

# Chapter 1

## Introduction

### 1.1 Motivation

Ship design is a multifaceted activity requiring the efficient utilization of resources to meet some functional requirements. A slender hull form is a requirement for minimization of resistance whereas maximizing cargo volume results in a fuller hull form. An optimization approach to such design is essential because it allows us to perform effective design synthesis on the basis of simultaneous consideration of all design requirements and provides a basis to rank competitive designs.

[1] follows an optimization approach to containership design. In this approach, the carrying capacity (number of containers) and the speed are fixed during the design process. The measure of merit used for the system is the least cost (annual average cost).

[2] presents a mathematical model for containership design optimization that considers operating costs incurred at container port terminals and in land transportation in addition to the annual average cost. The objective function used is the net present value index. Here again, the carrying capacity (number of containers) and the speed are fixed during the design process.

[3] also investigates a multidisciplinary optimization approach to containership design treating the number of containers and the speed as fixed parameters in the design process. The objective function used is a weighted average of the building cost, power and steel weight of the ship.

The multidisciplinary optimization approach to containership design presented in this thesis addresses the issues of treating the carrying capacity (number of containers) and the speed as variables in the design process. It also enforces the weight-displacement equality through an optimization based decomposition approach that speeds up the design process. The optimization is carried out using the DOT program from Vanderplaats Research and Development, Inc.

### 1.2 Methodology

This thesis defines and investigates a multidisciplinary design optimization (MDO) model for ship design. The model couples accepted naval architectural estimation methods with a nonlinear optimization tool allowing the designer to identify different objective functions, limits on the design variables and constraints on the design.

The various disciplines of the problem formulation have been constructed as modules and linked together as shown in the flow chart given in chapter 4. The modules involved are geometry, hydrostatics, resistance, propulsion, lightship weight, cargo, total weight and economics. Constraints have been imposed on the metacentric height required by the Coast Guard wind heel criterion, minimum required freeboard and the rolling period.

We look at the problem from the ship owner's perspective. We can choose from minimizing the required freight rate or maximizing the return on investment.

Treating speed as a design variable for a given trade route has the effect that the number of round trips per year varies. Thus speed needs to be adequately represented in the objective function. This is done by using the minimum required freight rate or the maximum return on investment as the objective function rather than using minimum weight or minimum annual average cost.

Hull geometry manipulation is done as a weighted average of two/ three user-defined basis hulls. There is/ are only one/ two design variable(s) controlling the hull shape, as the remaining design variable can be expressed in terms of the first (two) from the fact that they must sum to one.

Resistance is estimated using the Holtrop-Mennen regression method [4]. For power prediction, the propulsion module simply assumes an overall propulsive efficiency of 65 percent. The fuel rate is fixed at 120 gms/shp/hr, which is a reasonable figure for low-speed diesels [5].

The discrete container stowage issue has been addressed. The cargo module calculates the number of containers that can be stowed in the holds by employing a stowage factor on the total available hold volume. The cargo weight is now simply a product of the number of containers and the weight per container that is user-defined as twelve tons per TEU, which is the standard weight of a TEU.

The lightship and miscellaneous weights are based on a series of regression formulas. These, along with the fuel weight and the centers of gravity of the weight components are brought together in the total weight and center of gravity module.

The economics module calculates annual figures for building, operating and fuel costs. It also calculates the port and cruising times and the number of round trips made by the ship annually, which are needed to calculate the cargo handling, port and fuel costs .

The weight-displacement balance is maintained through an equality constraint on the optimization process. This has the advantage of speeding the design process over enforcing this balance through an internal loop to calculate draft at each iteration.

### 1.3 Overview of Problem Formulation Issues

A discussion of the problem formulation issues is included. A brief summary of these issues is as follows:

- The fact that the number of containers that can be stowed in the rows and columns of a hold and on deck are integers causes a discontinuity in the carrying capacity (number of containers) and hence in the objective function. This has been solved by:
  1. Expressing the number of containers below deck as a continuous function of the length, beam, depth and the block coefficient through a linear response surface fit.
  2. Expressing the number of containers above deck as a continuous function of the length and the beam through a linear response surface fit.
- The stowage factor accounts for the geometry of the hull form and the space occupied by the container guides. But the number of containers below deck shows a dependence on the block coefficient when calculated by employing the stowage factor on the total available hull volume. The dependence has been accurately represented by expressing the stowage factor explicitly as a function of the block coefficient.
- Shortening the port waiting time has the effect of increasing the optimum speed. This is due to the fact that a shorter port waiting time results in a shorter round trip time and hence an increase in the number of round trips made by the ship annually.
- The loading/ unloading rate has a significant influence on the time spent in port and hence on the optimum speed. It is a function of the number of cranes used to load and unload cargo. Therefore expressing the number of cranes as an increasing function of the length of the ship rather than assuming a constant number results in a faster ship and a more profitable design for the ship owner due to a lower required freight rate to breakeven.
- The number of tiers of containers on deck could be allocated a fixed number. But data from Panamax and post Panamax ships indicate otherwise [ ]. Further it is not necessarily an integer since it is averaged over the total available area on deck. This is accounted for by expressing the number of tiers as a function of the beam based on interpolation.

In this work, which has been accomplished jointly by the members of the FIRST team, among the author's contributions, have been the lightship weight, cargo, total weight and economics modules. An explanation of the formulation of these modules follows in chapters 2 and 3. Chapter 4 presents the statement of the optimization problem followed by chapter 5 that presents the results of the optimization process. The FIRST team conducted several runs of the MDO code and identified the effect of key parameters on

the design. This work is presented in chapter 6. The author conducted a study on the effect of three specific hull forms on the design that is presented in chapter 7. He also presents the use of alpha plots as a diagnostic tool to the designer in chapter 8. Chapter 9 discusses conclusions on the work and makes some suggestions for future work.