



NATIONAL TECHNICAL UNIVERSITY OF ATHENS
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PARAMETRIC DESIGN AND MULTI- OBJECTIVE OPTIMIZATION OF SWATH

DIPLOMA THESIS
OF
**PAPANDREOU
CHRISTOS**

SUPERVISOR PROFESSOR : A. D. PAPANIKOLAOU

C. Papandreou, Parametric Design and Multi-objective Optimization of SWATH
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INTRODUCTION

Shipping has been one of the earliest activities of the human race, as a result of the continuous struggle to survive, thrive, expand and explore. Throughout, the known history kingdoms, empires and economies have heavily depended on the sea and maritime transportation not only in the mean of conflict but more important in the means of communication, cooperation in the forms of trade and commerce. In the meantime, during the evolution of the scientific thinking and technology, shipping has been affected with several technological breakthroughs such as the introduction of sail, steam, iron and steel, welding procedures, diesel engines and many more.

While the ship technology advanced so did the operations and the support from a vast regulatory FRAMEWORK which initially depended solely on experience and mutual agreements but then was rationalized with the introduction of engineering and Naval Architectural principles.

Today, shipping is a very complex and volatile organism which is triggered and influenced by several exogenous organisms such as supply and demand

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functions, global conflicts and economy as well as ever increasing and sensitive oil prices. The ship designer, shipwright, owner, operator and charterer of today are challenged more than ever to survive not only due to the globalization and the increased level of competence but also due to the ever increasing order of volatility and uncertainty in global economic markets.

For this particular reason, when looking from a technical point of view, the Naval Architect of today is responsible not only for designing , delivering and operating a superior product but for making that product optimum in terms of efficiency, safety and more recently in terms of environmental friendliness. This term characterizes the 21st century, as it is a result of an excessive pressure from the society towards the policy makers to make steps towards a more sustainable and green profile in all levels of human activities including shipping.

When responsible for such a complex and difficult procedure the Naval Architect must be analytical and follow the principles of holism which is reflected in Holistic Ship design and Operation. Holistic Ship Design uses principles of Multi-Objective Optimization in order to solve conflicting arguments towards the best solution which satisfies the user requirements while it complies with the constraints set by society in form of Rules and Regulations.

This present thesis aims at giving a solution and a tool to the Naval Architect of today, and in particular those interested in Swath Design. Swaths are ideal for optimization since as ship systems usually they include a lot of contradicting requirements while the consequences of a potential accident can be catastrophic(referring to passenger ships).

More specific at this thesis chapter 1 is generally about CAD/CAE systems for ship design. It is described how are used , what they can do and there is a description about the software exploited in the present thesis.

Chapter 2 is relevant with optimization and how it works. It analyses the optimization problem , separates the single from the multi objective optimization and describes the genetic algorithms.

Chapter 3 talks about multi-hull ships at general and especially Swaths. It quotes the aspects the design parameters the history of Swath. In addition it describes the comparison of them with conventional ships and present the newly built Swath.

Chapter 4 contains the case study of the Swath design and optimization(AQ3) and it is obvious the core of the thesis. It is widely acknowledged that at present times an economic option is very attractive to the public, especially if we talk about passenger and car ships. So regarding to this, the optimization was made in order to minimize every aspect of resistance. As a result some designs were found for every need. Either the best model for a high speed that serves the public at summers or the best model at a relatively low speed that that serves at a non commercial period, or a optimized model for a combination of the above. All these accompanied with the strict regulations and safety rules.

All of these developments create a new (almost chaotic) patch that both the existing and new built ships have to respond to. It is generally admitted that these requirements change entirely the way we think about shipping in general and the challenge is big and often a handicap and burden for the operability and profitability of the owning and managing company. This creates a new need for innovative, safer and more efficient designs that will not mitigate the economic performance, sustainability and competitiveness of each concept. Initially though these designs are not easily acceptable by shipyards and need additional capital expenditure.

They key in making them a sustainable option is reduce the Operating Expenditures (OPEX) and maintenance costs, as well increase the availability and reliability of the product in order to achieve a balance. This balance will subsequently trigger new orders and investments towards this direction and in a long run a two Tier market, of upscale innovative ships and more conventional ones, with the last struggling to face the competition both in commercial and operating terms. It is the technology leap that will illustrate the potential of the new designs and establish them as actual and realistic solutions.

The present diploma thesis concludes with chapter 5 that describes a brief summary and outline of the work undertaken, providing some design directives for future, tender concepts as well as an outline of the Swath optimization (global and less detailed one). The contribution of the Thesis in Swath design is outlined and some perspectives for future work are underlined.

Finally appendix A and appendix B contains two small case studies. The first one is about an optimization of tri-hull with the same displacement of AQ3. The main matter is to minimize the waves produced by the hulls behind the main hull. The second one is an optimization of a tetra-hull with a diamond shape again trying to minimize the waves of the hulls behind the main hull, and hence the total resistance.

1. CAD/CAE SYSTEMS FOR SHIP DESIGN

1.1 Introduction

The tools and techniques used to design ship structures have evolved over the last forty years, from producing blueprints on the drafting board to the digital design of today. As computer technology became more powerful and less expensive, computer-aided-design (CAD) systems evolved to support the design of complex products. CAD and other related tools empower designers and engineers to create innovative products more quickly and efficiently.

1.2 Objectives of CAD and CAE applied to hull forms

The ultimate objective of every tool used for economic human activity is to obtain greater efficiency, effectiveness and a better quality. A greater efficiency means that less time, material and labour are necessary to obtain the desired results. Greater efficiency leads to:

- A shorter time to reach a certain design stage.
- Fast analytical calculations possible.
- Integration between CAD and CAE.
- Fast geometric manipulations.
- Increased job satisfaction.
- More freedom in the sequence of design activities (e.g. stability calculation based on a preliminary CAD model returns more accurate information at the initial stage of the design).

To be of greater effectiveness implies that more topics can be dealt with, which also lead to a better quality. For example:

- More design iterations, to come to an optimal design.
- Integration of analytical tools.
- 3-D visualization, to give all persons involved a better image of the vessel.
- Higher precision of the hull form definition.

On the other hand, CAD and CAE systems bring also some disadvantages with:

- The use of improper CAD/CAE systems, which force the designer into a corner.
- The usual need for very powerful hardware system to support it;
- A tendency to use always the latest CAD/CAE products, which may be unstable and error prone.
- A tendency to 'over-calculate', just because the computer gives the ability to, resulting in time-consuming procedures.

1.3 Ship design process

In ship design there are many domain-specific models of the design process, but Evans' design spiral (below) is probably the most well known. This model emphasizes that many design issues interact and must be considered in sequence, in increased detail in each pass around the spiral, until a single design that satisfies all constraints and balances all considerations is reached. Modern CAD/CAE systems allow a holistic design approach which aims at investigating many if not all important aspects at the same time. Such a synthesis model of CAE (below) allows exploring the design space to a greater extent and provides an efficient method of handling complex systems with many relationships and dependencies at once.

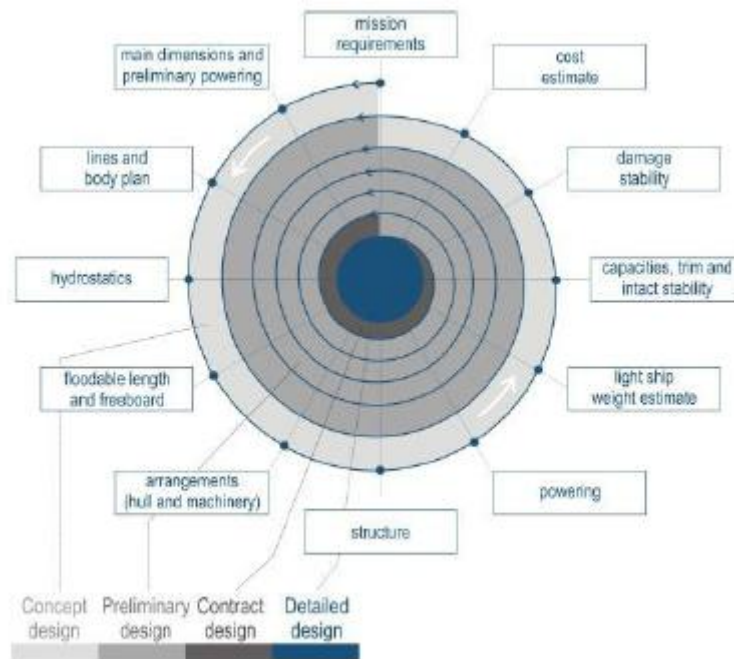


Figure 1.1 : Traditional design spiral[5]

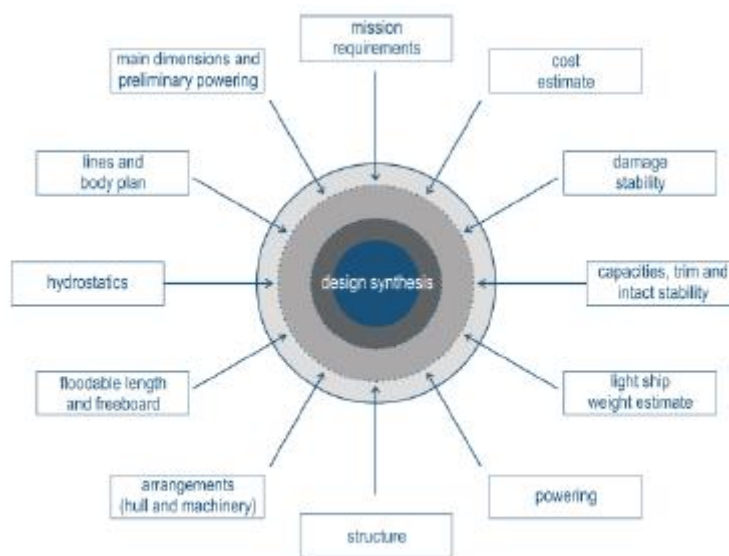


Figure 1.2 : Integrated approach[5]

1.4 An insight in fully-parametric ship design

In figure below the different modeling concepts are presented and compared on the basis of flexibility, required knowledge, effectiveness and cost in relevance to efficiency.

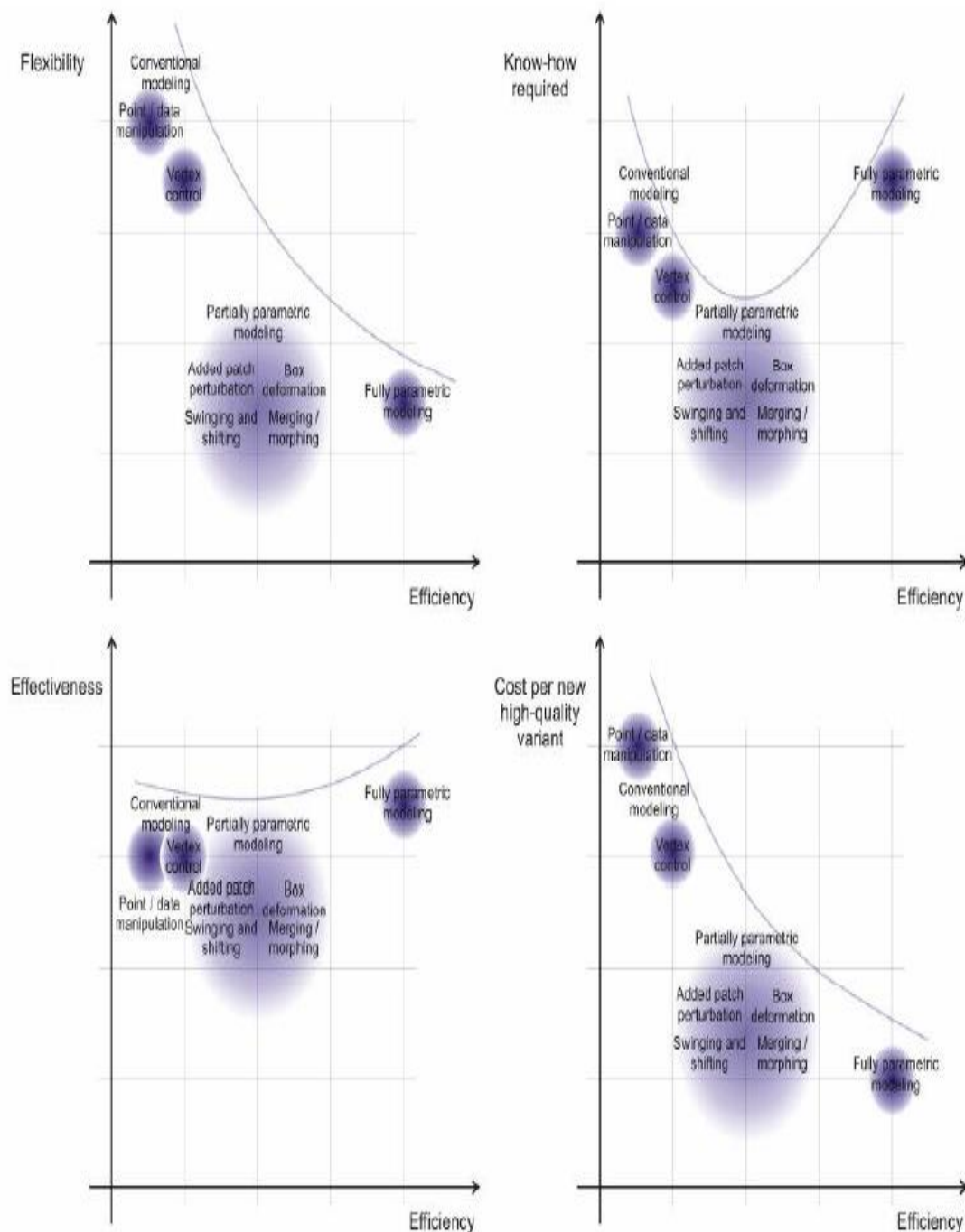


Figure 1.3 : Assessment of different geometric modeling techniques[14]

What can be derived by the figure above is that the fully parametric modeling technique yields excellent efficiency since only a few modifications are required in order to achieve a new fair hull form. This approach requires though a good knowledge of the basic elements of parametric modeling and the most time is consumed in order to set up the whole structure. Once the model is established, a wide variety of new designs is available, in contrast to conventional modeling where, setting up a hull form and browsing through new designs are equally time consuming and demands experience of the designer. Partially-parametric models build on existing shapes and prove to be an easy-handled approach for numerous tasks but it is not recommended for global and multi-objective investigations since the allowed modifications of the model are restricted. According to (Harries, 1998) , *the great advantage of parametric modeling is the ability to find the optimal balance between variability and simplicity, more precisely the balance between the freedom to be able to do everything and the restriction to do only what you really need.*

1.5 FRIENDSHIP-FRAMEWORK

The FRIENDSHIP-FRAMEWORK is a CAE package for the design of functional surfaces. It offers a wide range of CAD functionality for conventional NURBS-modeling, partially parametric modeling with various transformations and fully parametric modelling.

This software comes with a set of embedded variation and optimization strategies. These algorithms can be comfortably linked to the geometry and perform automatic variant creation. For that purpose, comprehensive variant and constraint management are provided .

Any program or tool which is needed for geometry design and analysis can be coupled. Convenient integration mechanisms make the external program an inherent part of the FRIENDSHIP-FRAMEWORK. By doing so, design and analysis expertise is centralized in order to streamline the design process. CFD solvers are coupled to the CAD through various levels of integration; tool- or project specific integration or by a common data interface. Therefore, results of CFD computations can be easily used as measures of merit for optimization procedures, driving the design process.

In addition to configuration and execution of external programs, comprehensive post-processing functionality is available. Result data gets visualized and tables are generated so that the entire design process finally takes place within a single workbench.

1.5.1 Design principles

A typical design procedure within the FRIENDSHIP-FRAMEWORK starts with a fully parametric model of the considered shape. During the geometry setup, objects are related to each other via introducing dependencies. Changes that are applied to one object are internally passed to dependent objects for update purposes. Surfaces are no longer described via basic point data. More intuitive descriptors (e.g. user-defined distributions which describe product properties) help to modify geometry smartly in a way that the resulting surfaces cover high fairness for geometrically feasible designs. Note that no “black-box” models are used, the engineer is completely free to set up any individual design. In the second step, parts of the geometry are linked to variation engines. Any floating-point number of the model setup can be varied. The user chooses a specific engine and defines bounds for variables as well as constraints and objectives. In order to be able to assess the manual or automatic variants, external software is coupled and configured. The engines simply evaluate parameters that request an external value. This transfers external data into the *FRIENDSHIP-FRAMEWORK*. Based on this integration – along with parametric geometry variation – sophisticated formal optimizations can be carried out .

1.5.2 Basic elements

The FRIENDSHIP-FRAMEWORK allows designing with a wide variety of point, curve and surface types. Curve intersection point, NURBS curve, lofted surface, Coons patch etc., are already known from other CAD programs and are fully-functional. Within the FRIENDSHIP-FRAMEWORK there are some special entities, which make the software a unique fully-parametric CAD tool. The most important of these is the following:

1.5.2.1 MetaSurfaces

They are novel surface entities developed for collecting information available in two distinct directions. They yield the Cartesian coordinates of any point on the surface for any pair of surface coordinates u and v , basically giving an unambiguous mapping from 2 to 3 as would, say, Bézier or B-Spline surfaces, too. However, they are more flexible as they do not assume any particular representation with regard to the curves they capture.

1.5.2.2 Feature modeling

Features are the way scripts can be implemented into a design. They work the same way than libraries for a programming language. On one hand can be produced with a little more than a click of the mouse instead of modeling them from the scratch every time which would take quite a while but on the other hand, the user has to be quite familiar with script writing, especially when difficult geometries and concepts are required.

Some are already provided by the editor but for advanced object definitions the user can create his own. They can for instance be used for interfacing the FF with an hydrostatics software like Hydromax. The feature then requires a meshed surface and a few data such as design waterline, displacement, LCG, VCG, LCB and then calls Hydromax to perform the calculations. The features then returns the results in the form of various objects, such as a righting lever curve for instance that can be used in the design.

They can be created either as "persistent", in the case their result will be an object incorporated to the current design, or transient if they are just needed to perform a task on the design (a geometric transformation for instance).

Features encapsulate any user-defined command sequence and that makes it available for writing macros and subroutines. They are high-level entities that can offer readily shaped and parameterized elements, as opposed to primitive

elements like points, lines and "normal" curves and surfaces and represent specific work processes which can be stored externally and reused.

Features work on the base of an editor where the necessary input parameters and types are specified as arguments and then a process is described via commands. This script is finally evaluated and returns the produced output that makes up the feature's attribute. Features are flexible and can be combined with each other providing sophisticated objects.

1.5.2.3 Curve engines

One of the useful objects for defining hull shapes in the FRIENDSHIP FRAMEWORK is called the Curve Engine. It allows for a type of curve to be defined at any position by a parameterization function of its position. In opposition to a classic hull design software where a few sections are defined at specific points along the hull length, the use of the curve engine allows to have a continuous section envelope running along the whole hull:

Basically, the curve engine combines a "template" curve definition with a continuous description of this definition. The template is formulated as Feature definition and describes a curve by means of its configurable parameters. Then, the curve engine takes this definition and connects the parameters with a functional description of them, i.e. distribution. This means that for each (abscissa) value in the interval of the functions, a curve can be generated where the information stems from the input functions (i.e. the ordinate value of them). (FRIENDSHIP Systems GmbH 2010)

Figure below shows a plot of a few sections generated by a curve engine. At the bottom in yellow, the curve used to parameter the lowest position of the section, that physically corresponds to the baseline. In black in the X-Z plane, the curve used to parameter the beam of the sections along the hull. The parameterization of a section is actually more complicated, and just two template curves are shown for clarity purpose.

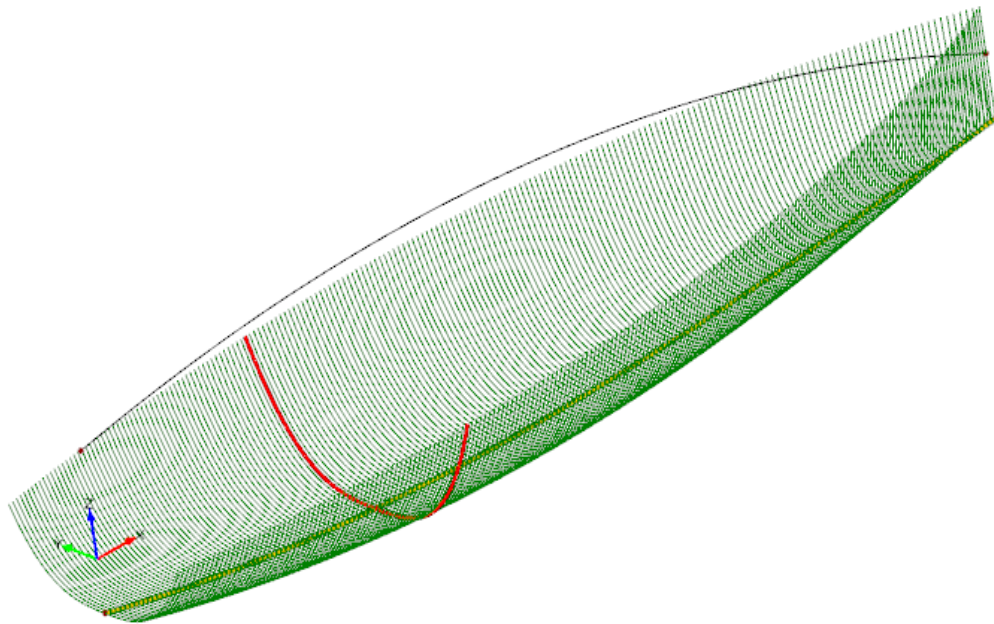


Figure 1.4 : A plot of a few sections generated by a curve engine

1.5.2.4 Design engine

In order to fulfill this objective of performance driven design, FF has several optimization algorithms implemented. The type of objects they belong to are "Design Engines". These design engines can be used to either alter an existing design or create new ones. These entities enclose several variation-optimization algorithms, embedded in FRIENDSHIP-FRAMEWORK, which are available for Design of Experiments, single-objective and multi-objective optimizations. To name some: Sobol, Exhaustive Search NSGA-II, Mosa etc. Design variables are chosen from the project which shall be involved in the variation/optimization. For the most engines the lower and upper bound need to be set, as well as the current value. Then, the evaluations are chosen, which are parameters involved in the project. The results of the variant creations are presented in a table, with the value of the variables used to create them, the Fparameter object(s) on which the evaluation is running and the constraints of the design that have been defined by the user.. The evaluations can be set as objectives which then are minimized. Equality or inequality constraints may also be involved. According to the underlying algorithm, these constraints may be considered or not.

2. Optimization

2.1 Introduction-The generic ship design optimization problem

Optimization is a process inextricably linked with human activity. The desire to consciously optimize the outcome of decisions is a uniquely human character trait .(Nowacki, 2003)

In a few words, optimization is the process of decision making when a number of alternative choices are available and an optimal solution has to be determined with regard to specific criteria, while taking into account the restrictions and constraints set by the environment.

In more details, decision making of all kinds involves the choice of one or more alternatives from a list of options. The list of options would normally all be more or less acceptable solutions for the problem at hand and consequences, both good and bad, flow from the exercise of choice. The aim of rational decision making therefore, is to maximize the positive consequences and minimize the negative ones. As these consequences are directly related to the decision made or opinion set, it is not unreasonable to treat the consequences as aspects of performance. The decision problem then becomes a matter of considering these aspects of performance of all the options available simultaneously so that the decision maker (DM) can exercise his choice. In other words, rational decision making involves choice within the context of multiple measures of performance or multiple criteria .

