# Pressurized Rescue Module System Hull and Transfer Skirt Design and Experimental Validation

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## Abstract

The Pressurized Rescue Module System (PRMS) is a remotely operated vessel which is designed to recover crew members from a disabled submarine (DISSUB). It has a crew of two for supporting rescue operations, and can transport up to 16 people. The PRMS is transported to a rescue site at sea, first from its home base by truck, air transport and then by ship; such portability requirements placed significant constraints on the system size, shape and weight. The system is launched from the vessel of opportunity (VOO), where it is remotely piloted to a maximum depth of 2000 feet by topside personnel. Attached to the PRMS is a transfer skirt which mates with the DISSUB and allows for the transfer of personnel from the DISSUB to the PRMS hull. The transfer skirt has an articulated joint that allows the PRMS to mate with the sub at any vertical angle between +/- 45 degrees, and at any yaw angle, thereby eliminating the constraint that a disabled sub lie essentially horizontal on the sea floor. The PRMS hull structure consists of a stiffened cylindrical hull with hemispherical heads and two personnel transfer hatches. The Deck Transfer Hatch (DTL) is located in the forward head and facilitates transferring personnel out of the rescue vehicle while on deck. The Transfer Skirt Hatch (TS) is located in the bottom of the vessel and is where people are brought on board from the disabled sub through the transfer skirt. The total envelope of the PRM hull and exostructure is 2.4 m x 2.4 m x 7.3 m (8 ft x 8 ft x 24 ft), and the envelope for the transfer skirt (which is detached from the hull during shipping) is 2.4 m x 2.4 m x 2.4 m (8 ft x 8 ft x 8 ft). Finite Element Analysis (FEA) and closed-form solutions are utilized in the design stage to optimize the vessel strength, size and weight. Key to this analysis was providing safe predictions of the buckling strength, particularly in regions where large openings are present in the hull. The PRM hull has two such openings; the forward and bottom hatches with their attendant reinforcements. Reduced buckling strengths for both the ring stiffened cylindrical hull and the hemispherical end closures, are obtained by first calculating a nominal shell buckling pressure assuming no large opening exists. These nominal buckling pressures include out-of-circularity and out-of-fairness effects for the cylindrical hull, and out-of-sphericity effects for the hemispherical and spherical shells, plus fabrication reduction factors. The reduced buckling pressure for the structural component in question is then determined by multiplying the nominal buckling pressure obtained from classical equations by a reduction factor obtained from FEA. The reduction factor is the ratio of peak von Mises stress in a far-field region away from the opening to the peak von Mises stress at the edge of the opening reinforcement. Since the stiffened regions surrounding the large opening are subject to stress concentration, a gradual taper is provided between the thickened regions and nominal shell thickness so as to minimize the stress concentration. Hydrostatic tests were performed for both the PRM hull and the transfer skirt (separately) to confirm the required

minimum buckling strength of 1.5 times the maximum operating pressure. Strain gages were monitored at approximately 200 locations for the PRM hull, and approximately 100 locations for the transfer skirt.

Satisfactory correlation was observed between strain gage data and FEA strain predictions, and in both cases, the minimum buckling strength requirements were satisfied using the procedures described above. This paper provides descriptions of the buckling strength analysis procedures, the finite element analysis results, and correlations with the hydrostatic test data which were used to verify the buckling strength of the PRMS.

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