Temasek Defence Systems Institute

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DEVELOPMENT AND SENSITIVITY ANALYSIS OF A MATHEMATICAL MODEL FOR MINE COUNTERMEASURE VESSELS IN THE EARLY DESIGN STAGE

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Objective

This thesis developed a simple mathematical model using the Model-Based Systems Engineering (MBSE) approach, to link the design parameters of a mine countermeasures vessel (MCMV), to its operational performance. Traditional approaches of configuring operational systems around a vessel's architectural design often have limited flexibility to accommodate design revisions. Without the need for time-consuming and comprehensive software analysis, the mathematical model can serve as a tool to make a preliminary feasibility assessment of vessel design parameters and potentially avoid costly redesign or modifications later in the development life cycle.

Main Research Ideas

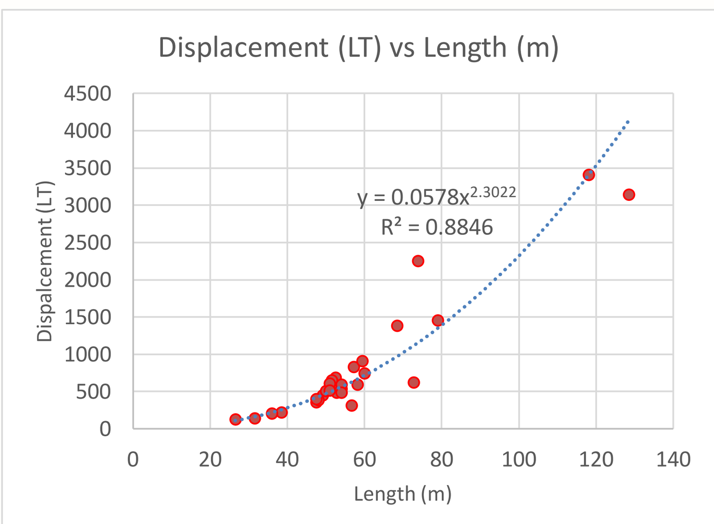
The key operational performance parameters of an MCMV examined in the thesis were speed (V), range (R), and payload carrying capacity (P). The goal was to establish a useable relationship between V, R and P, through the analysis of an MCMV's displacement as a function of a vessel's length (L) – a more intuitive parameter of ship size. This thesis leveraged on Dr. McKesson's five-parameter method and extend its application on MCMVs. Further sensitivity analysis was conducted by altering interacting coefficients and parameters in the mathematical equation to understand the extent of the effects on the variable relationship.

Research Results

Graph of Displacement Vs Length

Establishing relationship between the displacement and length using series of MCMV data.

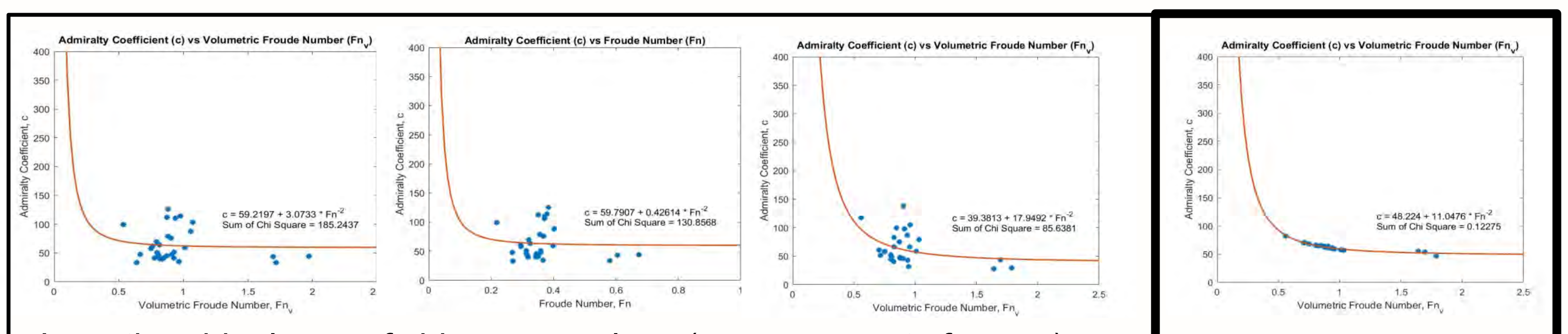
$$\Delta = 0.0578L^{2.30222}$$



Graph of Admiralty Coefficient (c) Vs Volumetric Froude Number / Froude Number

Using Dr McKesson's methodology, multiple iterations of plotting admiralty coefficients (*c*) against volumetric Froude number / Froude number to find a "best fit curve, represented by the equation as shown below. Using MATLAB, the aim was to find the value of m for which the sum of chi-square value was the smallest, which was m = 2.

$$c = a + \frac{b}{Fn_v{}^m}$$



Less than ideal sum of chi-square values (measurement of errors) calculated by relating the distance of actual data against theoretical curve fit.