Ship design is a typical optimization problem involving multiple and frequently contradictory objective functions and constraints [16]. With a system as complex as a ship, composed of many subsystems that are complicated on their own right, a naval architect is faced by a multiplicity of requirements, from the owner's needs and desires, engineering feasibility, imperatives of technological advancement, environmental considerations.

Solving the requirements of the sub-systems alone will often not produce an ideal result; the interactions amongst the sub-systems must be analyzed, leading to a ship design that truly is a multi-criteria decision problem. These MCDM methods can vary in complexity depending on not only the amount of parameters analyzed, but also how many of their interactions are thought out. In addition, subjectively becomes a factor into determining which criteria stand out above the others. How these criteria are weighted is up to the individual method itself . Thus, the difficulty lies in formulating the objective and all the constraints. For this reason, the main requirement when dealing with the generic ship optimization problem is that the designer has a picture of his objective, what he really wants to achieve .

2.2 Single Objective & Multi-Objective Optimization

In the classical optimization where there is only a single criterion and a set of satisfiable constraints, decision making approaches lead naturally to the solution. Once the criterion of interest is agreed upon -cost, for example- the choice of the most attractive action is not a matter of opinion. There can be some argument as to how the objective –cost, for example- may be computed but in any meaningful problem the method of computation is obviously a part of the definition of the criterion itself. In other words, the choice of criterion leads directly to the solution in the mono-criterion example and it is a solution that all parties can agree with.

However, sometimes a system must perform more than one mission or must meet multiple objectives simultaneously or consecutively, which without special assumptions may not be easy to accommodate in a single measure of merit. Therefore, in the case of multiple criteria formulation, decision makers can and will, in general, have different value systems leading to different priority orderings of the multiple, potentially conflicting performance criteria .

Ten or fifteen years ago, standard available optimization tools would focus on a single and limited aspect (e.g. shape, scantlings, propeller, ultimate strength, etc.) and a single objective would be targeted (weight, resistance, cavitation, etc.). Nowadays optimization tools tend to adopt a more generic approach and coupled with the fact that they have also become much more reliable this has made them more likely to be part of the standard design tool set that each designer uses on a day to day basis.

So regarding to the multi-objective optimization we can understand that requirements in design of any kind are often potentially in conflict. This is because there are few, if any systems that can combine the best of all performance aspects for all possible scenarios in the same design. If such utopian solutions exist then the obvious answer would be to go for them. But life being, the way it is, good values of some criteria inevitably go with poor values of others. The aim in multiple criteria decision making is then to find the best compromise solution . The Pareto optimality expresses exactly this formulation, namely the Pareto optimal solution is a set of possible solutions, a set of non-dominated solutions, in which no single objective can be improved without degrading the achievement of at least one other objective.

2.3 Generic optimization problem

The formulation of optimization problems is a conceptual modeling process that follows certain standard procedures and results in a specific problem definition, tailored for an application, e.g. in design .

From the viewpoint of information flows, the generic optimization problem and its basic elements may be defined as follows (see Figure):

- Input **E_I**: prescribed data, for example, requirements of the owner (DWT capacity, service speed etc).
- Output **E_O**: result of the evaluation of the system performance for given input (techno-economical characteristics of the ship,- optimal solution based on criterion/-a.
- Design variables **D**: free variables of the optimization problem (under the designer's control), for example, ship's main dimensions.
- Design parameters **P**: restriction parameters, constraints (extraneous influences, scenarios, side conditions, not under the designer's control).
- Merit functions **M**: measure of merit, expression of evaluation criterion/-a, objective function ($M(\mathbf{D}, \mathbf{P})$).
- Constraints **G**: boundary conditions of equality and/or inequality type, function of design variables and parameters ($G(\mathbf{D}, \mathbf{P})$).

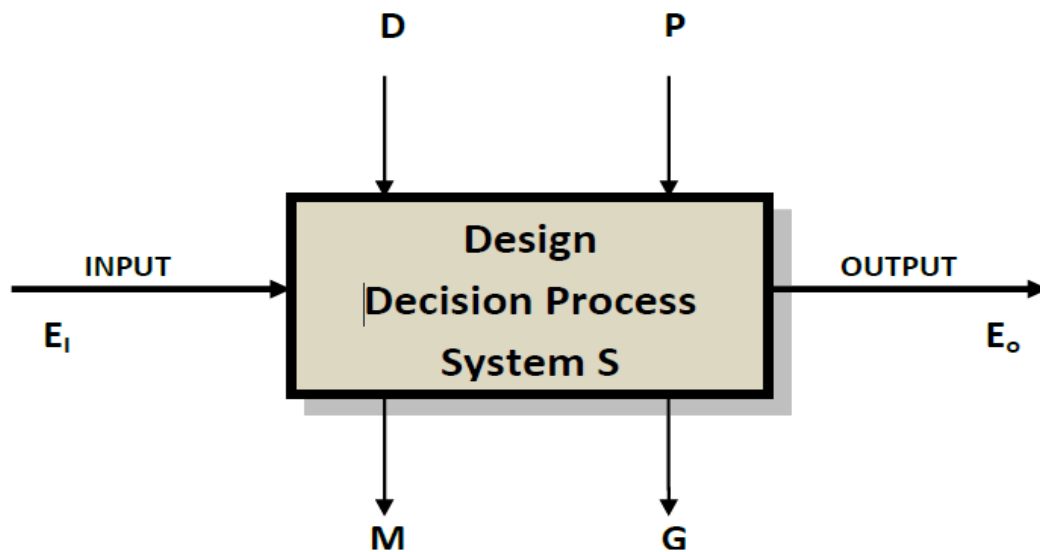


Figure 2.1 : Optimization System[7]

2.4 Solving a multi-objective optimization problem

As there usually exist multiple Pareto optimal solutions for multi-objective optimization problems, what it means to solve such a problem is not as straightforward as it is for a single objective optimization problem. Therefore, different researchers have defined the term "solving a multi-objective optimization problem" in various ways. This section summarizes some of them and the contexts in which they are used. Many methods convert the original problem with multiple objectives into a single objective optimization problem. This is called a scalarized problem. If scalarization is done carefully, Pareto optimality of the solutions obtained can be guaranteed.

Scalarizing a multi-objective optimization problem means formulating a single-objective optimization problems such that optimal solutions to the single-objective optimization problem are Pareto optimal solutions to the multi-objective optimization problem. With different parameters for the scalarization, different Pareto optimal solutions are produced. A well-known example is the so-called linear scalarization :

$$\min_{x \in X} \sum_{i=1}^k w_i f_i(x),$$

where the weights of the objectives $w_i > 0$ are the parameters of the scalarization.

Solving a multi-objective optimization problem is sometimes understood as approximating or computing all or a representative set of Pareto optimal solutions.

When decision making is emphasized, the objective of solving a multi-objective optimization problem is referred to supporting a decision maker in finding the most preferred Pareto optimal solution according to his/her preferences. The underlying assumption is that one solution to the problem must be identified to be implemented in practice. Here, a human decision maker (DM) plays an important role. (S)he is expected to be an expert in the problem domain.

The most preferred solution can be found using different philosophies. Generally multiobjective optimization methods are divided into four classes. In so-called no preference methods, no decision maker is expected to be available, but a neutral compromise solution is identified without preference information. The other classes are so-called a priori, a posteriori and interactive methods and they all involve preference information from the decision maker in different ways.

In a priori methods, preference information is first asked from the decision maker and then a solution best satisfying these preferences is found. In a posteriori methods, a representative set of Pareto optimal solutions is first found and then the decision maker must choose one of them. In interactive methods, the decision maker is allowed to iteratively search for the most preferred solution. In each iteration of the interactive method, the decision maker is shown Pareto optimal solution(s) and (s)he can tell how the solution(s) could be improved. The information given by the decision maker is then taken into account while generating new Pareto optimal solution(s) for the decision maker to study in the next iteration. In this way, the decision maker learns about the feasibility of his/her wishes and can concentrate on solutions that are interesting to him/her. The decision maker may stop the search whenever he/she wants to.

2.5 Design of experiment (DOE)

In general usage, design of experiments (DOE) or experimental design is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not.

In the design of experiments, the experimenter is often interested in the effect of some process or intervention (the "treatment") on some objects (the "experimental units"). Design of experiments is thus a discipline that has very broad application across all the natural and social sciences and engineering.

So DoE's are very effective to gather information about the optimization problem at hand and about the whole design space. DoE tables are useful to detect trends of the optimization variables with regard to the objectives of the problem. Alternatively, a DoE database may be searched to detect a suitable starting point for a subsequent focused optimization process. Or a DoE may serve as a database for response surface fitting, or for checking the response sensitivity of a design candidate.

A design of experiment is used to identify which factors are statistically significant and practically important to the overall design. Statistical significance refers to the mathematical test to distinguish between whether a design variable influences the change in the mean value of the outcome due to an effect described in the model and whether the change could have been observed in the data by chance alone. In essence, a design of experiment is a research method that contributes to identify the changes, the local minima/maxima, to get an idea about the shape of the objective functions and is used as a preliminary tool for exploration of the design space and exploitation of the best regions according to criteria in order to obtain a reasonable initial design for the subsequent optimization.

2.6 Genetic algorithms(GA)

In the computer science field of artificial intelligence, a genetic algorithm (GA) is a search heuristic that mimics the process of natural evolution. This heuristic (also sometimes called a metaheuristic) is routinely used to generate useful solutions to optimization and search problems. Genetic algorithms belong to the larger class of evolutionary algorithms(EA), which generate solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover.

Genetic algorithms (GA) are stochastic, nonlinear optimization methods that apply the principles of biological evolution . In particular, they utilize populations of solutions and apply selection, reproduction and mutation methods, in contrast to more traditional optimization methods which use gradient information to move between (successively better) points in solution space. That makes them uniquely adaptive to multi-objective problems such as finding Pareto frontiers.

A good definition provided by Koza (1998) is:

“The genetic algorithm is a highly parallel mathematical algorithm that transforms a set (population) of individual mathematical objects (typically fixed-length character strings patterned after chromosome strings), each with an associated fitness value, into a new population (i.e. the next generation) using operations patterned after the Darwinian principle of reproduction and survival of the fittest and after naturally occurring genetic operations (notably sexually re-combinations)”.

Actually, the genetic algorithm derives its behavior from a metaphor of one of the mechanisms of evolution in nature which is called hard selection. Under this scheme, only the best available individuals are retained for generating descendants. This contrast with soft selection, which offers a probabilistic mechanism for maintaining individuals to be parents of future progeny despite possessing relatively poorer objective values.

A genetic algorithm for a particular problem must have the following five components:

- A representation for potential solutions to the problem.
- A way to create an initial population of potential solutions.
- An evaluation function that plays the role of the environment, rating solutions in terms of their “fitness”.
- Genetic operators that alter the compositions of children.
- Values for various parameters that the genetic algorithm uses (population size, probabilities of applying genetic operators, etc).

Some of the basic terminology referred to GA is the following:

The fitness of an individual is a value that reflects its performance (i.e. how well solves a certain task). A fitness function is a mapping of the *chromosomes* (data structure that holds a “string” of task parameters or genes, analogous to the base-4 chromosomes present in our DNA) in a population to their corresponding fitness values. A fitness landscape is the hyper-surface obtained by applying the fitness function to every point in the search space.

If the solution of a problem can be represented by a set of N real-values parameters, then the job of finding this solution can be thought of as a search in an H -dimensional space. This region is simply referred to as the *search space* of the problem.

Exploitation is the process of using information gathered from previously visited points in the search space to determine which places might be profitable to visit next. Hill climbing is an example of exploitation, because it investigates adjacent points in the search space, and moves in the direction giving the greatest increase in fitness. Exploitation techniques are good at finding local minima (or maxima). The GA uses crossover as an exploitation mechanism.

Exploration is the process of visiting entirely new regions of search space, to see if anything promising may be found there. Unlike exploitation, exploration involves leaps into unknown regions. Random search is an example of exploration. Problems which have many local minima (maxima) can sometimes only be solved using exploration techniques such as random search. The GA uses mutation as an exploration mechanism.

Elitism is a mechanism which ensures that the chromosomes of the highly fit member(s) of the population are passed on to the next generation without being altered.

The basic operation of a GA is presented in the following segment of pseudo-code:

```
Generate initial population,  $G(0)$ ;  
Evaluate  $G(0)$ ;  
 $t:=0$ ;  
repeat  
     $t:=t+1$ ;  
    generate  $G(t)$  using  $G(t-1)$ ;  
    evaluate  $G(t)$ ;  
until a solution is found
```

First, an initial population, where the individuals are set of chromosomes

representing all possible solutions to the problem, is randomly generated. Then a fitness function is applied to each one of these chromosomes in order to measure the quality of the solution encoded. Knowing each chromosome's fitness, a selection process takes place to choose the individuals that will be parents of the following generation.

Some brief explanations are now follow for the algorithms that were utilized at the present diploma thesis:

Exhaustive Search:

Exhaustive Search - also called brute force method or direct search (note that it is not an optimization algorithm though) - is a straightforward algorithm which subdivides the feasible domain of each active design variable into the given number of subintervals and sets the variable to the resulting interval boundaries (e.g. one subdivision results in two evaluations). Note that at least one design variable must be given and active.

Sobol:

Basically, the Sobol is a deterministic algorithm that imitates the behavior of a random sequence. This kind of algorithm is also known as *quasi-random* or *low discrepancy* sequence. Similar to random number sequences the aim is a uniform sampling of the design space. But in this case the clustering effects of random sequences are reduced. Sobol type algorithms are known to have superior convergence than random sequences.

Best Practice

The Sobol is typically used in the first stage of an optimization process. Create some sample designs with it and have a look at the best candidates. Then, start a local search with an optimization engine (e.g. TSearch) in order to finetune the best candidates of the Sobol run further with regard to certain objectives and constraints.

NSGA-II:

The NSGA-II design engine implements the famous non-dominated sorting based multi-objective evolutionary algorithm. It requires settings for the number of generations, the population size, the mutation probability as well as the crossover probability.

The crossover probability affects the process of mixing up the genes of the parents while creating a child, e.g. if this value is zero the genes of one single-parent are just copied to the child without crossing w.r.t. the other parent.

Best Practice

This algorithm is a good choice for optimization problems where several - often conflicting - objectives need to be minimized (i.e. not just one objective). It can also consider inequality constraints. Alternatively, you can also choose the MOSA.

MOSA:

Dominance-Based Multi-Objective Simulated Annealing (MOSA) is an extended version of the common single-objective simulated annealing (SA) method. The idea behind SA is an analogy with thermodynamics where a slowly cooling metal adopts a low-energy crystalline state. Unlike this, if a liquid metal is cooled quickly it does not reach this minimum state - which follows the so-called Boltzmann probability distribution.

This specific design engine generates a number of samples (which is called duration) for each epoch using a fixed system temperature. After finishing an epoch the temperature is lowered and new samples are created again and so on. A sample is set by perturbing only one design variable where this variable is chosen at random and perturbed by means of a Laplacian distribution. Here, the attribute sigma is the scaling factor and sets the magnitude of the perturbation.

Best Practice

Choose this engine if you have several objectives (and not just one) that need to be minimized. The MOSA also considers inequality constraints. Alternatively, you can also choose the NSGA-II engine which solves the same optimization task.

3. MULTI HULL SHIPS AND SWATH

3.1 Multi hull ships

The growing demand for more space on the decks has led to the development and improvement of double hull vessels, which are used both as speedboats and as sailboats. The most common type of double hull vessels is the catamaran, which consists of two hulls that meet the requirements for buoyancy and stability and are linked by a superstructure, which gives the total usable volume of the catamaran. Each of the two hulls called demihull and may be symmetrical, asymmetrical or even fully asymmetrical to the centerline.

The main advantage of the catamaran is the large surface area of the deck, which makes it suitable for the carriage of passengers and vehicles. Note that a catamaran vessel with respect to a monogastric vessel shows the same displacement on average about 30% more surface deck. Additional advantage of the catamaran is a fact that the total width is much larger than that of a single-hull vessel, which is a particularly important factor for economic exploitation. Noteworthy also feature of catamaran is not only good behavior to the roll but also sufficient stability, partly due to the appropriate choice of the distance between the two hulls and the large moments of inertia of the two hulls, which contribute to the stability of the vessel and to reduce the accelerations which lead to roll. Finally, as an advantage of the catamaran can be mentioned the relatively lower draft in relation with a single hull boat of the same displacement. As a result can float in shallower seas and harbors as well as more freedom in selecting main dimensions that can lead to slender hulls with little resistance, which is not always possible in the design of single-hull vessels because stability requirements must be met.

The catamaran used since the early 1970s. By early 1990s started to manufacture longer catamarans from 70 to 100 meters, with modern tendencies to push catamaran more than 110 meters long and displacement of 2000 tons. In general, the construction of catamaran ships is more complicated than the construction of single-hull ships but simpler to manufacture other speedboats. As construction material steel is prevented and aluminum is preferred to the greatest possible reduction of the displacement which is necessary to achieve high speed. Finally, for propulsion water jets are commonly used and Diesel for main engines.

3.2 General aspects of SWATH

The name Swath is an acronym that originates from the words: Small Waterplane Area Twin Hull .

Ships of Swath type can be considered a special class catamaran. The SWATH has all the advantages of catamaran vessels as large deck area and comfortable satisfaction of the stability criteria. Their characteristics give them a lot of extra properties.

The SWATH consists of two lower hulls (gondolas) completely submerged below the surface of the sea which offer almost the entire lift. Above sea level looks like a common catamaran. The deck (box) links with the lower hulls with thin bases called struts (these are usually two or sometimes four ones). Struts are hydrodynamic designed in such way in order to reduce the strong wave resistance for which they are primarily responsible.

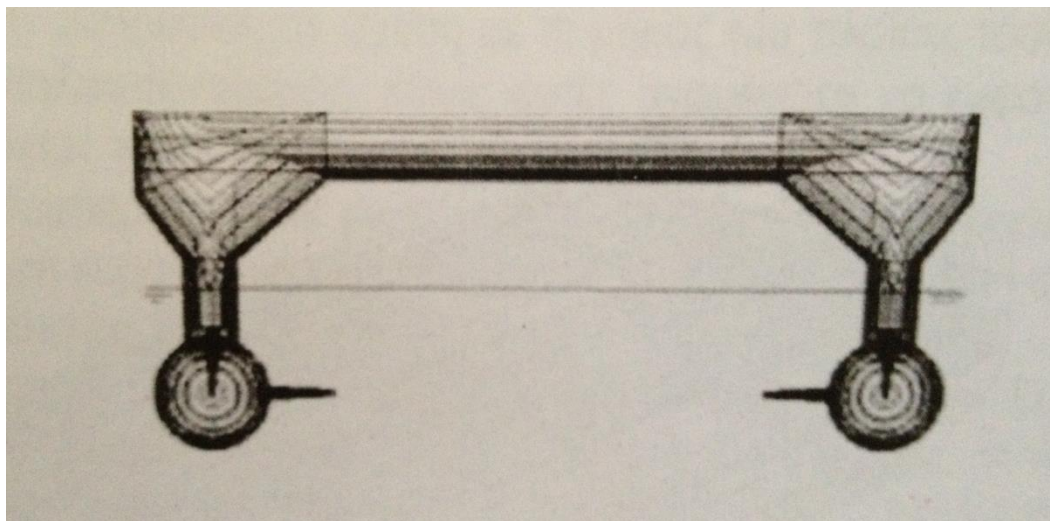


Figure 3.1: Typical Swath hull [3]

The main feature that is understood by its name is the small waterplane area that is accomplished from the immersion of the most of the displacement below the sea level. Swath vessels have a waterplane area diminished about 50% in relation to a catamaran. The specificity of the hull offers extremely good behavior to the sea waves. This is their great advantage in relation to the other technologically advanced ships which are forced to decrease their speed

in rough seas. Swath keep both their speed and the convenience of the passengers.

The slender hulls have little interaction with the sea. Not only they stimulate relatively small waves ,but also stimulation from the sea waves is reduced. That is why they have reduced wave resistance and excellent handling in rough seas.

The small wave resistance is small price relative to the increased friction resistance due to the large wetted surface of the submerged lower hulls. So for the low speed region where the frictional resistance is dominating the efficiency of the hull is moderate. Contrary at high speeds where the wave resistance is generally the major component of resistance, the Swath stands excellent from hydrodynamic side.

Moreover, the small production of waves enables you to pass close to shore without creating security problems in humans and boats.

A big problem although is the pitch instability espacially at high speeds. The pressure field induced to the surface of the vessel movement generates a tendency for increased trim (monk moment-nose diving).The solution used today and has eliminated the problem is the placement of stabilizing fins which are clearly shown in Figure 1.

3.3 SWATH Design Parameters

By changing some parameters can generate several alternative designs with differing, in general, characteristics. These parameters are for a SWATH , the waterline surface, the spacing of the hulls, the distance between the surface of the sea and wetdeck etc. Each change causes positive and negative effects. The challenge for the designer is to find the golden ratio.

The challenge in designing a successful SWATH vessel is not to minimize the motion of the vessel at the expense of other characteristics such as the power or the payload. Pursuing the movements of the ship to be significantly lower of

the commonly accepted limits for the comfort of passengers and crew. The excessive decrease the water area plane has a number of unpleasant side effects and problems such as lack of stability and high sensitivity changes in weight and center of gravity.

The ship movement are caused by forces that the waves create on the struts. These forces diminish with decreasing waterplane area of strut. With careful selection of the waterplane area of strut is feasible to reset the vertical forces due to wave to a narrow range of frequencies.

A decrease of the waterplane area makes necessary an increase the lateral distance between the hulls to ensure satisfactory stability for the ship. Having the hulls away from each other has a direct impact on the weight of the metal structure of the ship which is growing rapidly with the unsupported length. So typically reducing the water surface leads to a larger and more expensive vessel.

A decrease to the size of the strut (especially to the beam) has a result of space deficiency for the placement of the engine room and a lack of adequate opening for maintenance. Moreover the construction is more complex. . Examination of above parameters puts the problem in perspective and highlights the need for deep understanding of how the Swath hull reacts, before the optimization process.

Another aspect that deserves particular study is the gap between the sea level and the bottom of the cross structure connecting the hulls together. Reducing the gap essentially eliminates the big advantage of SWATH to maintain service speed even in rough seas. From the other side the existence of a large gap translates to a great height car deck making it difficult to disembark and embark passengers and vehicles.

3.4 Comparison of SWATH with conventional ships

Advantages of SWATH ships over conventional ships with the same payload and relatively lower speed are as follows:

- Less required horsepower, especially in high speed areas.
- Superior seakeeping behavior
- Adequate stability in all conditions
- Extremely good maneuvering

The consequences of the above is important. First, relatively higher speeds for the same power reduce the journey time and increase the number of trips per year with many economic benefits for the owner, especially in peak periods. The duration of the journey shrinks even more due to the reduced time of loading and unloading of the ship in ports. As we know these ships have a wider catapult. Moreover the excellent behavior of ships at sea, the comfort due to the large deck space, low noise level and vibrations, aesthetics and new technology that characterize this kind of ship are factors that make it an attractive option for the passengers.

To the weaknesses of the vessel are:

- Large frictional resistance of the ship especially at low speeds,
- The sensitivity to changes in the weight and the center of gravity and finally
- The necessity of stabilizing fins to reduce pitching.

