requires the continuing commitment of the other stakeholders below.

The Competition Site: The competition site needs to preserve the integrity of their physical infrastructure, and keep the added burden on their staff within reasonable bounds. They, too, need favorable media coverage and to obtain useful PR materials. The management of the site also needs for the event to be considered valuable to their superiors in their organization. Finally, the site must be capable of handling (and comfortable with) the presence of the public as audience during the competition itself.

The Student Participants: The students need the competition to be challenging and fun. Teams (and individual students) that are new to the competition need to feel that they can, in fact, achieve some measure of success despite their lack of experience. Teams (and students) that are veterans of past competitions must feel that each year places new challenges before them, and simply recycling the previous year's vehicle will be unlikely succeed. On site for the competition they need worktables, electrical power, shade, concessions offering food and drink, toilets, access to the competition waters for tests, and access to a small, shallow, pool for simple in-water tests. The competition site must have nearby lodging, ready deliveries of express packages, and nearby commercial airline service. Finally, students appreciate the opportunity to have their resumes passed off to potential employers in the field of ocean engineering.

The Judges: The judges need to have the chance to interact directly with the students, and have the opportunity to influence the students with their assessments and advice. Some of the judges are in positions where they hire young engineers, and appreciate the chance to see potential new hires working in a quasi-professional setting. The judges, too, require the physical amenities of the students, and also need a conference/lounge space at the competition site.

Industry Sponsors: The prime sponsors recruit additional sponsors from the underwater industry who provide funding and other resources. In addition to the need for favorable media coverage and obtaining useful PR materials, they need to be able to interact with the students (sometimes by providing a member of their staff to be a Judge), and by having their sponsorship recognized through the inclusion of their logos in materials produced by the event. They also need to get resumes from students that they might choose to recruit.

Academic Institutions: Some of the academic intuitions that are home to the student teams are closely engaged with their student's efforts while others are less so. At one end of the spectrum are those institutions where a faculty member has used the competition as the focus of a design subject. Other degrees of engagement that we have seen are close faculty supervision of a team of students who are not part of a subject, loose faculty supervision of a team, and, at the least, essentially no faculty supervision of a team (and often no institutional financial support of the team, either). For all of these schools, the competition must (at a minimum) be a safe and reputable activity for student participation. As faculty engagement increases, the competition needs to be seen as an effective tool for engaging students in the practice of engineering and a vehicle that helps them learn by doing. Finally, for the competition to be used as the basis of a design subject, the rules must be codified far enough in advance so as to allow a faculty member to create a syllabus around them.

Audience: The competition itself is a public event. The competition site must be open to the public and near enough to a center of population so that the public can readily travel there. Appropriate physical amenities must be provided (concessions, shade, water, toilets, etc.). The competition itself must be readily explained to the audience (who are presumed to have no technical background), with materials and public address announcements that adequately describe what the teams are being asked to accomplish. There must be interesting activities to watch, which includes water clear enough to see a submerged AUV swimming in the water!