SHALLOW WATER CHARACTERIZATION

1. DEFINITION

a. By *definition* shallow water is in general less than 50 fathoms (300 ft). This, however, depends on the fleet, less than 100 fathoms can be also considered shallow.

b. By *convention* the submarine is in shallow water any time the bottom is within the boat's test depth.

2. SHALLOW WATER OPERATIONS AND MISSIONS

a. Any P/D.

b. Shore surveillance which can be visual, electronic, or acoustic.

c. Special forces support:

- Launch a SEAL team from an SDV or through the escape trunks if an SDV is not around. For most shallow water operations, however, the submarine would not want to go too shallow, so an SDV will be necessary. This makes the hydrodynamic/control two body problem very interesting.

- Joint services operations support, "jointness" is becomimg increasingly popular. Examples are extraction from the submarine or insertion into the boat of paratroopers, or coordinated shore recon raids.

d. Mine warfare:

- The primary mission is laying mines.

- Locating/penetrating a mine field is also important.

e. Port blockade and deterrence.

f. Strike attack, especially using tomahawk land attack missiles.

g. Diesel submarine ASW is becoming increasingly important.

h. Torpedo engagement; e.g., attack anchorage.

i. Transit through choke points (e.g., Gibraltar or the straits of Hormuz): This can be either offensive (getting through) or defensive (wait for others to get through).

3. MISSIONS THAT HAVE HARD REQUIREMENTS

a. Navigation:

- Navigation is extremely important at shallow water; usually shallow water navigation requires 6 to 7 dedicated people as opposed to just 1in deep water.

b. Seal teams to launch:

- It places restrictions on boat speed, depth, and angle. Actual numbers depend on each particular platform used, for example for an SDV they can be obtained from the Naval Warfare Publications (NWP) Library on the SDV handbook.

c. Weapons deployment:

- It depends on speed, depth, angle, and heading. The latter is more important when keeping up with the battle group. In cases where the boat can freely choose its heading, an angle between +/- 45 deg. off the bow with respect to the waves is desirable. This gives a good compromise between small second order suction force and first order roll excitation. Data for each particular class of weapons (for example Tomahawk) can be obtained from the NWP Library for the respective weapon's handbook.

d. Surveillance:

- The primary concern is minimizing mast exposure to avoid detection.

e. Mine detection:

- It places requirements on main sonar. It is necessary to set a nonzero pitch angle on the boat that needs to be maintained for the duration of the mission. This is typically 2 to 3 degrees bow down, and it depends on the boat The reason for this requirement is that the main sonar usually looks slightly up for optimum sonar return, which was primarily established for under ice operations. Slow speed angle control and hovering become extremely important in this function. This is also a good justification for the need for automatic depth control.

f. Mine laying:

- When the mine is ejected through the torpedo tube, some water comes back into the torpedo room. This sets strict ballast limits and navigational accuracy is increased.

g. No towed array can be used in shallow water, therefore sonar detection is limited to the hull or spherical array.

4. ENVIRONMENTAL FACTORS THAT CAUSE PROBLEMS

a. Layer depth:

- If you graph the water temperature vs. depth, a layer is when transition from positive to negative gradient occurs. This is a good operating point for a submarine such as a boomer to sit and be hard to detect, sound waves radiate away from such a point. This is also a bad point or the boat to listen (for the same reason); so there is a best depth to listen and a different best depth to avoid detection. In deep water where a towed array is present, it can be deployed from the best depth to avoid detection and combine the best of both worlds. Towed arrays will not be used in shallow water though. Also, the above layers are not as pronounced in shallow water (again the shallow water environment is more uniform in its properties than deep water), so listening/detection depths will not be as clearly separated.

b. Gradients:

- Mainly temperature gradients are of concern but also salinity, particularly close to a river mouth; somebody mentioned South American rivers as especially troubling. Although shallow water is probably more uniform environment than deep water in its gradients, the proximity to bottom penalizes any buoyancy/depth variations more heavily.

- Salinity effects are very isolated and predictable from geometry and seasonal warning. The only time when salinity affects a large geographical area is when the mission is operating near the ice canopy or during an unusual spring flood/runoff.

c. Shallow:

- Slow depth changes to avoid grounding, pitch angle must be kept to a minimum.