All these suggests that the ship is not suitable for large loads transfer. Moreover, a Swath construction is expected to be more expensive than a conventional ship.

3.5 History of Swath

Swath ships are not a new invention, although are considered by most modern ship types and incorporate many new technologies. Below is a brief history of the invention and evolution of this type of ship:

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1880 - O.C.G. Lyidborg claims the patent for the first one-hull semi submerged ship.



Figure 3.2 [3]

1938 - Appears for the first time the idea of a small-waterplane area twin hull ship. The idea belongs to the Canadian Frederick G. Creed. Creed suggested this type of ship as the most suitable aircraft carrier for the British navy. After several years remade his proposal to the U.S. Navy but neither there was echoed. In 1946 Creed enshrines his patent in Britain.

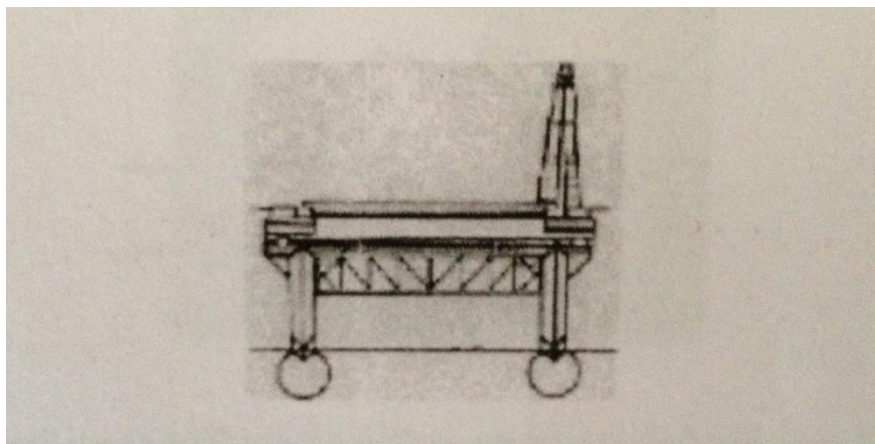


Figure 3.3 [3]

1959 - The U.S. Navy orients research on high-speed semi submerged ships. In these investigations H. Boericke propose a one-hull ship called 'shark form'. In 1962 enshrines that invention.

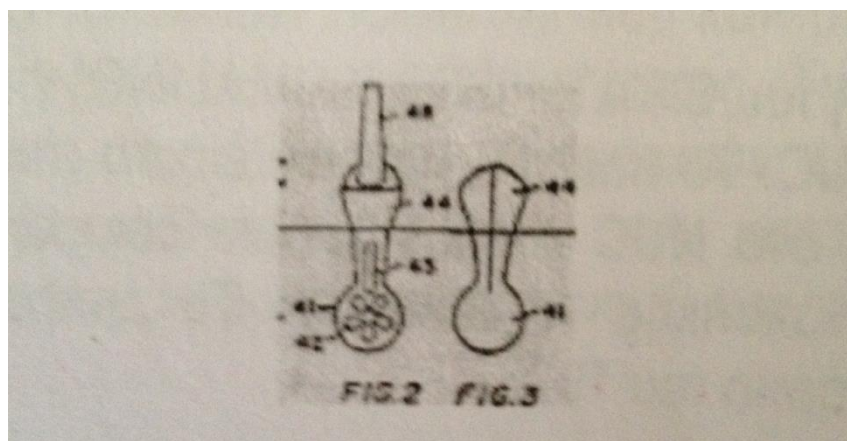


Figure 3.4 Shark Form [3]

1965 – Alan McClure from Houston suggests the ship “MOHOLE” for drilling platform.

1967- Dr Reuven Leopold from Litton Industries suggests to the US Navy the craft “TRISEC”



Figure 3.5 TRISEC [3]

1968 - The first low speed Swath “DUPLUS” from the shipyard Boele in Holland. The ship has a length of 40m and 1200t displacement. This is a research boat for finding oil. The designer J. J. Stenger was based on the observation that the submarines operating in small depth are influenced very little by the surface wave.

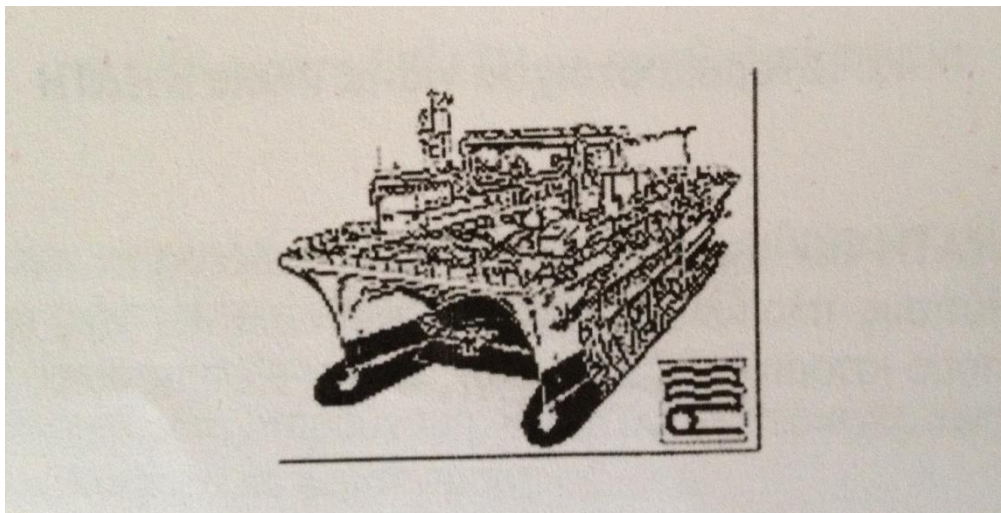


Figure 3.6 DUPLUS [3]

1968 - "A student of MIT suggests an optimized version of "MOHOLE" 'within a course. Then some experiments are made in the university tank with the model ship. He calls his vessel semi-submerged catamaran.

1968 - Dr. Tom Lang from Naval Underseas Center (NUC) of San Diego evolves a design for "high speed with semi-submerged hulls". Significant development of the project is the addition of moving fins to stabilize the ship at high speed. He puts the fins aft of the center of gravity of the vessel to control trim and pitching.

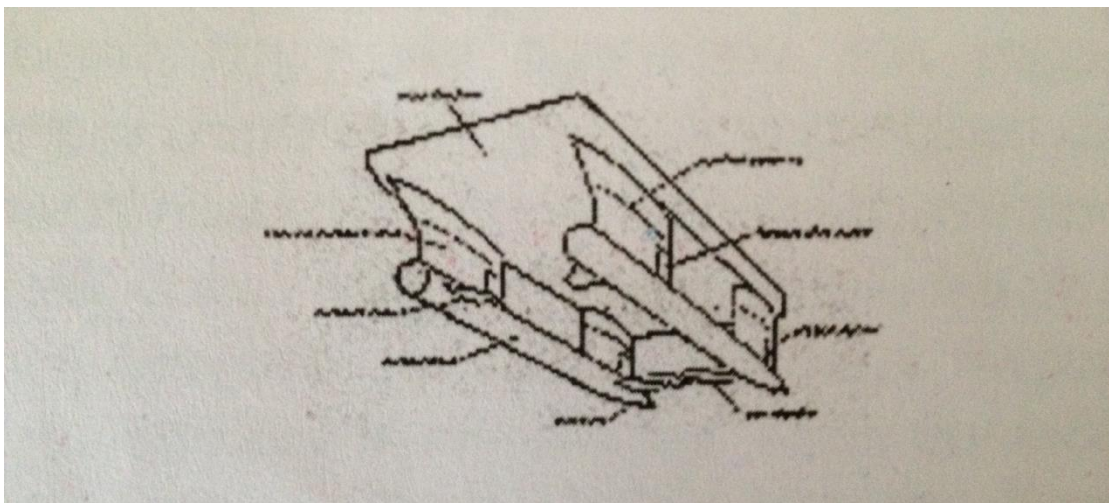


Figure 3.7 [3]

1970 - Mitsui Engineering & Shipbuilding Co. from Tokyo initiates a research to "semi submerged catamaran (SSC)".

1972 - The construction of Swath "SSP KAIMALINO" on behalf of NUC. The ship then arises after 13 months of research on NUC and 2.5 years of model tests and analytical design. The ship is finally working in March 1973.

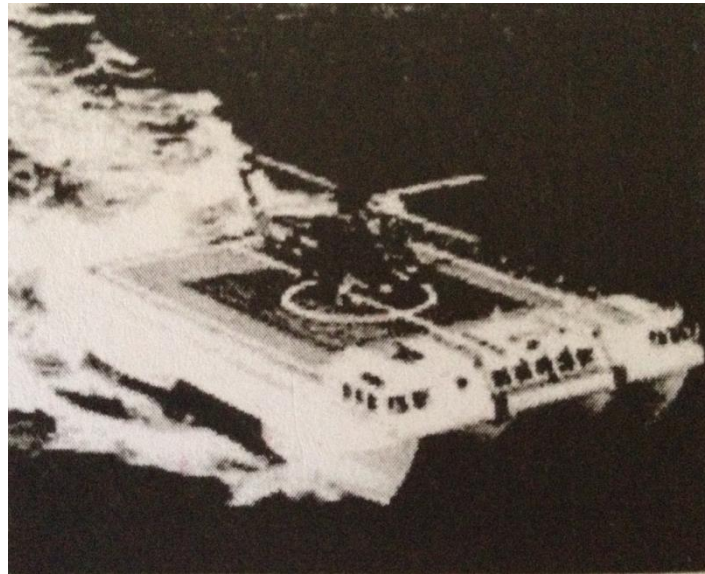


Figure 3.8 SSP KAIMALINO [3]

1973 – Swath acronym is officially used by the US Navy.

1979 - Shipyards Mitsui Engineering & Shipbuilding complete the world's first Swath intended for commercial use. It is the passenger ships “SEAGULL” with capacity of 446 passengers, at 26.5 knots speed.

1991 - The first of a 4 Swath series is delivered to Military Sealift Command. The vessel is designed by the U.S. Navy. We talk about “LONG VICTORIUS” with 71,5m length.

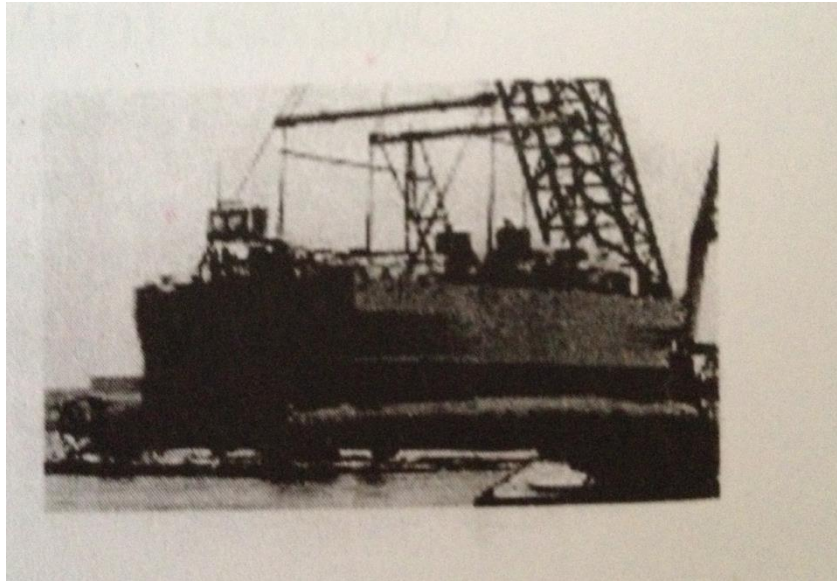


Figure 3.9 LONG VICTORIUS [3]

1992 - Shipyards Finyards deliver the first Swath cruise ship, the “Radisson Diamond” of “Diamond Cruise Ltd” company. The ship has a length of 131 m.

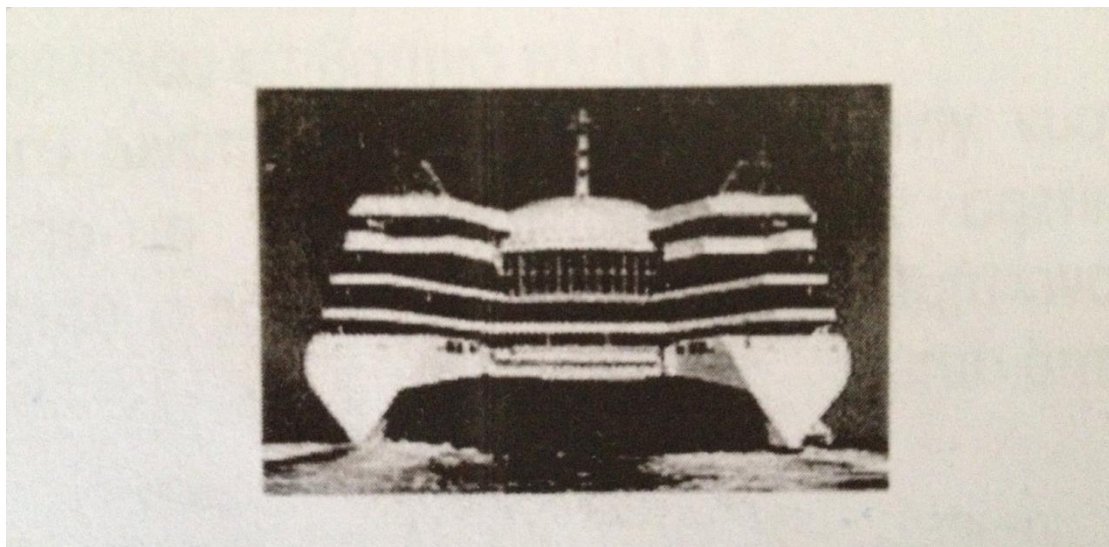


Figure 3.10 RADISSON DIAMOND [3]

1993 - The existence of the world's first stealth ship is revealed. This is the sea shadow A-frame Swath with 50m length. The ship belongs to the USA and is manufactured by Lockheed Missiles and Aerospace Co.



Figure 3.11 SEA SHADOW A-FRAME SWATH [3]

It is estimated that currently around 50 Swath ships are traveling in the seas around the world. Their sizes range from very small vessels with a displacement of less than 100 t, to the largest Swath ever built, the cruise ship Radisson Diamond built in Finland in 1992, with 11,500 t displacement and 131 m length. Most of Swath ships are built in the U.S. and serve research or military purposes. The material most preferred in the manufacture of Swath is aluminum. The diagram below shows the distribution of ships in number compared to their displacement.

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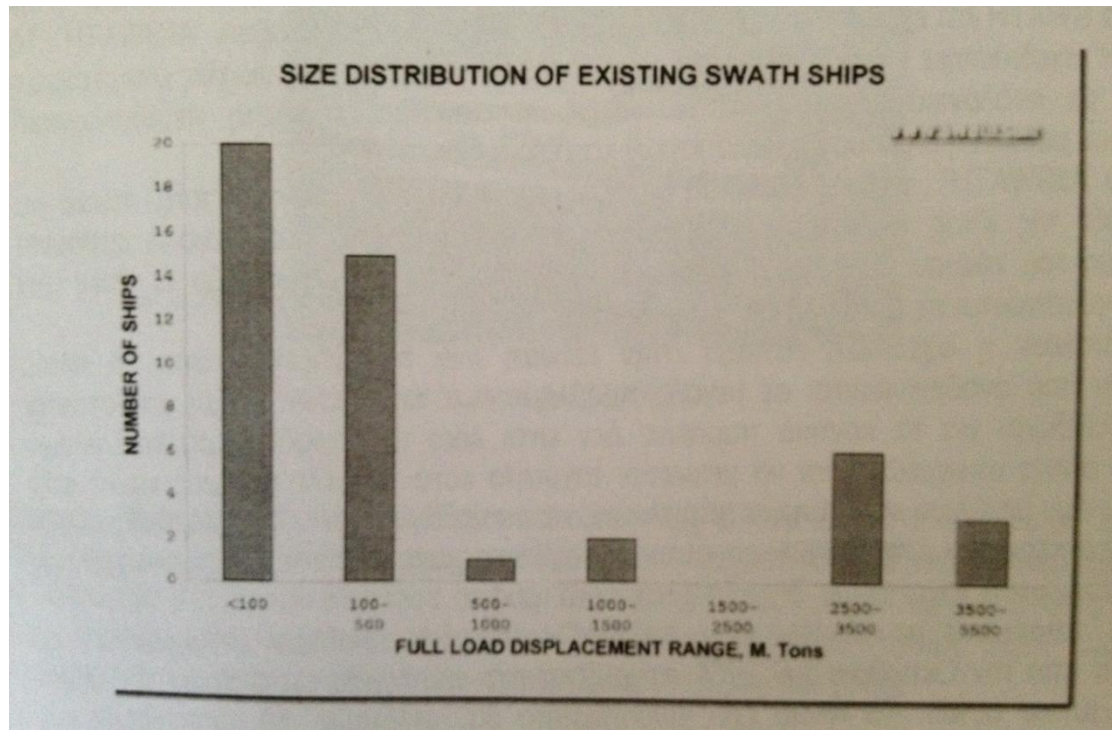


Figure 3.12 Size distribution of existing SWATH ships [3]

3.6 New-built Swath

Occasionally extensive research has been done on these ships and have recorded some very innovative designs that exploit the features and advantages of this type of hull. These are some of them:

FS Class 751 research vessel: Thyssen Nordseewerke recently studied and built an innovative and contemporary research SWATH 3500 t. displacement. The vessel has a diesel engine propulsion power of 4160 KW. It can travel 5000nm in its service speed of 15Kn. The choice of this type of hull is due to the excellent performance of this vessel in waves. Small responses in relation to the situation of the sea greatly helps the investigations this ship serves

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already. Moreover, the large deck space is necessary for scientific equipment and research needs. The ship was launched in October 2003 .

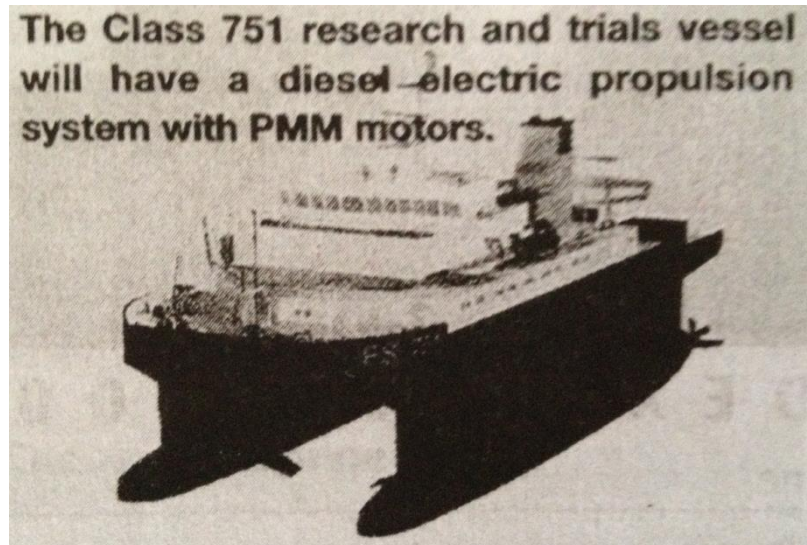


Figure 3.13 FS Class 751 [3]

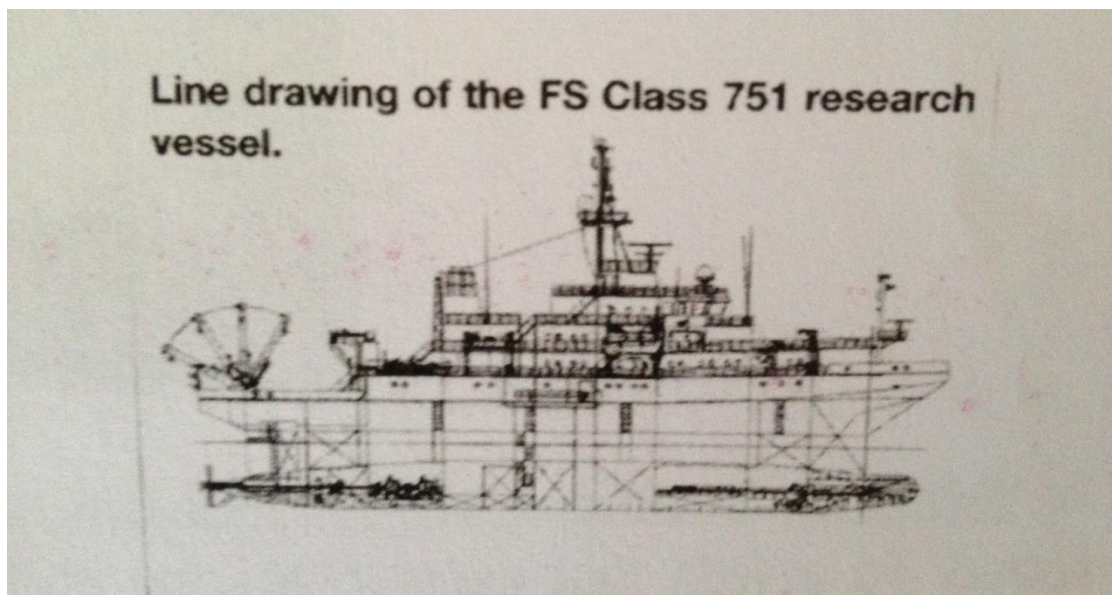


Figure 3.14 FS Class 751 [3]

AliSWATH: Another revolutionary design effort of Swath ship is developed by the famous Italian shipyard Rodriquez. Shipyards Rodriquez specialize in designing high-speed passenger crafts and have a large and experienced design department. In their effort to renew their proposals have turned to Swath technology and have already come up with a design they call ' AliSWATH '. 'AliSWATH' designed to satisfy modern requirements such as high service speed with low fuel consumption, little environmental pollution and making reduced waves during the trip.

'AliSWATH' with length of 70 m, will has less power than conventional vessels in order to achieve the same speed. Reduced consumption is large commercial advantage of this vessel especially in these times that fuel prices vary in particularly high levels.

Moreover, the design focuses on reducing its output waves. This is a large problem of high-speed ships and often become dangerous to the nearby coast. There are many examples of speedboats which are required to reduce speed when passing from the near shore due to the large making waves which is dangerous for humans and small boats. Speed reduction moderates the most important advantages of high speed ships, their speed.

Experiments with AliSWATH model were very encouraging so at October 2004 started to built in the shipyards of the company the first ship of this type. The ship has a capacity of 500 passengers, 50 cars and a displacement of only 500t. The company believes that this design would be the future to the high-speed passenger ships.

