# Design and Development of a Simulation Based Design Model for Submarines Incorporating Material Properties and Driven by AI and ML

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## Abstract

Submarines are considered as weight critical, especially as operational diving depth increases. An appropriate high strength/low density structural configuration is required and it needs to be compatible with the ease of fabrication and toughness. In the present thesis, our aims is for design and development of a 'simulation based design model (SBDM)' for submarines incorporating material properties and driven by artificial intelligence and machine learning. The SBDM leads to a modular design approach and we integrate the optimization process into the design of conventionally designed submarines by incorporating different materials. Central idea is to design and develop designs that can be operable in higher depths, help in reducing the weight and cost of the pressure hull. In the SBDM the design modules are independent, and they are integrated from end to end to ensure that there is an efficient model for software development

**Module 1 - User defined design module:** In this module we take input parameters of pressure hull like operating depth of submarine, thickness, diameter of pressure hull, length between the bulkhead, size and number of ring stiffeners for the stiffened hull. We have considered different materials ( MA - AL 2014-T6; MB - Steel AISI 4130; MC - Steel A36; MD - Carbon fiber; ME - E-glass fiber; MF - Ti-A16-4V) and material properties ( Modulus of elasticity, Poisson's ratio, yield stress - compression yield strength, tensile strength, material density.). These parameters are used in Module 2 for analysis based design.

**Module 2 - Analysis based design module:** In analysis module we have use Matlab*™ (Trademark and copyright with the Mathworks, Inc., USA) to carry out analysis. We consider different parameters (e.g. the effect of bulkheads) and study the variation of minimum buckling pressure ($p_m$) between t/R and L/R with respect to different modes, shell and ring frame, and factor of safety, etc.

We study in detail two critical cases: Case 1 - Unstiffened cylinder, and Case 2 - Stiffened cylinder. In the Case 1; we have analysed minimum buckling pressure ($p_m$) with L/D, t/D ratio and found that, to maximize $p_m$, t/D should be increased because when thickness of pressure hull increases and its diameter is reduced, the strength of pressure hull increases, thus its $p_m$ increases, while L/D should be decreased because if L/D is greater, pressure hull will become slender and cannot withstand high underwater pressure. And materials with high modulus of elasticity are preferable than other materials. In the Case 2; variation of overall buckling pressure ($p_n$), with operating depth is plotted, also spacing between the ring stiffener and number of rings required is measured and analyzed. Results shows that materials with high modulus of elasticity are showing greater values of $p_n$. Thickness of the pressure hull is directly proportional to length of spacing between the rings. Also, when materials with high compression yield strength are used, it shows less spacing between the rings. Hence to reduce the weight of the pressure hull, shell with lesser thickness and more no of rings are required which can achieve by using material with high compression yield strength. By analyzing all the parameters required for design of pressure hull, the application of different materials is analysed and our results show that the steel and titanium alloys (MB - Steel AISI 4130 and MF - Ti-A16-4V) have wider range of applications.

We utilise the artificial intelligence and machine learning to reach our goals and we predict the minimum buckling pressure using machine learning and deep learning models. The data is generated using formulations with python programming.

**Module 3 - Product design module:** In this module we use the results of Module 2 to design the real data driven submarines and focus on numerical simulations in Abaqus**™ (Trademark and copyright with Dassault Systèmes, France). Finally, we present different real world data driven design examples and show the range of applicability and importance of the proposed SBDM.

**Usages of software solution systems:** Matlab*™, Python programming and Abaqus**™.

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