- If the mission has a requirement to sit on the bottom either in a resting or surveillance mode, bottom types and conditions in most areas of interest are unknown. This means that the mission submarine could be damaged or lost by getting stuck or buried in the bottom.

d. Weather:

- High sea state prevents detection but inhibits weapon deployment. I don't think this will be a problem in shallow water, weapons cannot be deployed at sea state 5. In shallow water motions of the boat and proximity will probably dominate the operation envelope. Also rain can be an issue, it affects the seekers of certain missiles such as Harpoons.

- The effect of the surface weather is amplified in shallow water. While there is no difference in ship handling in high sea states between deep and shallow water there is loss of acoustics with high surface winds and/or rain. A high acoustic sea state will severely limit active and passive sonar detection ranges. The degradation to the capabilities of the mission can be severe.

- A low acoustic sea state can be just as bad to the mission as a high sea state. When the background noise drops to very low levels then the mission becomes highly vulnerable to counter detection because of the higher signal to noise ratio and the ducting effect extending the range of counter detection.

e. Proximity:

- Effects on torpedo target acquisition, acoustic interaction of sonar returns from the bottom. For example, the Mark 48 torpedo handbook has shallow water specifications. This is part of the NWP Library.

f. Sonar:

- Passive sonar range is reduced due to increased background noise in shallow water.

- Active sonar detection range is reduced due to reverberation. The active sonar is used more often in shallow than deep water.

g. Mechanical:

- In warm water the condenser temperature goes up and so does fouling on the condenser tubes.

- At sustained slow speeds of the boat there is increased likelihood of steam cutting of the main engine throttles. At low settings where the throttle opens a small amount, the steam can actually cut a flow path on the seating surface of the valve. This requires a complete engine shut-down which is done ashore.

h. Other:

- The most unpredictable environmental problem involves biological noise raising the general background and/or sector background noise level. This is a very difficult problem for human operators to overcome since there can be target masking and false target generation.

5. STEALTH REQUIREMENTS RELATING TO MANEUVERABILITY

a. Acoustic noise occurring from plane surface motion. This is similar to deep water, possibly less of a problem due to less frequent and not as drastic maneuvering.

b. Cavitation is the main issue of concern since it is more likely to cavitate in shallow depths or PD than in deep water.

c. Detection from SAR due to free surface scars and striations. How do scars and striations change in shallow water?

d. More small boats, oil rigs, and biologics in shallow/littoral water; therefore more background noise, which adversely affects the detection range. Most people seem to think that the submarine's ability to detect is more important than stealth. This depends naturally on the adversary, stealth becomes more important when dealing with a powerful enemy.

6. MISSIONS THAT CAN BE IMPROVED USING AUTOMATIC CONTROL

a. Depth control at slow speed:

- Depth changes in shallow waters are normally performed using the planes. Caution is certainly required to ensure that large angles are not placed on the ship. This calls for better coordination between stern and bow planes.

- When below PD even in shallow waters, sufficient speed is generally available to avoid planes reversal, although this may be quite sensitive to both bottom and free surface effects.

- The indications of proper depth control for the DO may not be the best. At times the expected depth may not match the look from the OOD's periscope. The depth control gages also vary in accuracy and one is normally chosen as correct and utilized. The image seen through the periscope at the DO station would provide real feedback to the DO on depth keeping. Even a good watch section may fall sleep at the wheel looking at the gages. You also have to keep in mind the difference between day and night operations. A blackened control room has a completely different feel.

b. Proper trim attributes:

- Submarines normally get a satisfactory trim at 150 ft and 1/3 bell propulsion setting (about 5-6 knots). In review of the sound velocity profile (SVP) the dive officer (DO) compensates for the expected change in ship's trim at PD. Unfortunately, the DO may not have the time to do this properly due to operational commitments. Watch to watch compensations are normally unsatisfactory. Since the SVP may change dramatically in shallow waters the old history may be invalid and the compensation wrong from the start. Many DO's prefer to go up to PD heavy enough to prevent broaching and get a better trim there.

- The human element in depth keeping and trim is significant. The qualifications of the DO, chief of the watch (COW), and planesmen vary to a certain extent. The biggest problem is that the planesmen overcompensate in the operation of the planes in the movement of cycling the planes up and down to catch the ship from changing depth. This full cycling of planes even momentarily prevents the DO from acknowledging the problems with the ship's trim. Plane motion may also cause hydraulic transients which can be counter detected.

- The COW has different tools at hand for changing the ballast of the ship. The trim pump with variable speed, the deep/shallow cord, and the depth control tanks are options. Which is quicker or noisier in a certain situation?

c. Course changing:

- The vast majority of problems with submarine depth control concerned course changing. There are several competing effects. Use of the rudder causes the ship to roll, reduces speed, and may introduce some moment. As the course changes, the effects of sea direction change. To maintain depth control requires adjustment of propeller speed, adjustment of trim, and very close attention by the ship's control party.