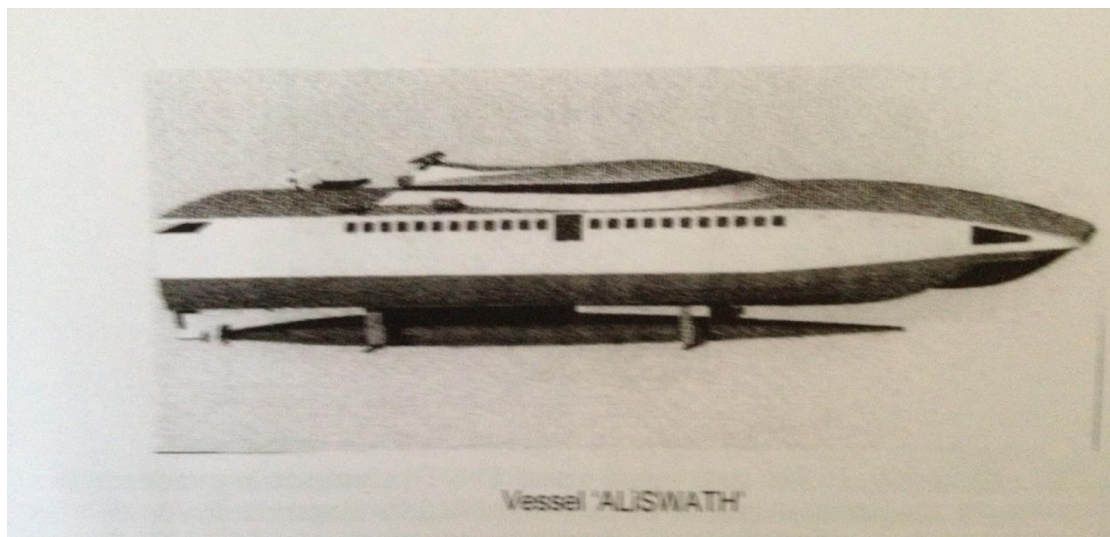


Figure 3.15 Vessel ALISWATH [3]

Damen Royal Schelde yard: Two new passenger Swath manufactured in Damen Royal Schelde yard. Manufacturer justifies the choice of SWATH saying they are in his priorities seaworthiness and reliability of ships. Swath ships renowned for their seaworthiness even in rough weather conditions where other vessels cannot make it. For reliability purposes was chosen diesel-electric propulsion that is also characterized by high flexibility. The ship can travel satisfactory even in case of loss of one of the two diesel engines that propel the main generators. The two vessels operate between Vlissingen and Breskens and put into the sea in March 2004 .



Figure 3.16 Vessel PLANET [3]

Explorer: Minesweeper SWATH with a length of 25 m from Aberking & Rasmussen shipyard in Germany. The 25 meter long Swath is used by the German navy. It is operating in the North Sea since 2004 after successfully passed strict tests on the behavior at sea waves because it has sensitive radio control equipment for demining .

HSSS 1500 – HSSS 900: These two Hybrid - semi SWATH serve routes between Europe and England with great success. They offer extremely high speeds, excellent behavior in waves and are the finest examples of commercial application of SWATH.

SHIP NAME	HSSS 1500 – STENA EXPLORER	HSSS 900 - STENA
SHIP TYPE	Pass./Car Ferry Liner	Pass./Car Ferry Liner
LENGTH, OA [m]	126.60	88.00
LENGTH, BP [m]	107.50	
BEAM, WL/OA [m]	-/40	-/30
LOA/BOA	3.17	2.93
DEPTH [m]	12.50	12.60
DRAFT [m]	4.50	3.70
STRUT TYPE	S I N G L E	S I N G L E
LOWER HULL TYPE	Hybrid -Semi SWATH	Hybrid -Semi SWATH
HULL MATERIAL	AL	AE
DISPLACEMENT [tons]	1500	450
POWER [SHP]	100.000	46.260
PROPELLER TYPE	4 KaMeWa Waterjets	2 KaMeWa Waterjets
SPEED [knots]	43 (top)	40
FROUDE	0.68	0.75
CAPACITY / DWT/ PAYLOAD	1500/375	900/210
COMPLETION DATE	1995	1996
DESIGNER/BUILDER	Finn yards, Finland / STENA	Westamarin, Norway / STENA
OWNER/OPERATOR	STENA	STENA

Table 3.1 Characteristics of HSSS 1500- STENA EXPLORER and HSSS 900- STENA [3]

Finally we should also mention the highly successful and internationally recognized Swath designs made in the past from the "ship's design" laboratory of EMP. It is about the passenger 'Aegean Queen', the research vessel 'SMURV' and the speedboat containership 'SMUCC'. Ships have the following characteristics:

SHIP NAME SHIP TYPE	AEGEAN QUEEN Pass./Car Ferry Liner	SMUCC FEEDER CONTAINERSHIP	SMURV Research Vessel
LENGTH, OA [m]	51.50	51.50	39.00
LENGTH, BP [m]	50.00	50.00	33.00
BEAM, WL/OA [m]	25.00/31.70	25.00/31.70	18.00
LOA/BOA	1.64	1.64	2.17
DEPTH [m]	9.50	9.50	11.20
DRAFT [m]	5.00	5.00	4.50
STRUT TYPE	SINGLE	SINGLE	SINGLE
LOWER HULL TYPE	bottle like	bottle like	bone like
HULL MATERIAL	STEEL/AL	STEEL	STEEL/AL
DISPLACEMENT [tons]	1060	1060	610
POWER [SHP]	20.000	14.800/29.600	9.500
PROPELLER TYPE	C P P	C P P	C P P
SPEED [Kn]	3.0	26/36	22(top)
FROUDE	0.70	0.60/0.84	0.63
CAPACITY / DWT/PAYLOAD	800 Pass. / 88 Cars /225 tons DWT	60 TEU Containers/ 427 - 497 tons DWT	90 tons payload
COMPLETION DATE	1989	1994	1992
DESIGNER/BUILDER	NTUA/	NTUA/-	NTUA-EUROMAR/-
OWNER/OPERATOR			

Table 3.2 Characteristics of Aegean Queen, SMUCC FEEDER and SMURV [3]

4. MICHLET

Before MICHLET is presented and explained the way it works it is wise to mention some things about components of resistance and thin ship theory.

4.1 Components of ship's resistance

When a ship is moving through water there will be forces opposing the motion. The total resistance, R_t , of a ship is defined as the force needed to tow the ship at a constant speed and it can be divided into subcomponents in different ways (Figure below).

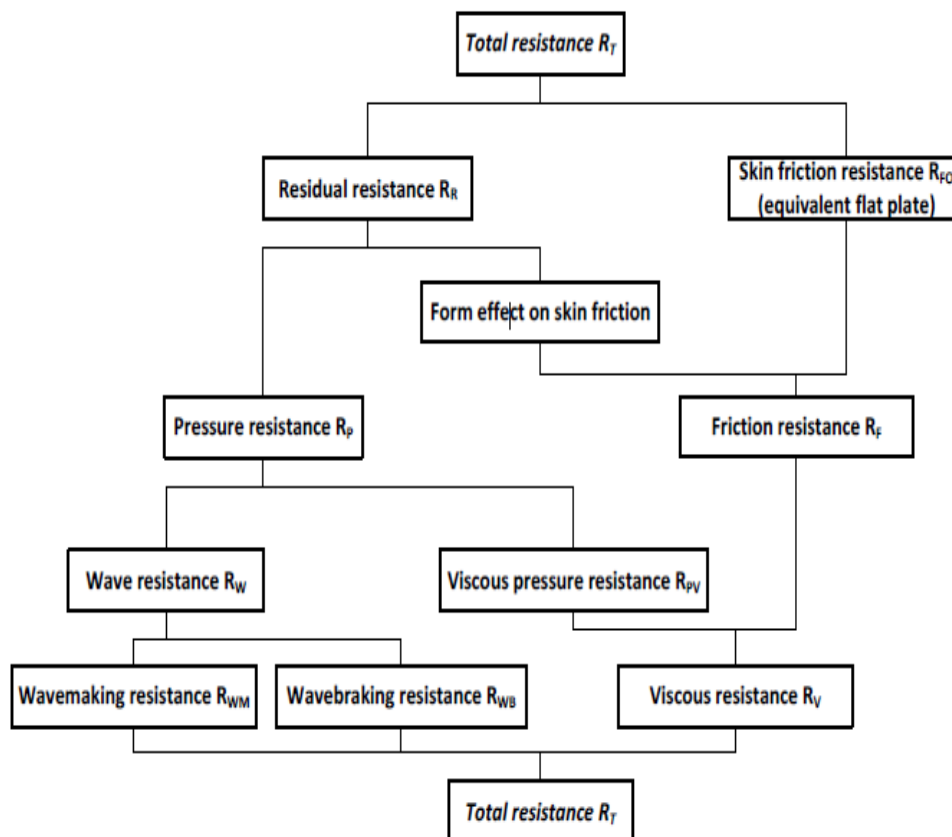


Figure 4.1 :Components of resistance [14]

One way is to divide it into skin friction resistance R_{FO} , and residuary resistance R_R , which includes all components related to the three dimensional form of the ship and wave-making resistance. It can also be divided according to physical phenomena into viscous resistance, R_V , and wave resistance, R_W .

Further on, the viscous resistance consists of the frictional and pressure component. So the elaborated subdivision looks as follow:

The total resistance of a ship can be divided into three main parts [10]:

- wave resistance
- frictional resistance
- viscous pressure resistance

For each of the parts of the total resistance different effects are primarily causative. Wave resistance depends on the lost energy due to the wave production of the ship as a partially submerged body disturbing the free surface of a fluid, thus waves are created due to water particles being removed from their equilibrium position. Secondly, sheer stresses between parts of the fluid with different velocities are the reason for the frictional resistance. These sheer stresses occur in the area close to the wall, within the boundary layer. Directly at the surface of the body, or at a wall, the fluids velocity is equal to zero, but at the outer end of the boundary layer the velocity is equal 99% of the undisturbed fluid velocity. Viscous pressure resistance consists of effects like flow separation and turbulence, which are mainly appearing in areas where the velocity of the fluid is decreasing and therewith the thickness of the boundary layers is increasing.

4.2 Thin ship theory

This section was taken verbatim from E.O. Tuck (1987).

The thin ship theory of Michell represents the ship by a centre-plane source distribution proportional to its longitudinal rate of change of thickness (local beam). The only requirement for its validity is that that quantity be small. Hence the theory applies as well to submerged as surface piercing bodies.

Another way of putting this argument is that slender bodies are also thin. To a certain extent, slender body theory is superfluous. Even where a body looks more slender than thin, it is unlikely that (to leading order) modeling it by a centre-line singularity achieves more than modeling it by a centre-plane singularity.

Indeed, there are examples where one can prove that this is the case, and wave resistance is one of them. Thus, for surface-piercing ships, Vossers (1962) and I (Tuck 1963) derived the slender ship wave resistance formula laboriously from first principles, but Maruo (1962) was able to show very simply that it could be obtained from Michell's thin-ship formula by letting the draft go to zero.

So why use slender body theory at all. This is a good question to which there could be several answers. One is to dispute the evidence that thin ship theory subsumes slender body theory. Since there is no exact formula for wave resistance, one cannot say from the theoretical point of view which is the better approximation. So the slender body result (even though it is an “approximation” to the Michell result) could perhaps be more accurate as an estimate of the true wave resistance. Many doubt this very much. There are elements in the Michell theory (such as exponential decay with depth) that are absent in the slender body theory, and it would be better if would be present – although some people might assert the opposite. Anyway, the evidence of comparison with experiment seems to favour Michell.

The thin and slender body theories only agree to leading order in slenderness. If one expects to improve upon either theory by including second-order contributions, there is a case for picking the more appropriate model, but there have been very few attempts at second-order theories, and no successes as far it is known. This is certainly irrelevant to the present review, since nothing second order has been proposed for SWATHs, or should be.

The remaining argument for slender body theory is that it is a valuable computational simplification. That is, if the body is indeed slender as well as thin, we might as well make use of that fact in some way. Certainly there is one immediate simplification in the data preparation, since the shape of cross section is irrelevant in slender body theory, but input to thin ship theory. It is believed this is such a minor matter, hence will be ignored. I feel that the composite “slender body and thin strut” approach adopted by “Salvesen et al” is hardly less difficult to implement than a full thin-body approach, and, when the third (controversial) body-strut source distribution is also put in, any advantage of simplicity disappears.

4.3 The code MICHLET

This section was taken verbatim from the Michlet manual.

MICHLET is a computer workbench, that was created by Mr. L. Lazauskas, and can be used for investigations into some aspects of ship hydrodynamics. Although it is not a ship design program, MICHLET can be used for preliminary design work such as estimating the resistance, wave elevation patterns and bottom pressure signatures of mono-hulls, multi-hulls and submarines.

MICHLET calculates the total (viscous + wave) resistance and far-field wave elevations of thin monohulls and multihulls using the ship thin theory.

MICHLET is not an easy program for newcomers to hull design. A familiarity with the first few chapters of an introductory Naval Architecture text would be useful. There are several good WWW articles that might serve as sufficient introduction.

There are many opportunities to waste a lot of computer time and human effort with MICHLET. Incorrect specification of parameters in the input file could result in completely useless output and it is imperative that users gain familiarity with the input file and its nuances.

4.4 Basic considerations

This section was taken verbatim from the Michlet manual.
Co-ordinate System:

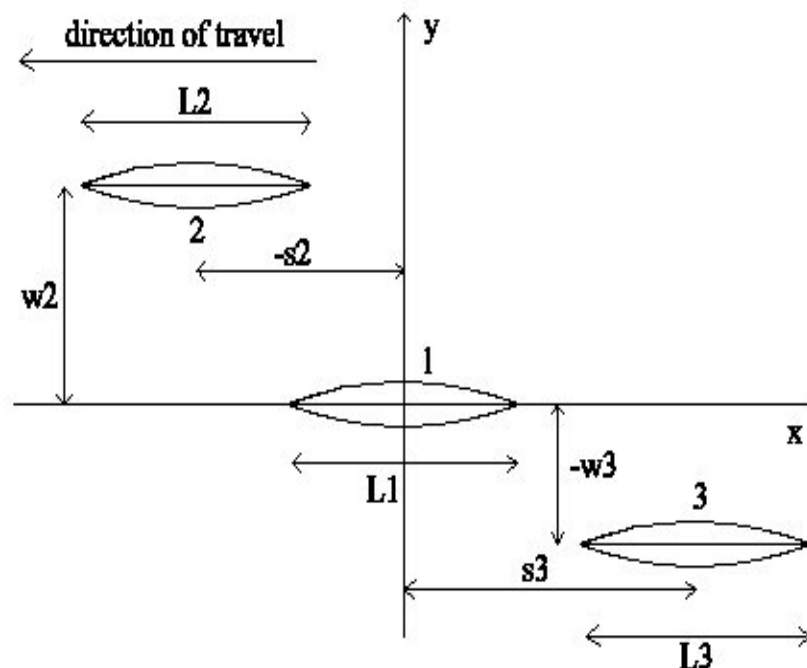


Figure 4.2: Co-ordinate system for general multihulls[22]

The co-ordinate system and hull parameters are shown in Figure 1. X is positive astern, y is positive to starboard, and z is positive upwards. The undisturbed water surface is the plane $z = 0$. Hull centre-planes are parallel to the x-axis. The shapes of the hulls can be different from each other, however, they are assumed to be symmetric with respect to their own centre-planes. The overall vessel need not to be laterally symmetric.

Each hull has a nominal centre point ($x = s_i$, $y = w_i$, $z = 0$). The centre of the main hull, hull 1, is always located at the origin. The centre of all other hulls are then measured relative to the main hull, i.e. to hull 1 s_i is the longitudinal separation distance of the i^{th} hull measured relative to the first hull and is defined as positive astern. Hence by definition, $s_1 = 0$. w_i is the lateral separation distance of the i^{th} hull relative to the first hull (positive to starboard). Hence by definition, $w_1 = 0$. For example, in the arrangement shown in Figure1, s_2 has a negative value, and w_2 is positive. For hull 3, s_3 is negative and w_3 is positive.

4.5 Calculation of resistance

This section was taken verbatim from the Michlet manual.

MICHLET calculates a variety of resistance components. Wave resistance is estimated using Michell's thin ship theory augmented for (among others) transom stern effects and boundary layer displacement thickness effects.

For mono-hulls and for the individual hulls of a multihull, output includes:

Rh :	Hydrostatic resistance on transom stern
Rf :	Skin friction
Rwtrans :	Wave resistance of transverse wave system
Rwdiv :	Wave resistance of diverging wave system
Rw =	$Rwtrans + Rwdiv$
Rform :	Form drag
Rt :	Total resistance
Rr :	Residual resistance = $Rt - Rf$

Note that for supercritical depth-based Froude numbers, $Rwtrans$ is always equal to zero: there are no transverse waves!

As well as the components defined above, MICHLET also calculates the following interference resistance components:

Rwtinter :	Interference resistance of transverse waves
Rwdinter :	Interference resistance of diverging waves
Rwinter =	$Rwtinter + Rwdinter$

Note that for these interference components, positive values mean no beneficial interference, (i.e. resistance is increased) negative values mean that there is some beneficial wave cancellation (i.e. resistance is decreased).

4.6 Input files

This section was taken verbatim from the Michlet manual.

MICHLET uses plain text files for input and output. In addition, some plots are saved as pcx graphic files. Text files can be read and saved using plain text

editors. Please note that you cannot use word-processors (for example, Word) to edit MICHLET input files, unless you force them to save files in ASCII format.

There are many shareware graphics programs that can be used to view pcx files and to convert them to other graphic formats if necessary.

When MICHLET is run, it reads in a file named in.mlt and clears all output files in the directory where the MICHLET executable files reside. If you do not save previous output, old results will be overwritten and lost.

in.mlt

Initial input to MICHLET is via the plain text file called in.mlt.

At this stage, it is probably a good idea to have an example in.mlt file loaded into your text editor, or to have a printout of one handy.

Comments can be placed in the file by preceding them with the # symbol, which should appear in the first column of the line. Comments should be no longer than 79 characters, and should not be placed within a column of numbers.

If errors are encountered while the in.mlt file is being read, a message will be displayed on-screen and also written to the out.mlt file before the program terminates. Tracking down errors in the in.mlt file can be a little tricky. Sometimes an error in one input line will cause an error to be reported for a line further on in the in.mlt file. If an error is encountered, and no immediate reason for the error can be discerned, check a few lines back in the file to see if something was improperly specified.

4.7 General input files

At this point it is necessary to make clear that this section was taken again verbatim from the Michlet manual.

The Input File Type and Input File Subtype are used to control the types of input file that can be used. Similarly, Output File Type and Output File Subtype are used to control the types of output files that are generated.

Course Particulars

The Course Particulars parameter is reserved for future enhancements.

Number of Vessels

The number of hulls for the vessel or ensemble must be an integer equal to 1, 2, 3, 4 or 5.

Fluid Properties

The gravitational acceleration (in ms^{-2}) should be entered as a decimal. Most MICHLET examples use a value of $g = 9.80665 \text{ ms}^{-2}$.

Water density (in kgm^{-3}) must be entered as a decimal. Most example files use a value of 1025.9 kgm^{-3} , the density of sea water at 15° , or 999.0 kgm^{-3} , the density of fresh water at 15° . Water kinematic viscosity (in $\text{m}^2\text{s}^{-1} \times 10^{-6}$) must be entered as a decimal. Most example files use a value of 1.18831 (sea water at 15°), or 1.13902 (fresh water at 15°). Note the units that are used.

The (non-dimensional) base eddy kinematic viscosity, v_B , must be entered as a decimal. Most example files use a value of 10.0. This quantity, which is not a property of water alone, depends on the nature of a particular flow.

The main effect of eddy viscosity is to damp high frequency waves. However, if a wave pattern seems to be corrupted by spurious, very high frequency waves, it could be because the value for N_θ is too small. First try increasing the value of N_θ then, if that doesn't fix the problem (and if it is actually a problem) increase the size of the base eddy viscosity.

The eddy kinematic viscosity, v_T , is calculated according to the formula:

$$v_T = v + LUv_B \quad (1)$$

where L is the length of the vessel, U is the ship speed, and v is the kinematic viscosity of water.

Water depth (in metres) must be entered as a decimal. To simulate infinite depth use a large value (e.g. 10000.0m). You must ensure that hulls (in their squatted attitudes) do not run aground. The next four parameters are not used in any calculations in this version, however the program expects appropriate values to be present.

Air density (in kgm^{-3}) must be entered as a decimal. Most example files use a value of 1.26 kgm^{-3} . Air kinematic viscosity (in $\text{m}^2\text{s}^{-1} \times 10^{-6}$) must be entered as a decimal. Most example files use a value of 14.4.

Wind speed (in ms^{-1}) must be entered as a decimal.

Wind direction (degrees) must be entered as a decimal. The convention is that 0° corresponds to a head wind; 180° signifies a tail wind.

Ship Speed Range

The next three parameters specify the speeds (in ms^{-1}) at which to calculate the resistance and wave elevations, via the minimum speed, U_{\min} , the maximum speed, U_{\max} , and the number of speeds, N_U .

The minimum speed and maximum speed must be decimals. N_U must be an integer greater than or equal to 2 and less than or equal to 101.

Leeway

The Leeway parameter is reserved for future enhancements.

Number of Stations and Waterlines

The number of stations, N_x , used to represent the hull surface must be an odd integer greater than or equal to 5 and less than or equal to 81. The number of

waterlines, N_z , must be an odd integer greater than or equal to 5 and less than or equal to 81. The actual bow and stern ends are counted as stations.

Ship Loading Type

The Ship Loading Type determines the formula to be used in the calculation of the distance from the baseline to the centre of gravity of the ship (i.e KG, in naval architectural parlance). In this version of MICHLET, the only allowable value is 3, which requires three comma-separated Ship Loading Formula Parameters to be specified on a separate line. Suppose that these three parameters are a,b and c. The three-parameter formula used in this version of MICHLET is:

$$KGOA = a(TOA + bLOA^c) \quad (2)$$

Where TOA is the maximum draft, and LOA is the overall length of the ship. For monohulls TOA and LOA are just the draft and length of the hull, respectively. If you are unsure of where the centre of gravity is located for your vessel, a reasonable rough estimate is the maximum draft. In this case, use the following line in the input file : 1.0,0.0,0.0

Remember to take into account the fact that you have used a rough estimate when interpreting your results.

Wave Resistance Parameters

N_θ is used in the calculation of the wave integrals, e.g. see Tuck and Lazauskas . It must be an even integer greater than or equal to 10 and less than or equal to 4096. For reasonable accuracy (2-3 figures) of wave resistance calculations N_θ should be set to at least 160 for mono-hulls, 320 for double-hulls, 640 for tri-hulls, 960 for tetra-hulls, and 1280 for penta-hulls. The value should be set to larger values for wave elevation calculations far from the ship. Note that some example files distributed with MICHLET use smaller values than these recommendations. The purpose of the examples is to provide quick demonstrations of certain features. Accuracy is of secondary importance.

Before embarking on your own design problem, check that N_θ is large enough to ensure accurate solutions, but not too large so that run times are unbearably long.

Before calculating wave resistance and other ship wave quantities, MICHLET first adds an estimate of the boundary layer displacement thickness to the hull offsets. In general, the effect of the boundary layer is small, except for small model-sized hulls. For larger ships travelling at high speeds the effect is negligible.

The default in MICHLET is to include boundary layer effects, and these can increase execution time. To perform calculations without boundary layer effects use a negative value for N_θ . For example, if the value

-160 is input, this will cause MICHLET to use 160 intervals of θ in all wave calculations and the boundary layer displacement thickness will not be added to the hull offsets.

Viscous Resistance

Skin-friction

Choices for the skin-friction method are:

- 0 : None
- 1 : ITTC 1957
- 2 : Grigson's algorithm

Form factors

Form factors can be applied separately to the viscous drag component and to the wave drag component.