Marked improvement with error significantly reduced.

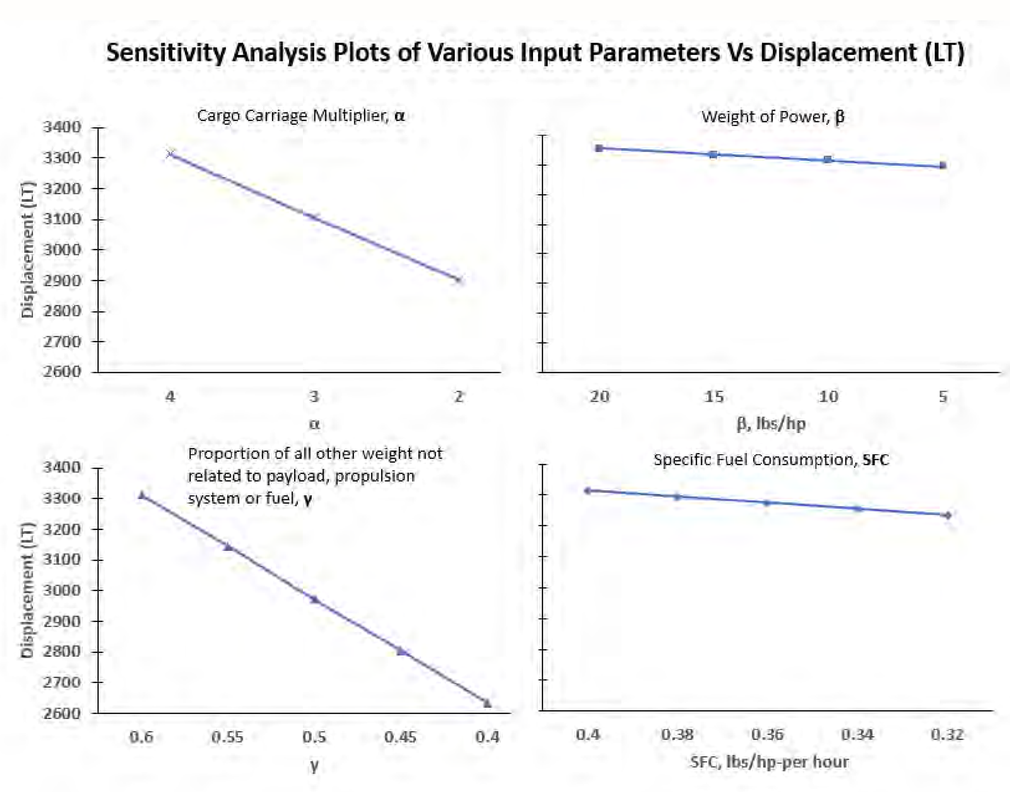
Main Mathematical Equation

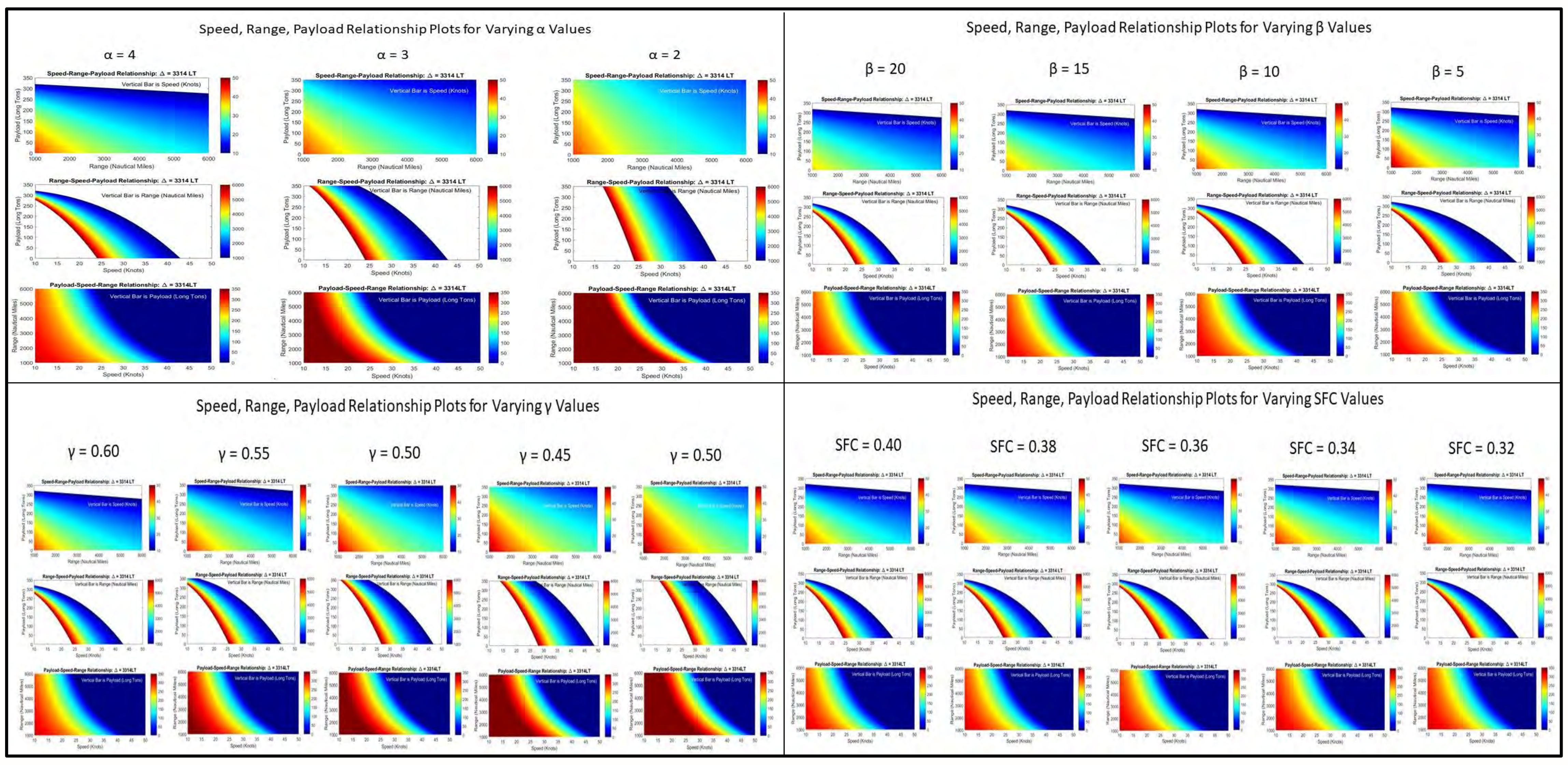
A series mathematical manipulations were done to incorporate interacting coefficients and parameters such as α, β, γ, SFC, a, and b. The equation eventually ties in the relationship between the variables of L, V, R, P and interacting coefficients and parameters, in which the vessel's displacement can be calculated. Parameters can be varied to obtain a range of displacement values and study their effects on V, R, and P.

$$\Delta = \alpha P + \gamma\Delta + \left(\beta + \frac{(SFC)R}{V}\right)\left(a + b\frac{g}{V^2}\left(\frac{\Delta}{\rho}\right)^{\frac{1}{3}}\right)\left(\frac{\Delta}{\rho}\right)^{\frac{2}{3}}V^3$$

Sensitivity Analysis Plots of V, R and P Relationship by Varying Interacting Coefficients and Parameters

The effects on the relationship of V, R and P could be determined by varying the values of the interacting coefficients and values. This provides insights on the sensitivity of these values and the magnitude of change effect that they have on a vessel's V, R and P. A series of sensitivity plots were constructed as shown.





Benefits and Follow Up Research

The results obtained served as preliminary insights for determining feasible ranges of MCMV design parameters. It has shown that the MBSE approach can be used to link vessel design parameters to their operational performance. The study of these design parameters provide insights about their impact on displacement, speed, range, and payload capacity. The success of the model could potentially be applied to other types of operational vessels and be used as preliminary considerations to enhance operational performance when designing future MCMVs. Future follow up research could include the analysis of unmanned systems such as UUVs or USVs, which is a common MCM system in many MCMVs today.

References

McKesson, Chris B. 2010. "The Utility of Very Simple Models for Very Complex Systems." In Proceedings of the 2010 Conference on Grand Challenges in Modeling & Simulation. 23–29. https://www.researchgate.net/publication/262164291_The_utility_of_very_simple_models_for_very_complex_systems.
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