V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

In this study we have evaluated the vertical plane response of submersible vehicles in the proximity of a free surface in deep and shallow waters. A potential flow, strip theory solver is used for the computations. For deep water operations periscope submergence and sail broaching criteria are used to map the operability envelope of the vehicle for different sea directions, sea states, operating depths and vehicle speeds. The operability of the vehicle is quantified by calculating a certain operability index. For shallow water operations in addition to the above two criteria, a third criterion is considered which is the collision of the vehicle with the sea-bed. The primary conclusions from this study are summarized below:

1. For the periscope submergence criterion head seas appear to cause larger number of violations than following seas regardless of the water depth. Also, the operability index does not change much with water depth. The effect of shallow water on this criterion is insignificant. An optimum operating depth can be found which minimizes the expected number of periscope submergence events. This depth is a weak function of vehicle speed.
2. For the sail broaching criterion the operability index does not appear to depend on sea direction in a consistent way. Higher sea states correspond to smaller operability indices for a given sea direction. The operability index does not change significantly with speed or operating depth and it generally increases with increasing operating depth. For the sail broaching criterion, water depth has a more important effect than for periscope submergence on both the value of the operability index and the shape of

the polar plots. In general, the operability index is decreasing with decreasing water depth.

3. For the collision criterion in shallow water, the operability index decreases as the water depth becomes smaller. The shape of the polar plots changes significantly with water depth.
4. For all criteria combined, it appears that certain combinations of vehicle speed and operating depth may result in higher values for the operability index. It should be mentioned that this depends on the relative magnitude of the individual criteria. In general, the sail broaching criterion dominates the collision criterion for the parameters selected in this study. It can be seen that, in general, the operability index is decreasing for decreasing water depth. Shallow water effects seem to be insignificant for depths exceeding 30 submarine diameters.

B. RECOMMENDATIONS

The following is a list of recommendations for further research on near surface response of submersible vehicles:

1. For periscope submergence in a given sea direction the motion point appears to move more in phase with the incoming waves as sea states become more severe. Even though the criterion is not exceeded in such high sea states, the average wave height may exceed the exposed periscope length. Since the periscope moves in phase with the waves, the operator's visual horizon may be very small. This can causes the operations to be difficult to conduct even though the criterion is not violated. Such situations should be analyzed with proper simulation studies.

2. Evaluate the effect of different geometric hull parameters, on the operability index. Such parameters may be, for example, the length, diameter, and prismatic coefficients of the hull.
3. Evaluate the effects of second order wave forces and motions on vehicle response. Even though these motions are slowly varying and can be controlled to a certain extent, they may alter both the values of the operability indices and the shape of the corresponding polar plots.