Choices for the viscous form factor method are:

- 0 : None
- 3 : Dual

The viscous drag form factor can be useful for analyzing (and designing for) the effects of hull fouling. For example, if we assume (by rule of thumb) that there is a 0.1% increase in friction resistance per day, then after 6 months we should make an allowance of approximately 18% beyond the usual ITTC friction. In this case, use a value of 1.18 for the viscous form factor.

It is important to note that the ITTC line is not a skin friction line. The ITTC line is considered to be a correlation line and as such it contains some allowance for three dimensional (i.e. form) effects. If further form effects are included, there is a danger of double-counting. In some cases, (e.g. correlating experiments and computer estimates) this will not necessarily be a problem. The dual viscous drag form factor can be used when you want to apply a form factor to the wave resistance as well as to the skin-friction.

Sea-Bed Pressure Signatures

Pressures exerted by the vessel onto the bottom of the ocean can stir up sediments and trigger some types of anti-ship mines.

Choices for the pressure signature method are:

- 0 : None
- 1 : Slender body approximation due to E.O. Tuck. Valid only for slender vessels and for sub-critical depth-based Froude numbers (i.e. $F_h < 1$).

Wave Pattern Domains

Wave elevations can be calculated over two differently-shaped domains.

In Figure 2, the co-ordinate origin is at the centre of Hull 1 (refer back to Figure 1). The sectorial patch on the left of Figure 9 requires five parameters. R_0 and R_1 (both decimals greater than 0.0) determine the (radial) extent of the wave elevation patch. The value of β determines the angular extent of the patch either side of the track of hull 1. The number of radial nodes, N_R and the number of beta nodes, N_β , (both integers between 2 and 200, inclusive) determine the fineness of the grid for the calculation of wave elevations. A value of 100 for both parameters gives reasonable results for reasonable running times.

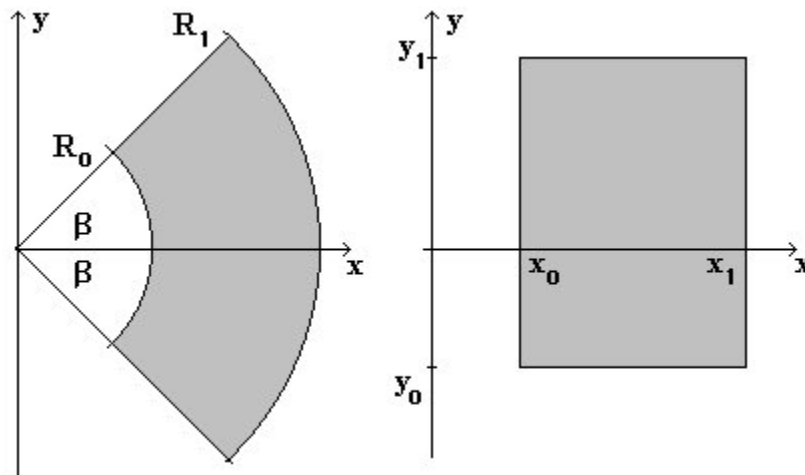


Figure 4.3: Wave elevation contour domains[22]

Hull Offset Data

It does not matter whether the offsets describing each hull are in dimensional or non-dimensional form. MICHLET will automatically scale the offsets to the individual hull displacements. It is very important to note that all hull offsets input to MICHLET, or output by MICHLET, are for the underwater portion of the hull only. You can, however, specify a value for the sinkage to raise or lower

the hull with respect to the undisturbed free surface.

All offsets at the bow (the first row) must be equal to zero (decimal). Stern offsets (the last row) may all be zero (no transom) or some non-zero if there is a transom stern of a shape determined by the non-zero offsets. The number of rows (cross-sections) and columns (waterlines) in the offset data must be the same as the number of stations and waterlines specified earlier. Offsets are separated by commas, and there is no comma at the end of each row.

Hull offsets in comma-separated format can also be read from file. For example, if the input line for the first hull contains only the value -1, then MICHLET will read offsets from the file useroff1.csv. If the offset input line for

the second hull was specified in the same way, MICHLET would read offsets from the file useroff2.csv. Similarly for hulls 3, 4 and 5.

Hull Geometry

Displacement volume, hull length and draft

Following the offset table for the first hull, the displacement volume, length and draft must be specified.

Demihull separation distances

After the draft has been specified, the longitudinal and lateral separation distances (relative to the first hull) must be specified. For a monohull, these will both be set to 0.0, irrespective of the values entered by the user (refer to Figure 1).

Loading type

The Loading Type determines the formula to be used in the calculation of the distance from the baseline to the centre of gravity. The method to be used is identical to that used for the Ship Loading Type. Here though, the loading applies to the hulls individually. For a multihull, the individual hulls can be loaded using one formula, and the KG of the ensemble as a whole can be calculated using another formula. This can lead to interesting results during the optimization of multi-hulls.

Trim and sinkage

Trim must be specified in degrees (positive bow up) and must lie between -10° and 10° . Sinkage is positive when draft is increased, negative when the hull rises out of the water.

Appendages

The Number of Appendages should be left as 0 in the present version of MICHLET.

Other Particulars

The Other Particulars field is reserved for special applications and should be left as 0 in this version of MICHLET.

Multihull Geometry

If the number of hulls was set as 1 earlier in the in.mlt file, any further lines in the input file will not be read. If the number of hulls is 2 or more, then the details of the second hull, and the displacement volume, hull length, and hull draft, etc of the second hull are also required. Similarly, for the third, fourth and fifth hulls.

5. CASE STUDY – DESIGN AND OPTIMIZATION OF AQ3

5.1 DESIGN OF AQ3

5.1.1 Parametric model design

The design of such a vessel is based on economical and technical demands of the ship owner, physical restrictions, regulations about functionality and safety the new technological evolutions. The engineer must couple all the above to bring a result that is economical optimized with a productive exploit of the initial fund.

This coupling becomes even more difficult when the vessel is a relatively new type and basic elements are not easily provided. The design procedure though is again the known helicoidal curve. Since it is a parametric model FRIENDSHIP FRAMEWORK is one of the best software that you can work with. Something that needs to be mentioned here is that the designing procedure consists of many steps. In order to come up with an innovative model these steps must be included at a loop so all imperfections should be eliminated.

Now at the beginning a parametric conventional model was created within the GUI interface of FRAMEWORK. This was composed by three parts.

GONDOLA

The first part was the gondola. Gondola is the lower hull of the ship that holds most of the displacement and it is fully submerged under the free surface of the sea. It is assumed that the vessel has a standard form with the following characteristics:

- Lower hulls are of circular cross section.
- Lower hulls consist of ellipsoidal nose, parallel midbody and parabolic tail whose lengths can be varied.
- Lower hull axis are horizontal parallel and symmetric to the centerplane.

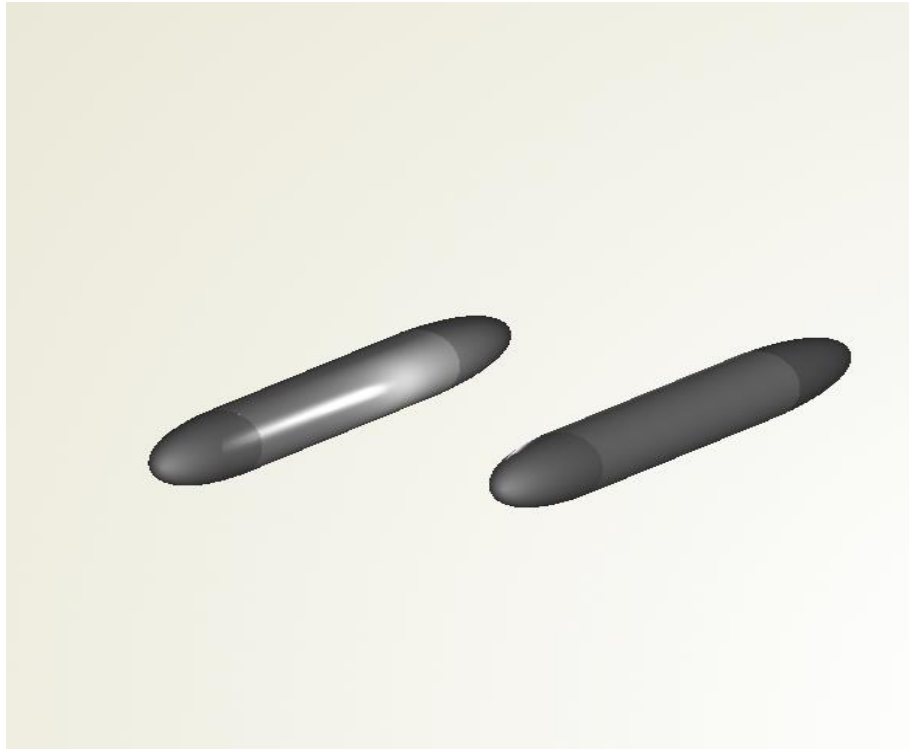


Figure 5.1 Gondola

STRUT

The second part is the strut. This connects gondola with the deck. Struts must be hydrodynamic optimized so that the wave resistance must be as less as possible. Again some assumptions must be made and they are as follows:

- Struts lie in vertical planes , single strut per hull concept.
- Strut profiles parabolic nose ,parallel midbody and parabolic tail. Their lengths can be varied but in a standard rate of gondolas lengths.

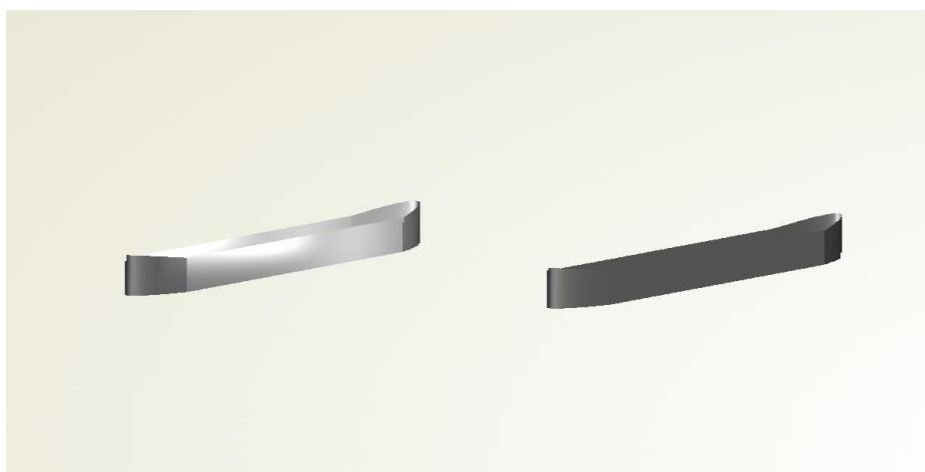


Figure 5.2 Strut

BOX

The third part is the box. It is the deck of the vessel where passengers are accommodated. It was not studied in depth because it does not offer to the hydrodynamic resistance of the ship, therefore it was not optimized and design only for aesthetic purposes.

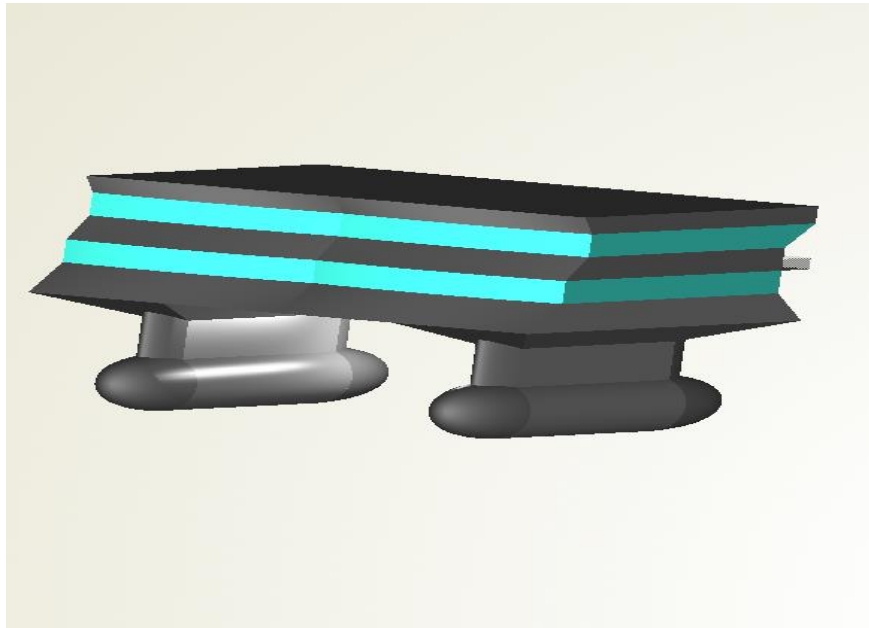


Figure 5.3 Swath(with box)

5.1.2 INITIAL PARAMETERS

So on the basis of these geometrical characteristics the wetted part of the swath part can be described in the terms of the following parameters:

- Lengthgondola= lower hull length
- Lgn=lower hull nose length
- Lgt= lower hull tail length
- Rad= lower hull radius
- Draft= lower hull draft
- Latsep= half distance between lower hulls
- Bstrut= Strut beam
- Lstr_n=strut nose length
- Lstr_t=strut tail length

So this was the initial (conventional as referred above) model. With that model we could make a global optimization. But it was missing a serious parameter that was not included so that we could not address a local form optimization. A parameter that could express the displacement distribution. That was the reason that the previous model was not sufficient. So a new model had to be created that could include this parameter. In order to include the aforementioned parameter feature programming was a must. FRIENDSHIP FRAMEWORK has a kind of surface that called metasurface. This is created by a section and a guide curve. Firstly the section is created then the curve and finally the metasurface is created as the section is guided by the guide curve. With this way we do not have a parallel midbody as we mentioned before and we have a curve that when we change it, the displacement distribution can be varied. The name of the last parameter is radmid and we include it at optimization.

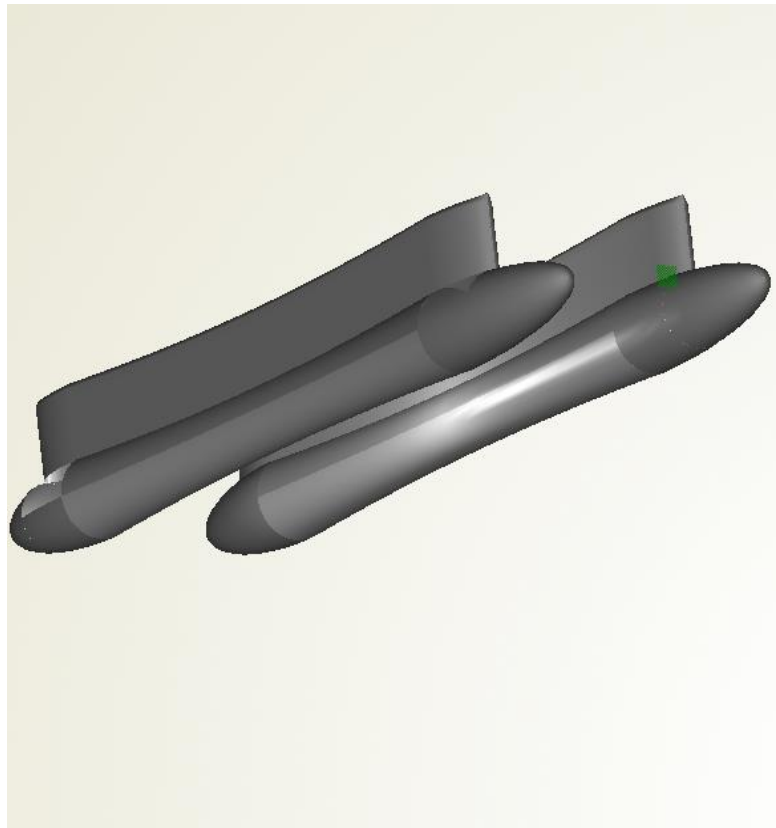


Figure 5.4 Model without a parallel midbody

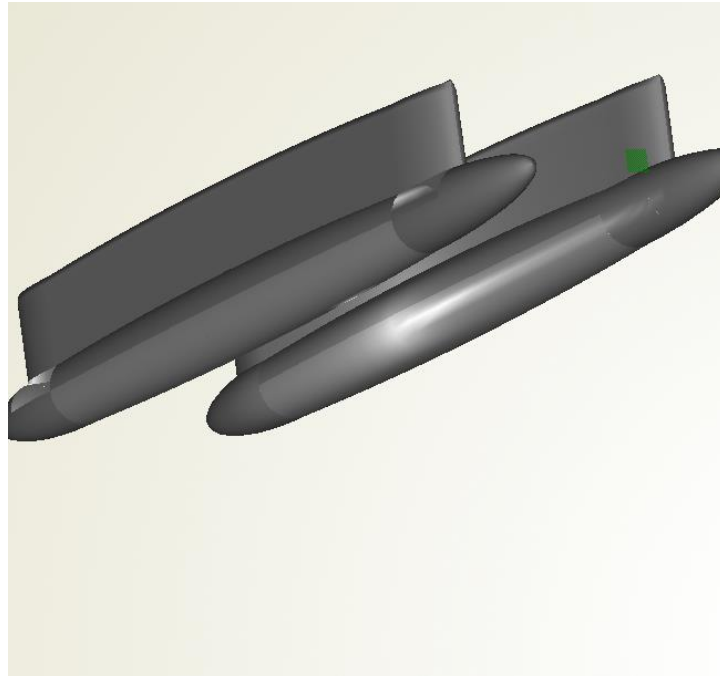


Figure 5.4 Model without a parallel midbody

In this point we have to mention that from the above parameters we have to remove Rad from independent and to make it dependent. This is because when one or more parameters varies, the displacement changes. But we need a constant displacement of 1000t. So we have to express the volume analytically and find the Rad that leads to the desired displacement. This procedure must be done automatically when any of the parameters changes, so an algorithm is created within the FRIENDSHIP FRAMEWORK to do this job.

As for the Draft parameter in order to validate the results of Aegean Queen we had to keep it constant too at 5m. The only constrain was the following: At the operation of the vessel displacement changes are expected to be made. To be at the safe side an extreme case was considered so that if we do not face problems at it we will be confident that no problems should be turn up. So a 10 percent change to the initial displacement was considered and the draft was checked. With the Awl existed there was no problem at the draft that lied above 4m.

5.1.3 FINAL PARAMETERS

After all the above again on the basis of these geometrical characteristics the wetted part of the swath part can be described in the terms of the following parameters:

- Lengthgondola= lower hull length
- Lgn=lower hull nose length
- Lgt= lower hull tail length
- Radmid= Displacement distribution parameter
- Latsep= half distance between lower hulls
- Bstrut= Strut beam
- Lstr_n=strut nose length
- Lstr_t=strut tail length

5.2 OPTIMISATION PROCEDURE

To investigate and develop innovative solutions, the designer requires a tool that does not enforce detailed definition and allows easy reconfiguration of arrangements and systems. Looking at the case of a innovative Swath, a CAE environment(FRIENDSHIP FRAMEWORK) is established to examine key measures of merit for a considerable numbers of variants simultaneously: Geometry, capacity, and hydrodynamics were computed by means of simulation codes.

In the case of this diploma thesis, the definition “optimization model” implies a whole system that is built up by several subsystems in order to approach the design of a novel Swath in a holistic way. The target of this holistic approach is to create a fully parametric model able to vary in a wide range of dimensions and form parameters and to return a large number of valuable information predicting numerous features and properties of the subject. Further on an optimization process takes place in several steps based on the collected data, obtained from a large number of design variants.

Based on simulation driven design the designer is able to handle as many issues as possible simultaneously. Obviously this is not a trivial task, therefore a number of assumptions have to be made and the design problem has to be viewed by specific perspectives, in order to define the boundaries and the targets of the investigation. The main idea is to set up a large flexible model that is able to predict automatically and accurately a large number of properties regarding geometry, resistance and capacity. Therefore a number of specialized tools have been integrated that allow a thorough insight and increase the efficiency of the results. Thus, a numerous designs are achieved quickly and accurately that enable comparisons and optimization.

5.3 HYDROSTATICS

One of the main steps is the hydrostatics calculation. The calculation of the hydrostatic quantities of every design is realized within the FRIENDSHIP-FRAMEWORK based on an embedded computation for a given configuration. The configuration receives as input the hull in form of offset groups through a mechanism of automated adaption. Usually 3-4 offset-groups are included regarding the complexity of the design. In our case only one offset group was enough since the geometry is not so complex. But the density of the offsets was changed regarding the complexity of its parts along the vessel. Additionally, the sinkage and heel of the vessel are required input as well. In this case no heel is considered.

When the configuration is ready the FHydroComputation is triggered which returns a table with all basic hydrostatic quantities. Further properties that derive from hydrostatic calculation such as coefficients KM, BM etc are manually defined and are automatically updated for every computation.

An illustration of SAC and of the submerged body in the form of section is also given, pointing out the position of LCB and LCF. Another important quantity is the estimation of the wetted surface, which is also needed later on when MICHLET is called in the optimization problem. For this estimation an appropriate feature, embedded in FRIENDSHIP-FRAMEWORK is used. This feature executes the computation of the wetted surface for a given section group at specific draft. For this feature a section group of 90 sections that derive from the hull body, is utilized, returning an accurate wetted surface estimation. Last but not least is the waterplane area A_{wl} which is a very significant quantity for the integrity of the draft as mentioned before. In the following pictures are presented some illustrations of the hydrostatic properties and the SAC.

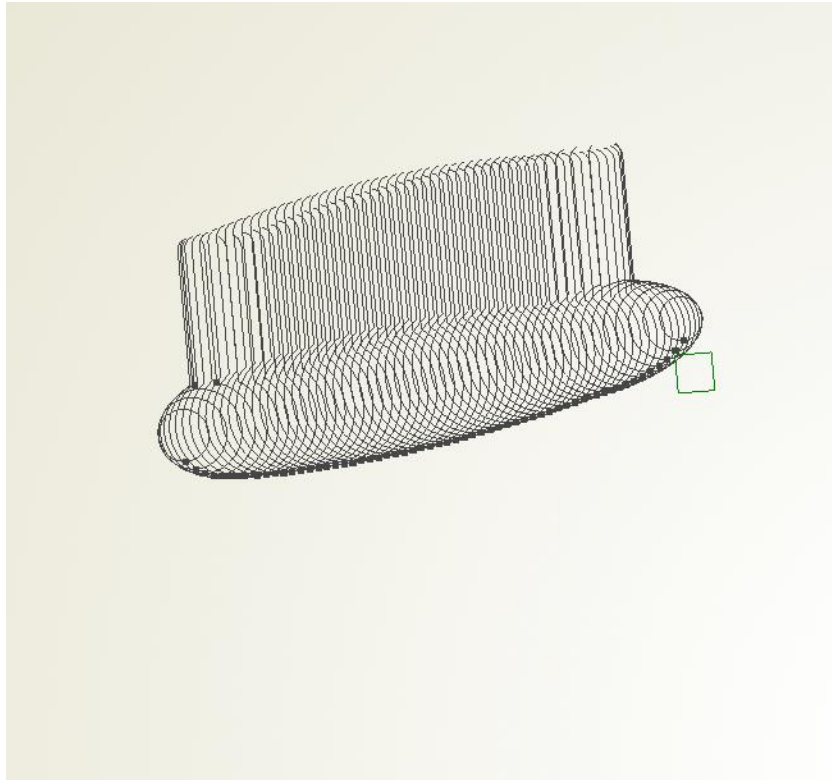


Figure 5.5 Sections of single hull

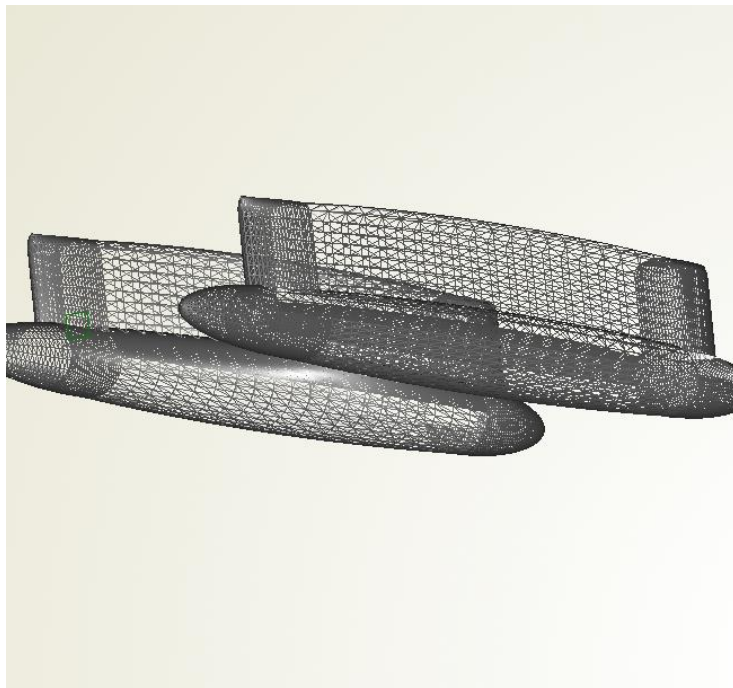


Figure 5.6 Offset density



Figure 5.7 SAC

5.4 MICHLET INTEGRATION

After the parametric model was created and the hydrostatics configuration and computation were embedded, a resistance code had to be inserted in order retrieve evaluations. So MICHLET coupling had to be accomplished.