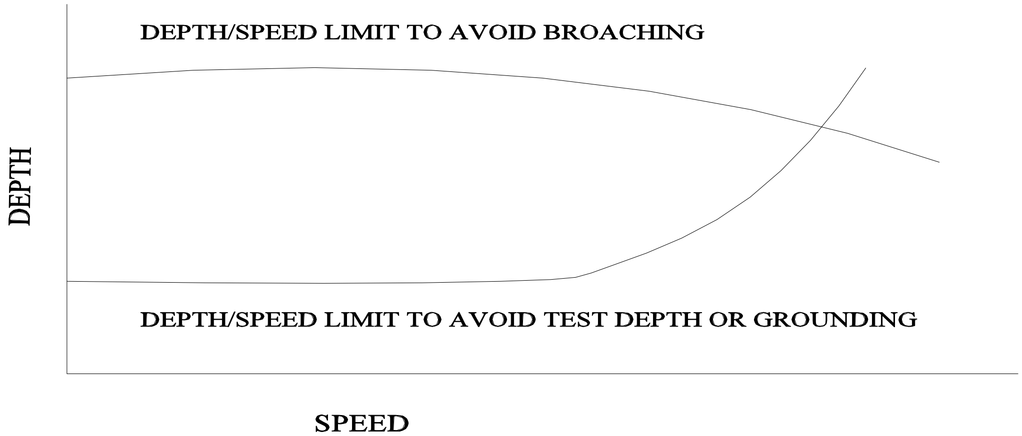
- A submarine at PD is virtually motionless with respect to surface traffic. This is due to both slow speed and small rudder angles to avoid broaching. It is easy to imagine how several surface contacts could accidentally corner a slowly turning submarine at PD, forcing it to go deep.

- The OOD can ruin a PD evolution by ordering too much rudder with too little speed. Speed drops significantly with the use of full rudder and the ship sinks.

7. OTHER

a. Restrictions for shallow water operations:

- All submersibles have a safe operating envelope (SOE). The boundaries of the SOE are dictated by the boat's ability to recover from a control plane casualty. the shallow limits are set to prevent either an inadvertent excursion above collision avoidance depth or an inadvertent broach. The deep limits are sliding with depth of water so that the submersible will not ground on the bottom.



b. How can the mission detect that it has been counter detected and then escape?

- Unfortunately, this is a very complicated question. The first part, detecting a counter detection, is difficult and the methods are for the most part classified, but the mission must be fitted with an ability to distinguish if a sonar or radar counter detection has been made. Continuous lock-on is an obvious indicator but the odds that this will occur are small. The second part, once we have decided that the mission has been counter detected, there must be an escape procedure programmed into the mission with a possibility of a self destruct to prevent capture and down loading of the missions log. This has to be addressed, otherwise missions into hostile waters should not be attempted.

c. What is the effect of mission planning and on-board navigation inputs on the mission?

- The major problem with GPS is that it is too accurate for the charts that are presently in use. Errors of 1 to 2 NM in charts can be present. With a crew this error can be detected and compensated for, whereas an unmanned mission has no method for detecting or compensating for this. As an example imagine trying to enter a river mouth that is bounded by sandbars with a narrow channel dredged for access, with an error of only 0.5 NM the mission has a very high probability of grounding and failing to find the channel. This problem can be made worse as the mission distances increase since the onboard navigation errors will compound on top of the chart errors that the mission planner has inserted into the submersible.

SUGGESTIONS FOR R&D

- Simulation and Control:
  - Development of a real time graphical simulator with a man in the loop.
  - Simulation of an automatic trim compensation system.
- Parametrics:
  - Establish a quantitative performance index relating hull form to maneuvering. Validation of the index will be through the graphical simulator.
  - How does dive plane reversal depend on proximity to bottom/free surface? Are there certain trim attributes for which planes reversal is particularly sensitive to hydrodynamic modeling?
- Intelligent Control:
  - Incorporation of a tri-level rational behavior model (RBM) software architecture including strategic, tactical, and execution levels.
- Hydrodynamics:
  - Potential flow modeling of proximity forces and moments. This should be accurate enough, yet fast to allow real time graphical simulation implementation.
  - Experimental study of scars and striations in the proximity of a solid boundary.
  - Viscous flow analysis of the two body interaction problem, such as SDV/submarine.