FRIENDSHIP FRAMEWORK has some connections available with external software like SHIPFLOW Hydromax, Neptune etc. But unfortunately it does not have an available connection with MICHLET. So a new generic integration(or “new software connector” as it was renamed at the new version of FRIENDSHIP FRAMEWORK) had to be set up. This integration is generally not too complex. Just a definition, a configuration , a computation, and a connector that analyses input files and geometry and returns the output results. In this case though, there was a serious problem that had to be solved. MICHLET is an executable that needs user interference in order to extract the results. Some specific buttons must be pressed with a time delay because of the intermediate calculations. So a batch mode of MICHLET was needed. At a contact with the designer of MICHLET I was informed that there was not a batch mode of this code available. So a script in visual basic was created in order to overcome this difficulty. As a result a FRIENDSHIP-MICHLET integration was feasible with the support of this visual basic script inside a batch file. Some basic photos are illustrated here:

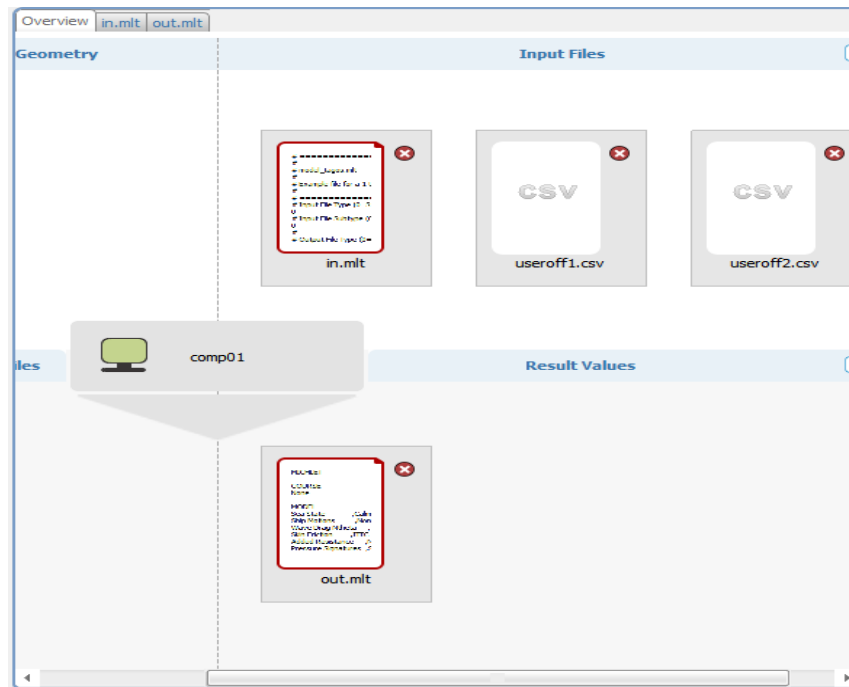


Figure 5.8 Connector

Template Name: in.mlt

Overview | in.mlt | out.mlt

```
# Input File Subtype (0=Standard)
0
# ===== OUTPUT FILE TYPE AND SUBTYPE =====
# Output File Type (0=Standard)
0
# Output File Subtype (0=Standard)
0
# ===== COURSE AND VESSEL TYPE =====
# Course Particulars (0=None)
0
# Number of Hulls (1, 2, ..., or 5)
2
# ===== PHYSICAL QUANTITIES =====
# Gravitational Acceleration (m/sec/sec) (min 9.6, max 9.9)
9.80665
# ===== WATER PROPERTIES =====
# Water Density (kg/cubic metre) (min 995.0, max 1030.0)
1025.0
# Water Kin. Viscosity (sq. m/sec * 10^-6) (min 0.5, max 2.0)
1.141
# Base Eddy Kin. Viscosity (non-dimensional, min 1.0)
10.0
# Water Depth (metres) (max=10000.0)
10000.0
# ===== AIR PROPERTIES =====
# Air Density (kg/cubic metre) (min 0.9, max 2.0)
1.226
# Air Kin. Viscosity (sq. m/sec * 10^-6) (min 10.0, max 20.0)
14.4
# Wind Speed (m/sec)
0.0
# Wind Direction (degrees)
0.0
# ===== CALCULATION PARAMETERS =====
# Minimum Speed (m/sec) (min 0.01, max 51.9)
6
# Maximum Speed (m/sec) (max 52.0)
20
# Number of Speeds (min 2, max 101)
15
```

General

Template Name: out.mlt

Column Separator

Spaces & Tabs: ☒ X

Regular Expression:

Values

Name: +

Type: FDouble

Line: -225

Column: 2

Anchor String:

Occurrence: First

Results Preview

	Value	Type
R15_5kn	152.302	FDouble
R31_Kn	640.877	FDouble

File

8.000000,	88.063753,	152.302396
9.000000,	123.123881,	203.167067
10.000000,	287.032769,	384.491690
11.000000,	412.709527,	529.175468
12.000000,	467.863761,	604.910323
13.000000,	475.380416,	634.565317
14.000000,	458.625254,	641.491814
15.000000,	433.187277,	641.265662
16.000000,	406.068366,	640.876651
17.000000,	382.869779,	645.914854
18.000000,	361.297160,	654.075523
19.000000,	342.011423,	666.009873
20.000000,	327.105412,	683.801659

HULL DETAILS

Number of stations: 63

Number of waterlines: 9

Section Areas (m^2)

x/Lpp,	Hull 1,	Hull 2
0.0000,	0.000000,	0.000000
0.0161,	1.546746,	1.546746
0.0823,	2.562253,	2.562253
0.0484,	3.198227,	3.198227
0.0645,	5.104868,	5.104868
0.0806,	6.286785,	6.286785
0.0968,	7.100738,	7.100738
0.1129,	7.713572,	7.713572
0.1290,	9.438811,	9.438811
0.1452,	10.580843,	10.580843
0.1613,	11.270098,	11.270098
0.1774,	11.688323,	11.688323
0.1935,	11.887384,	11.887384
0.2097,	11.912005,	11.912005
0.2258,	11.912005,	11.912005
0.2419,	11.912005,	11.912005
0.2581,	11.912005,	11.912005
0.2742,	11.912005,	11.912005
0.2903,	11.912005,	11.912005

Figure 5.9 In and out files processing by FRIENDSHIP

After the integration was achieved the input files were connected to the parameters and the output files with the evaluations in order to automate the procedure. The last step after all these was to give the geometry to MICHLET. Back again to feature programming an algorithm was needed to be created and to extract the geometry from FRIENDSHIP, whenever a little change is made, to the MICHLET input files.

5.5 EVALUATIONS OF THE OPTIMIZATION

Throughout the investigation a basic structure regarding the optimization process occurs in two stages as listed below:

- Automated and systematic exploration of the multidimensional design space with analysis sequences for more than 500 designs.
- Automated deterministic detailed optimization of best selected range from exploration, with multi-objective genetic algorithms, utilizing many form parameters.

At the very beginning, the design engine called, Exhaustive search is used. This is an algorithm used in designs of experiments, where objectives are only evaluated. This method of identification of the problem is used only at the early stage.

Later, in order to gain a better insight into the design space and obtain a reasonable subsequent optimization, a design of experiment is set with a SOBOL Design Engine, embedded in FRIENDSHIP FRAMEWORK.

The deterministic SOBOL algorithm is a so-called quasi-random or low discrepancy sequence and imitates the behavior of a random sequence. It is more efficient and less random than a (pseudo) random number sequence, which spreads points randomly in the design space. These sequences use a base of two to form successively finer uniform partitions of the unit interval, and then reorder the coordinates in each dimension . In this way, a uniform sampling of the design space is attained, offering a better overview of the design space, depending on the density of available variants. Sobol type algorithms are known to have superior convergence than random sequences .

For the multi-objective optimization, the Non-dominated Sorting Algorithm II (NSGAII) is utilized. The main advantages of this algorithm are that it applies Pareto-based ranking schemes and avoids “trapping” between local maxima (or minima). More information about the NSGA-II may be found at the theoretical session.

The main objectives that are monitored and optimized during the optimization procedure reflect clearly the scope of this project. The holistic design approach is implemented to this design problem with the following objectives:

- Minimization of the total resistance(R_t) at $V=15.5Kn$
- Minimization of the total resistance(R_t) at $V=31Kn$

Moreover some constraints should be introduced in order to get feasible designs. The main constraints used were:

- Displacement evaluation should not diverge from 1000t
- Area of waterplane(A_{wl}) should not be less than a limit about 120 m² in order to avoid enormous changes to draft as mentioned above.
- For practical reasons B_{str} should be less than 1.6 m (and for easier success of the constrain above)
- Draft=5 m (constant)
- L_{str_n}, L_{str_t} : should be a rate of L_{gn}, L_{gt} (no more than 30-60 %, depending on radius) for practical reasons (to have a clear flow at propeller etc)

Something that must be stated here is that the control of geometric irregularities occur very often in the case of arbitrary parametric design where large variation is required. So these constraints ensure that the developed geometry will remain within feasible boundaries regarding its shape and contributes in avoiding system crashes which are not rare when dealing with sophisticated holistic systems.

5.5.1 DESIGN OF EXPERIMENT (DOE)

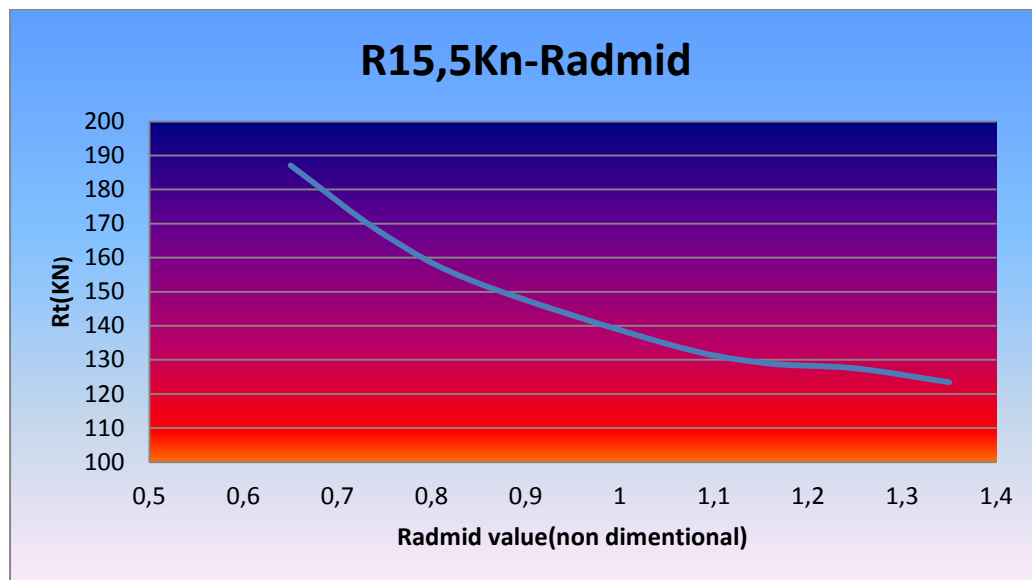
As referred and above the optimization initiated with a design engine called “exhaustive search”. This engine just asks two things. The first one is the range of the parameters and the second the subdivisions. The subdivision is a number that defines how many equal spacings the range of the parameter will have. So this is the number of models that are created.

After that the “Sobol” design engine was called. Firstly with “Sobol” a verification of the results of “exhaustive search” was performed. After that a deeper investigation of the design space was made. So the tendency of every single parameter was understood in detail.

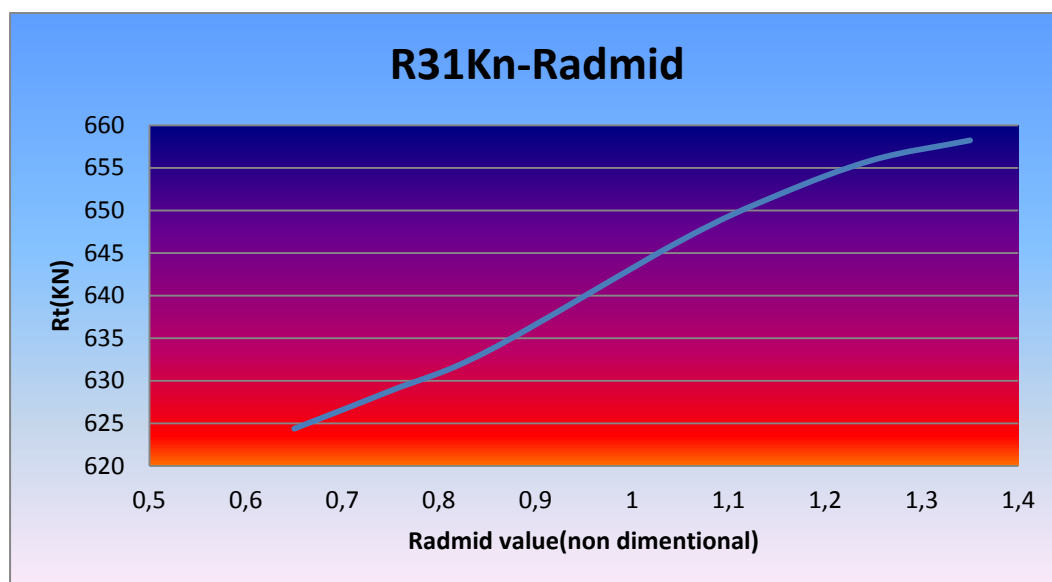
We need to mention that R15,5Kn is the total resistance of the vessel at 15,5Knots and R31Kn is the total resistance of the vessel at 31Knots. Both are measured in KiloNewtons(KN).

Here is presented the trend of every parameter for the low and the high speed:

- **Radmid= Displacement distribution parameter**(for parameter value ≈ 1 there is a parallel midbody, for parameter value >1 there is a displacement distribution to the centre, along the length, and for parameter value <1 there is a displacement distribution to the edge, along the length).



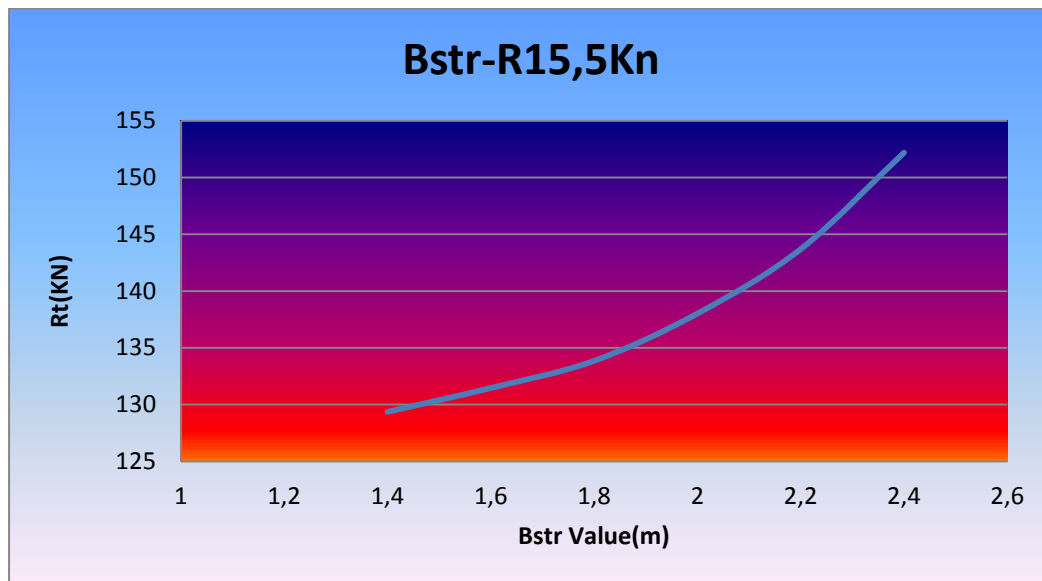
Graph 1 Rt-Radmid



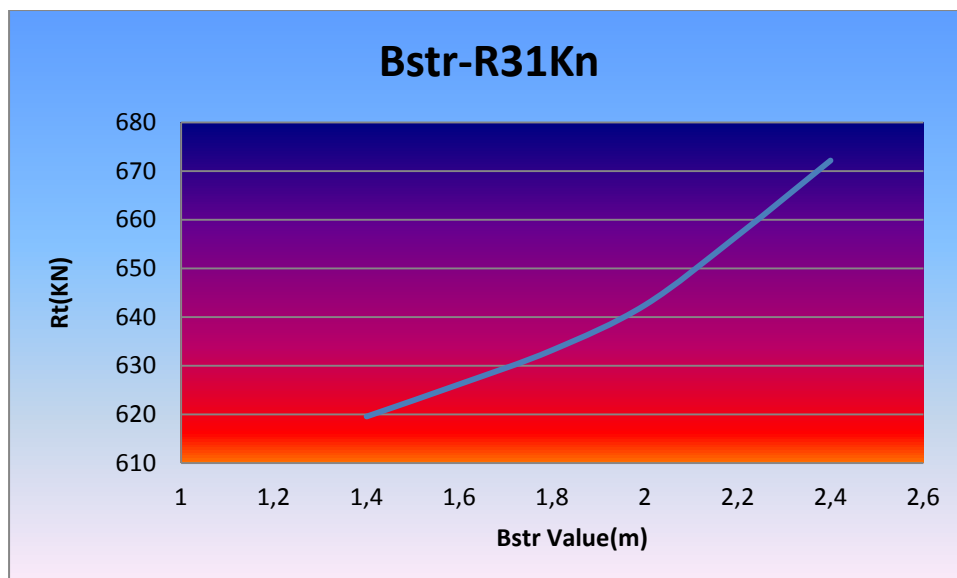
Graph 2 Rt-Radmid

It is obvious that for the low speed an increase at radmid decreases the total resistance. For the high speed the converse it is happening.

- **Bstrut= Strut beam**



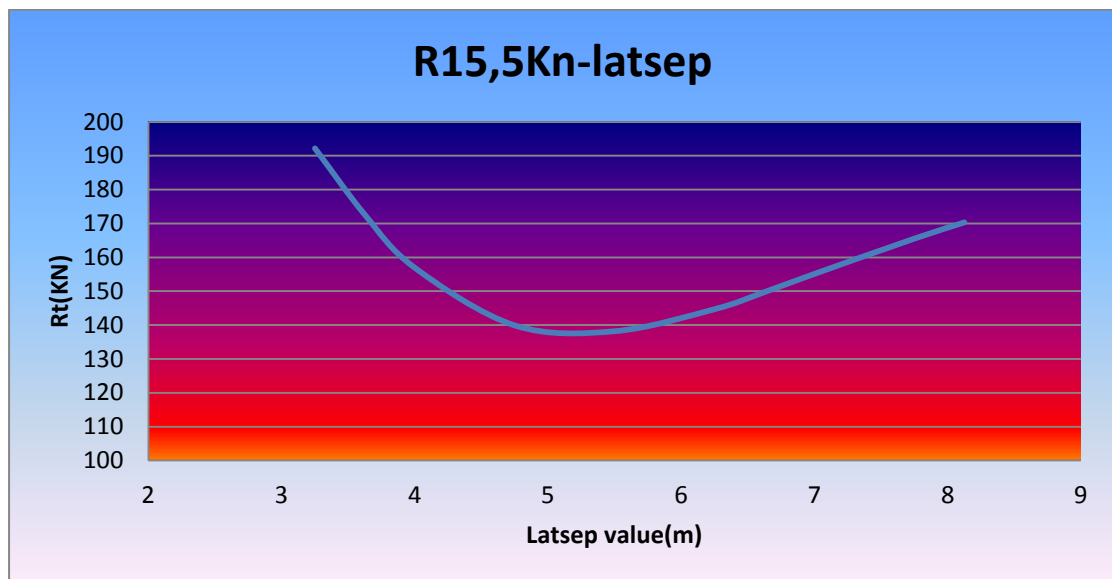
Graph 3 Rt-Bstr



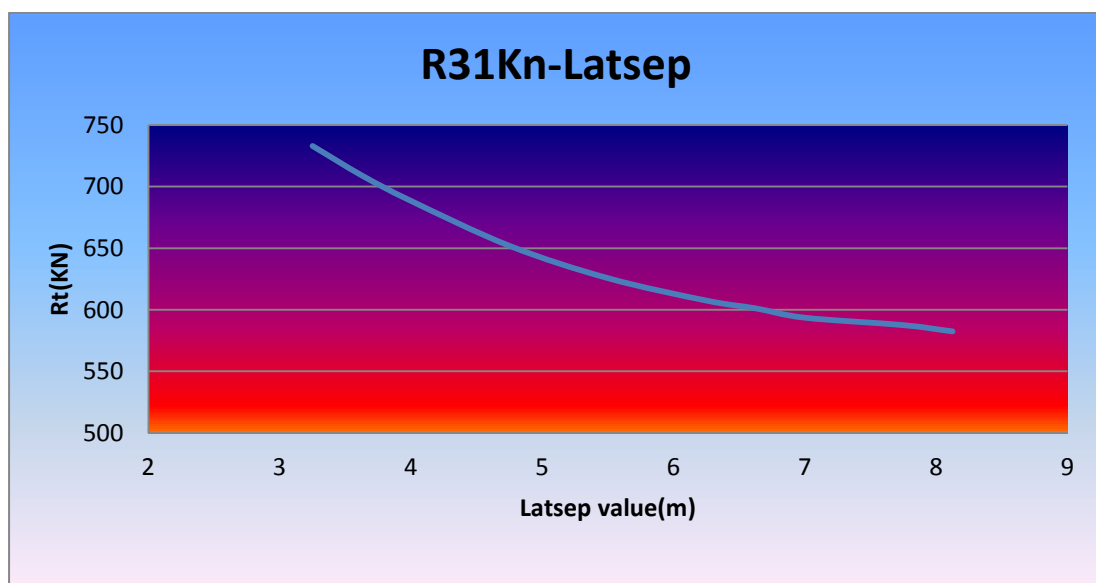
Graph 4 Rt-Bstr

Here it is clear for both speeds that an increase to Bstr increases the total resistance.

- Latsep= half distance between lower hulls



Graph 5 Rt-Latsep

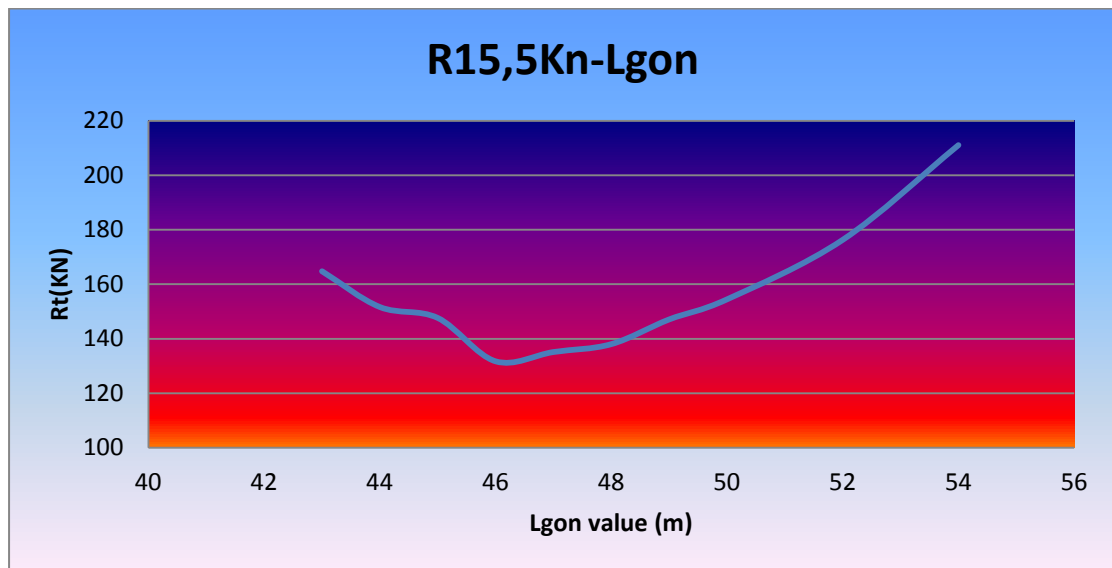


Graph 6 Rt-Latsep

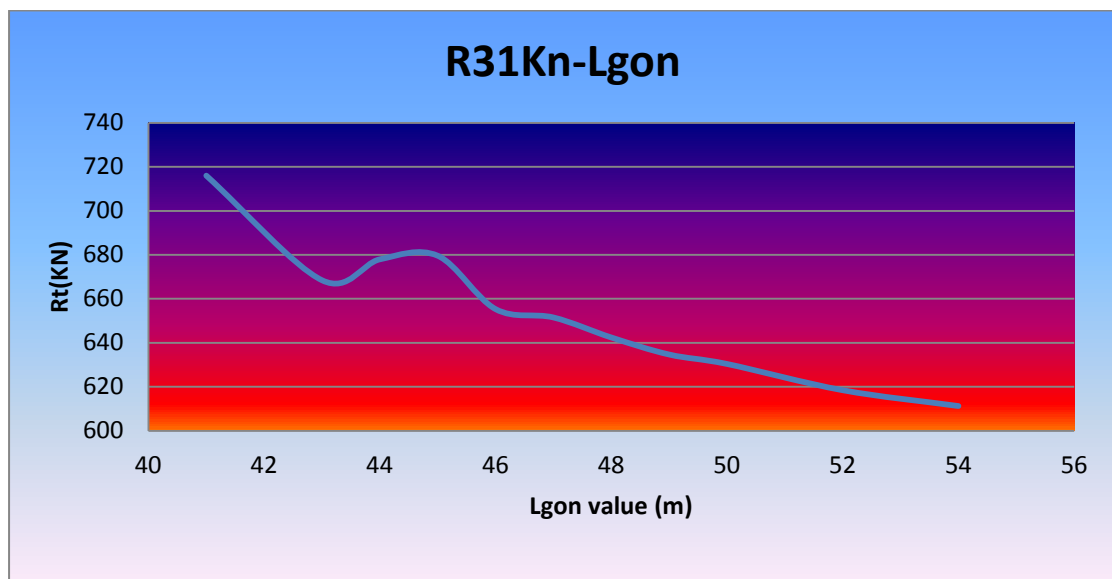
About Latsep we can notice the following: For the low speed and within the given logical range we see a total minimum that is about at 5m. So the optimum distance between lower hulls is about 10m .

For the high speed there is no minimum but the total resistance decreases with an increase at Latsep. The point is that we cannot push this parameter a lot because structural problems will turn up.

- Lengthgondola= lower hull length



Graph 7 Rt-Lgon

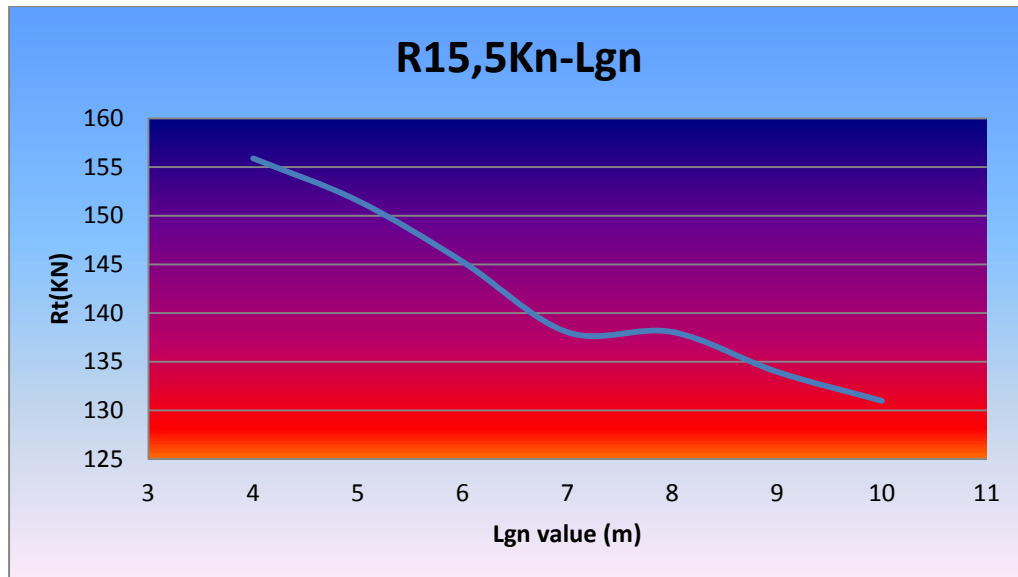


Graph 8 Rt-Lgon

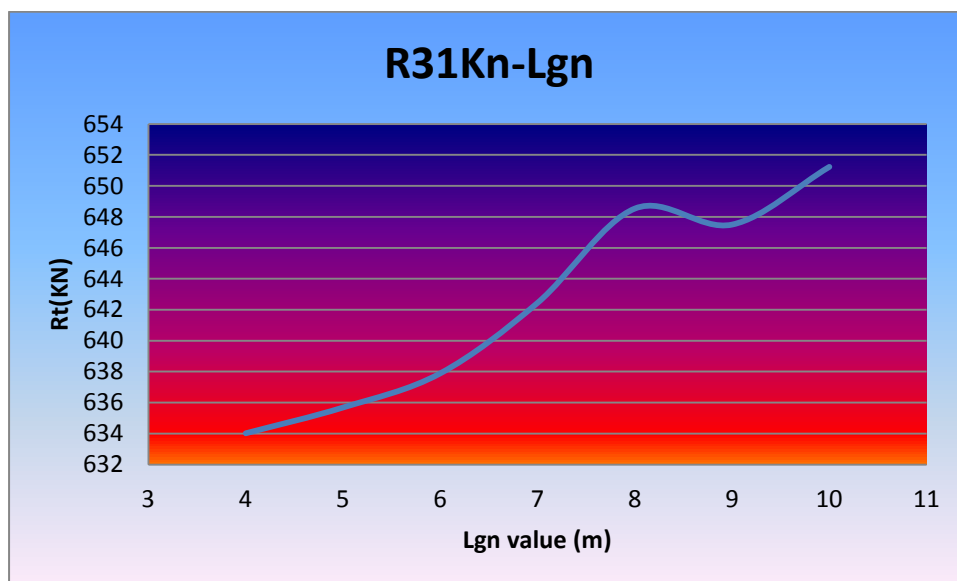
Here we observe for the low speed that there are some local minimum and a total minimum for least total resistance that is about at parameter value 46 m.

Now for the high speed beyond some irregularities at 44 m an increase at Lengthgondola (essentially at its parallel body) decreases the total resistance.

- Lgn=lower hull nose length



Graph 9 Rt-Lgn

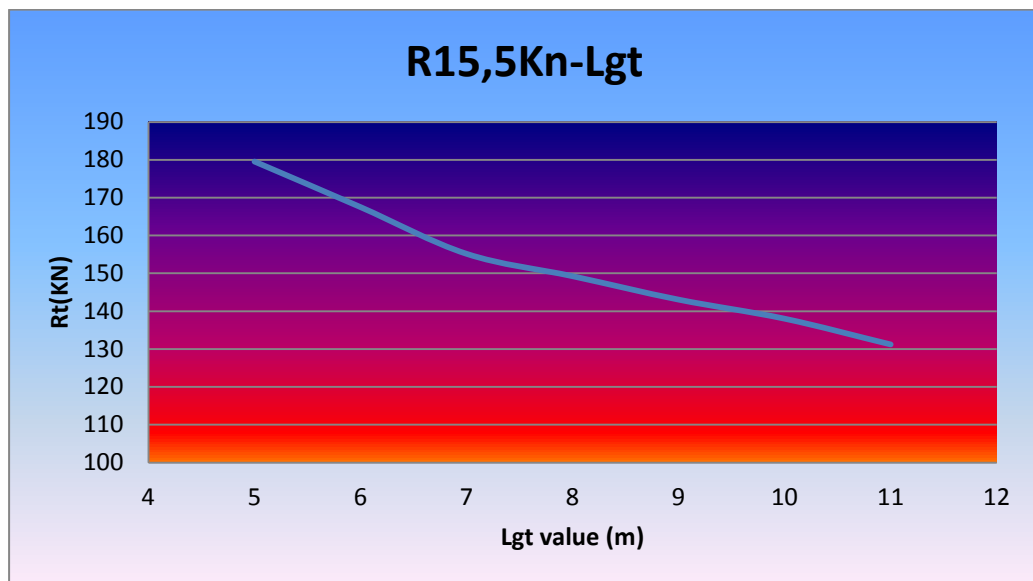


Graph 10 Rt-Lgn

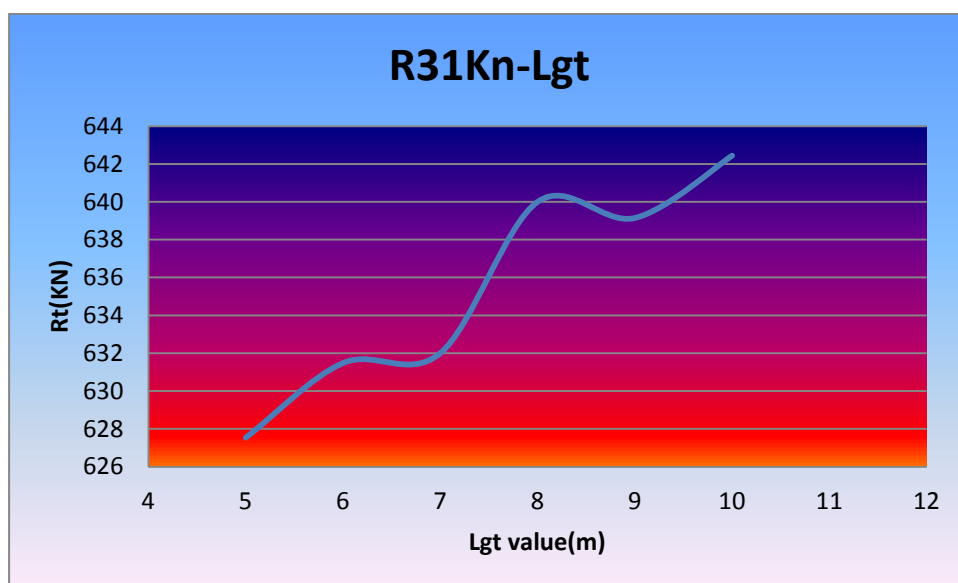
About Lgn we can notice that generally in low speed as we increase the parameter value total resistance decreases. On the contrary at the high speed the opposite is happening so an increase at Lgn increases the total resistance.

C. Papandreou, Parametric Design and Multi-objective Optimization of SWATH
Diploma Thesis, NTUA, Ship Design Laboratory, June 2013

- Lgt= lower hull tail length



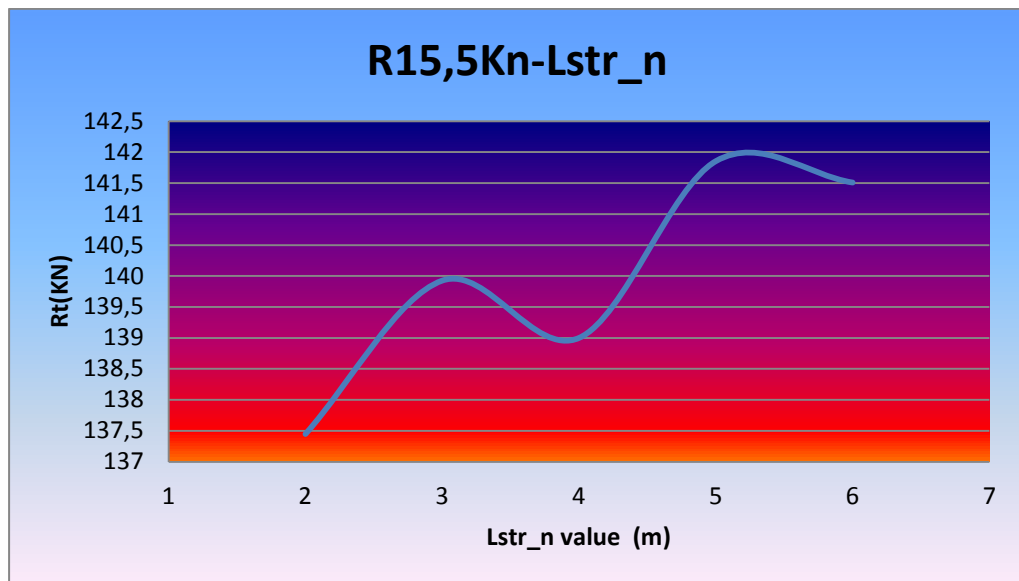
Graph 11 Rt-Lgt



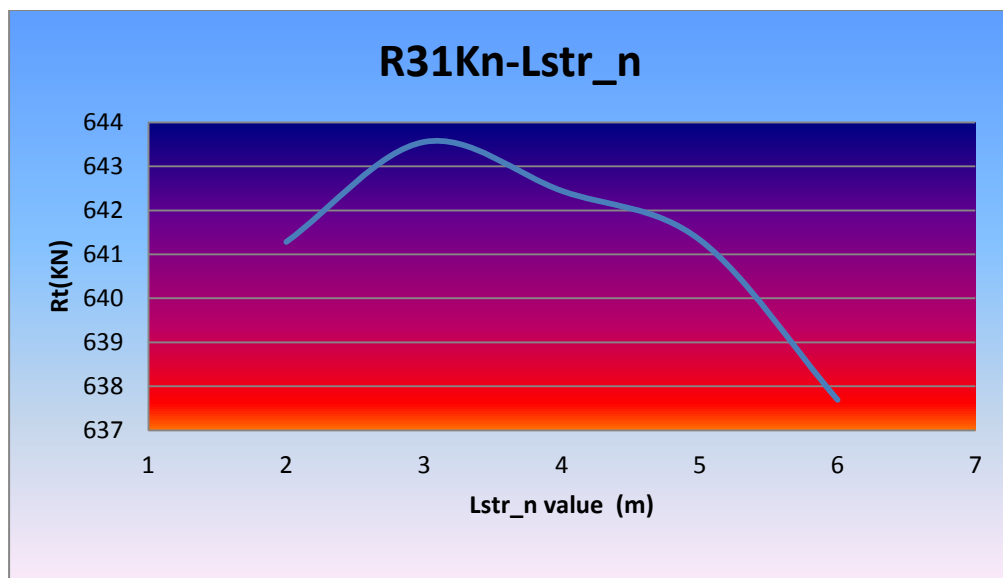
Graph 12 Rt-Lgt

Here as for Lgt the results are almost the same with the previous one (Lgn). Apart from some little irregularities, at low speed an increase to the Lgt decreases the total resistance. On the contrary at the high speed the opposite is happening again.

- **Lstr_n=**strut nose length



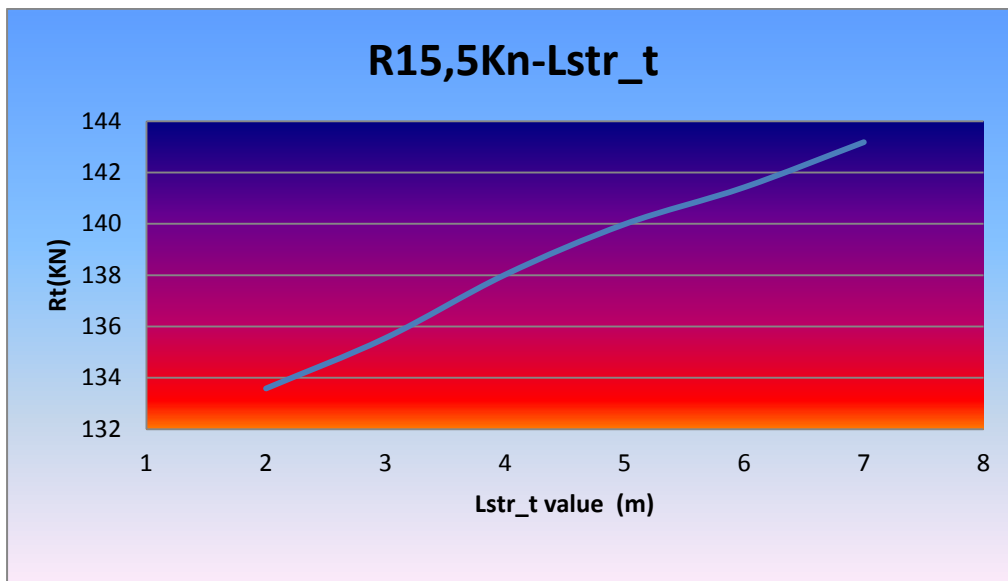
Graph 13 Rt-Lstr_n



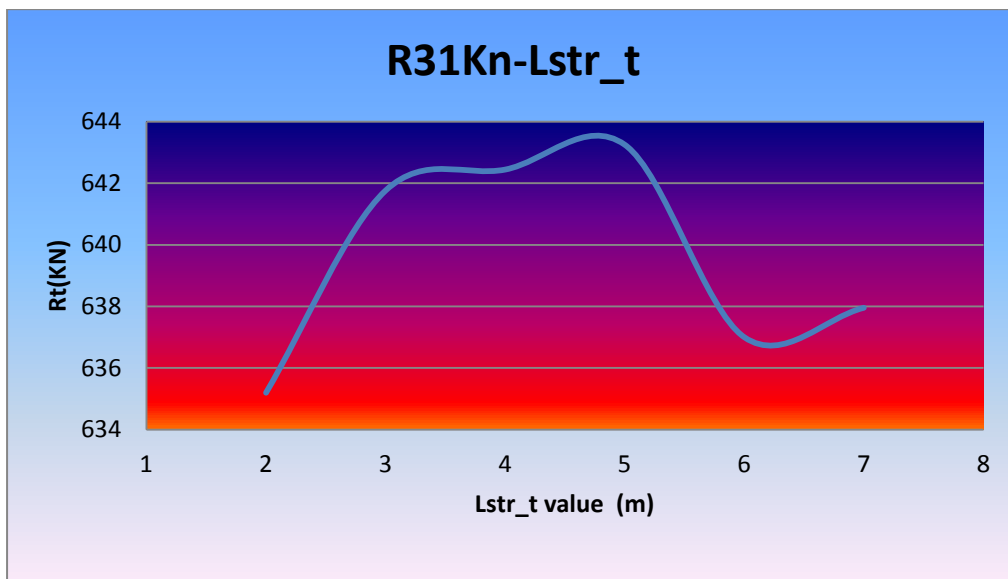
Graph 14 Rt-Lstr_n

Lstr_n seems to decrease for minimum total resistance at low speed and to increase at high speed. But this tendency is not so obvious. Generally as we can see a great change at its value has very little response to the total resistance.

- L_{str_t} =strut tail length



Graph 15 R_t - L_{str_t}



Graph 16 R_t - L_{str_t}

Lastly L_{str_t} tends to decrease for least total resistance for low speed. About the high speed a total maximum seems to be created at from 3 to 5 m so this area should be avoided. But again as L_{str_n} the response to the total resistance is least. That is the reason which other factors may overpass this restricted area. As mentioned earlier we need a clean flow at the propeller so L_{str_t} must be a rate of L_{gt} (about 30-60%)

5.5.2 MULTI OBJECTIVE OPTIMIZATION-GENETIC ALGORITHMS

Since the design of experiment has provided us with a lot of feedback regarding the response of the Swath while varying, it is time now to proceed to the formal multi-objective optimization. The range of the parameters has been reduced after a thorough examination of the best designs of the DoE. As a result, a region of good variants within the space of feasible design has been identified. In this area, the optimization will be executed in order to find the best design and provide the Pareto-Frontier. The NSGA-II will be utilized to perform the multi-criteria optimization. The genetic algorithm will run many times in order to within a reduced better range each time. That will not only find more optimal designs but it will also make sure that the genetic algorithm will not be trapped to local minimum(often due to the elitism). The same procedure will be followed with the MOSA algorithm to be absolutely sure about the results .

Generally the boundaries of the parameters was given to the algorithm as follows:

Design Variables						
	Design Variable	Lower	Value	Upper	Active	
1	radmid	0.6	1.4	1.4	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
2	bstrut	1.6	2	2.2	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
3	lat_sep	4	5	8.5	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
4	lengthgon	45	48	55	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
5	Lgonnose	7	7	12	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
6	Lgontail	8	10	12	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
7	Lstrnose	2	4	4	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
8	Lstrtail	2	4	4	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
9					<input type="checkbox"/>	

Table 1 Parameter boundaries for optimization

Evaluation of the results. (NSGA II).

The range of the parameters and the objectives are listed below:

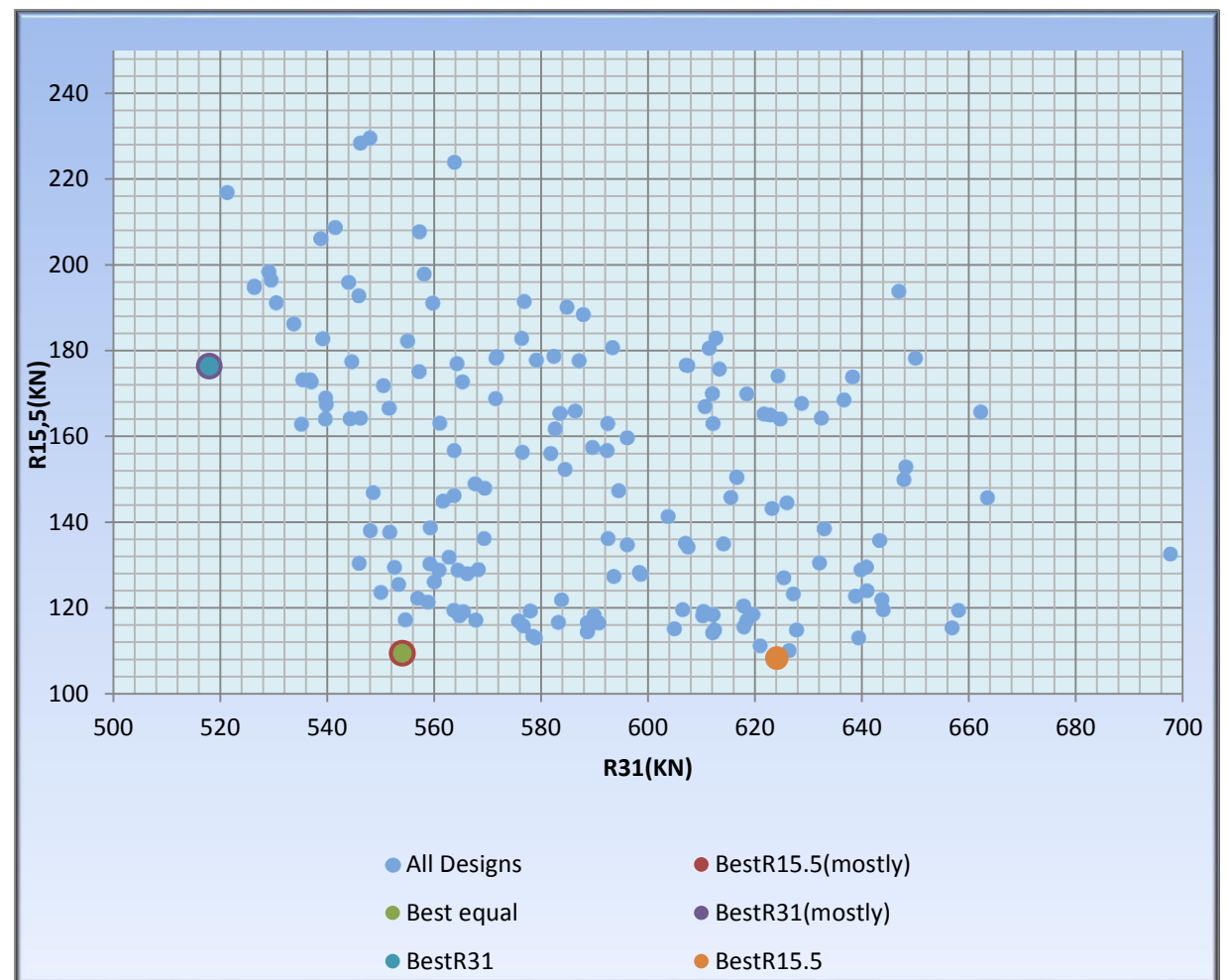
Attribute	Active	Active	Active	Active
Name	radmid	bstrut	lat_sep	lengthgon
Scope	parameters	parameters	parameters	parameters
Reference				
Lower Bound	0.60255131	1.6048707	4.0736095	45.344244
Upper Bound	1.3960327	2.1994598	8.4903182	54.958495
Feasible Designs: 93.684211 %				
Mean Utilization Index				
Mean	1.0500518	1.7998573	6.3110455	52.103841
Sample Standard Deviation	0.23645229	0.17783071	1.4866057	2.0247272
Error-free: 100 %	100%	100%	100%	100%

Attribute	Active	Active	Active	Active
Name	Lgonnose	Lgontail	Lstrnose	Lstrtail
Scope	parameters	parameters	parameters	parameters
Reference				
Lower Bound	7.0031281	8.2167391	2.2061799	2.0011292
Upper Bound	11.917449	11.994934	3.9727779	3.9998474
Feasible Designs: 93.684211 %				
Mean Utilization Index				
Mean	9.7057407	10.472107	3.081656	2.9350684
Sample Standard Deviation	1.3172165	1.0922828	0.44441585	0.66124031
Error-free: 100 %	100%	100%	100%	100%

Attribute	Objective	Objective
Name	eval_R31_Kn	eval_R15_5Kn
Scope		
Reference		
Lower Bound	517.93083	108.27897
Upper Bound	713.19734	248.93628
Feasible Designs: 93.684211 %		
Mean Utilization Index		
Mean	591.22205	147.76153
Sample Standard Deviation	39.421179	29.476837
Error-free: 100 %	100%	100%

Table 2 Boundaries of parameter and evaluations (NSGA-II)

The following diagram depict the scatter of the objectives. It is shown that the best compromises have been achieved since the Pareto-Frontier is apparent.



Graph 17: Evaluations R15,5 vs R31 (NSGA-II)

It should be mentioned here that the non-feasible designs were excluded from the above diagram. In every diagram, the reference design is not close to the Pareto-Frontier in terms of the objectives. That proves the fact that there was a merit, and that the genetic algorithm has completed its task successfully. Therefore it can be assumed that the NSGA II found the best compromises for the two objectives.

Evaluation of the results. (MOSA)

The range of the parameters and the objectives are listed below:

Attribute	Active	Active	Active	Active
Name	radmid	bstrut	lat_sep	lengthgon
Scope	parameters	parameters	parameters	parameters
Reference				
Lower Bound	0.65371715	1.6014161	5.0036622	48.058962
Upper Bound	1.3491241	1.9980102	7.961272	54.98825
Feasible Designs: 100 %				
Mean Utilization Index				
Mean	0.98187214	1.7814974	6.4512987	51.786094
Sample Standard Deviation	0.21149661	0.11556939	0.86434069	1.9454628
Error-free: 100 %	100%	100%	100%	100%

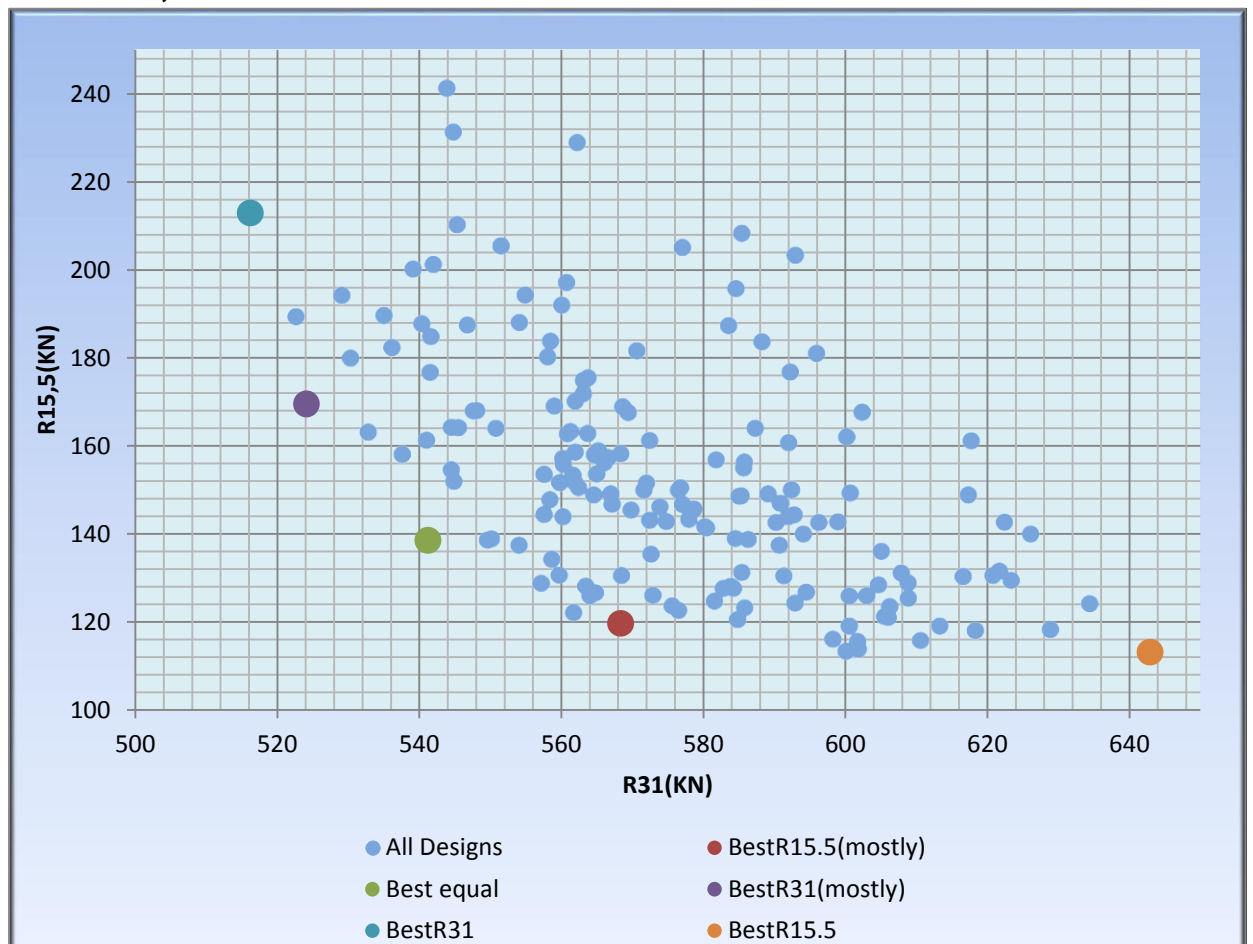
Attribute	Active	Active	Active	Active
Name	Lgonnose	Lgontail	Lstrnose	Lstrtail
Scope	parameters	parameters	parameters	parameters
Reference				
Lower Bound	7.0012207	7.013123	2.0119633	2.0001831
Upper Bound	11.96353	11.987182	3.995056	3.9872433
Feasible Designs: 100 %				
Mean Utilization Index				
Mean	9.4847611	9.4018827	3.126414	2.9242085
Sample Standard Deviation	1.4094057	1.4488046	0.54435999	0.55892417
Error-free: 100 %	100%	100%	100%	100%

Attribute	Objective	Objective
Name	eval_R31_Kn	eval_R15_5Kn
Scope		
Reference		
Lower Bound	516.17165	113.13601
Upper Bound	642.90352	254.47853
Feasible Designs: 100 %		
Mean Utilization Index		
Mean	575.57692	153.94938
Sample Standard Deviation	25.279107	27.25996
Error-free: 100 %	100%	100%

Table 3 Boundaries of parameter and evaluations (MOSA)

The following diagram depict the scatter of the objectives .It is shown that the best compromises have been achieved since the Pareto-Frontier is apparent.

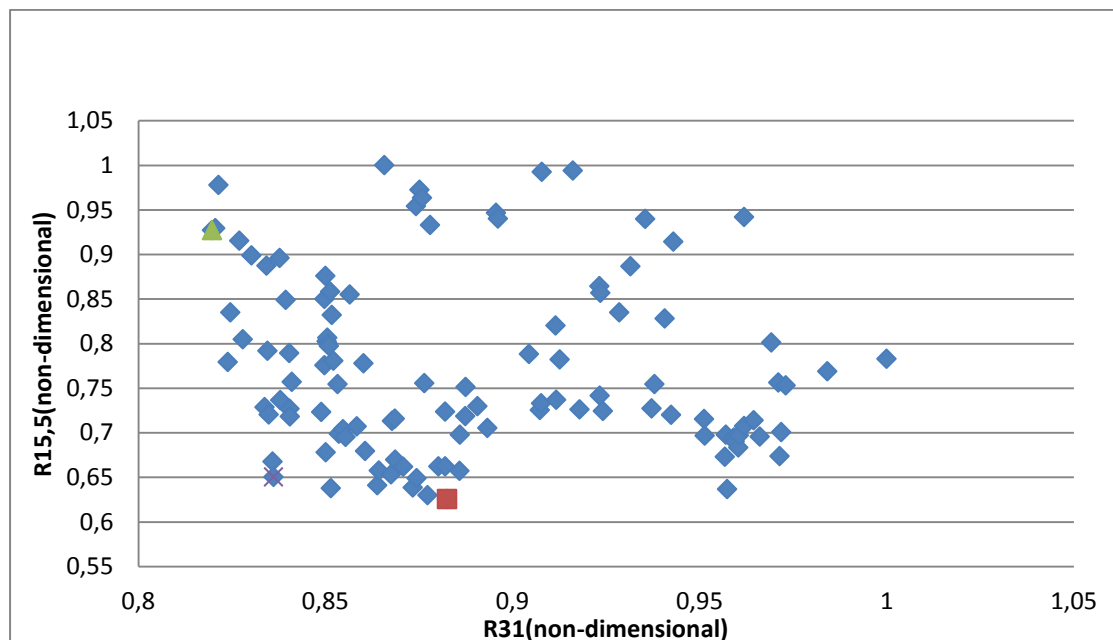
MOSA R15,5 Kn vs R31 Kn



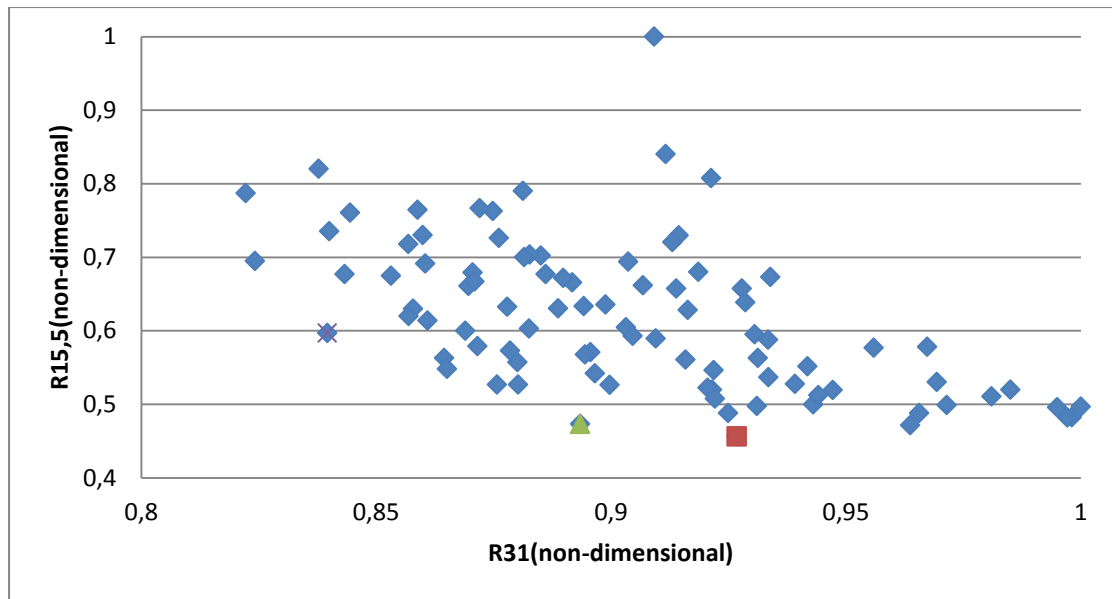
Graph 18: Evaluations R15,5 vs R31 (MOSA)

It should be mentioned here that the non-feasible designs were excluded from the above diagram. In every diagram, the reference design is not close to the Pareto-Frontier in terms of the objectives. That proves the fact that there was a merit, and that the genetic algorithm has completed its task successfully. Therefore it can be assumed that the MOSA found the best compromises for the two objectives.

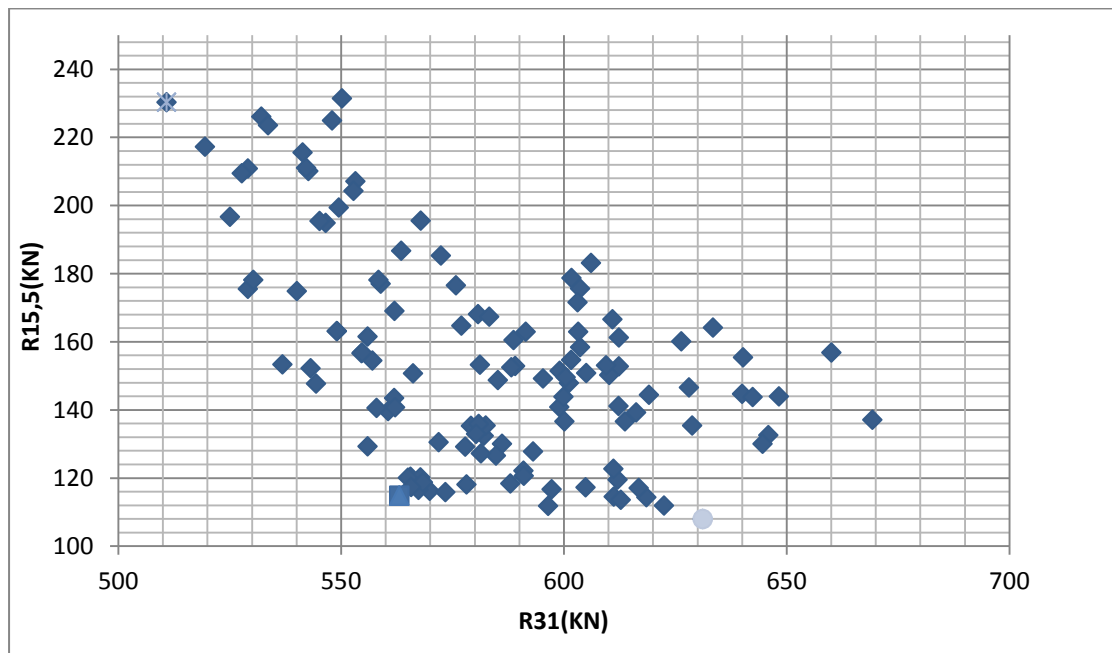
For reasons of completeness some diagrams from previous runs are presented here.



Graph 19: Evaluations R15,5 vs R31



Graph 20: Evaluations R15,5 vs R31



Graph 21: Evaluations R15,5 vs R31

5.6 Best Designs

The multi-objective optimization created a wide variety of feasible designs. It also achieved to develop designs of best compromise, while keeping the constraints in an acceptable range. Pareto frontiers in the above diagrams prove this fact. In order to choose some the best designs, an objective function must be introduced in order to meet specific needs. There are formal procedures for this task like Multiple Attribute Decision Making (MADM) presented by Sen and Yang. In this case, a manual exploitation of the design space with the objective functions is conducted.

Regarding with the objective function we chose three best designs that have already been shown in the above diagrams (NSGA II).

The first one is based 80% at the low speed and 20% at the high speed. The second one is based 50% at the low speed and 50% at the high speed. These two coincides to be the same design and is as follows:

Name	Value	Lower Bound	Upper Bound
parameters radmid	1.36739	0.6	1.4
parameters bstrut	1.62266	1.6	2.2
parameters lat_sep	8.45956	4	8.5
parameters lengthgon	54.4867	45	55
parameters Lgonnose	11.7202	7	12
parameters Lgontail	10.6411	8	12
parameters Lstrnose	2.65064	2	4
parameters Lstrtail	2.36014	2	4

Evaluations		
Name	Value	Is Objective
eval_R31_Kn	554.037	Yes
eval_R15_5Kn	109.443	Yes

Table 4 Parameter and evaluation values of mostly R155 and best equal (NSGA-II)

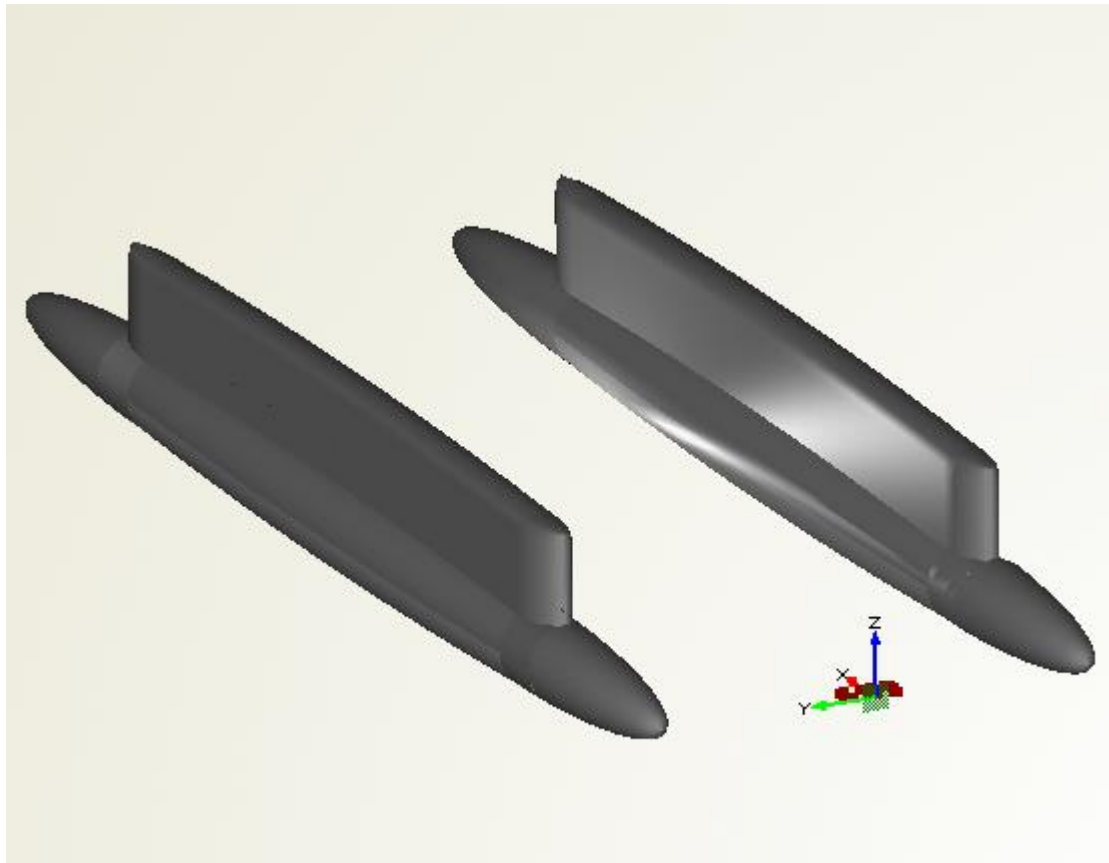


Figure 5.10 Best design for low (and equal) speed (NSGA-II)

The third one is based 20% at the low speed and 80% at the high speed and is as follows:

Name	Value	Lower Bound	Upper Bound
parameters radmid	0.648634	0.6	1.4
parameters bstrut	1.62735	1.6	2.2
parameters lat_sep	8.08272	4	8.5
parameters lengthgon	53.7378	45	55
parameters Lgonnose	10.7559	7	12
parameters Lgontail	11.936	8	12
parameters Lstrnose	2.70939	2	4
parameters Lstrtail	2.39707	2	4

☒ Evaluations

Name	Value	Is Objective
eval_R31_Kn	517.931	Yes
eval_R15_5Kn	176.364	Yes

Table 5 Parameter and evaluation values of mostly R31 (NSGA-II)

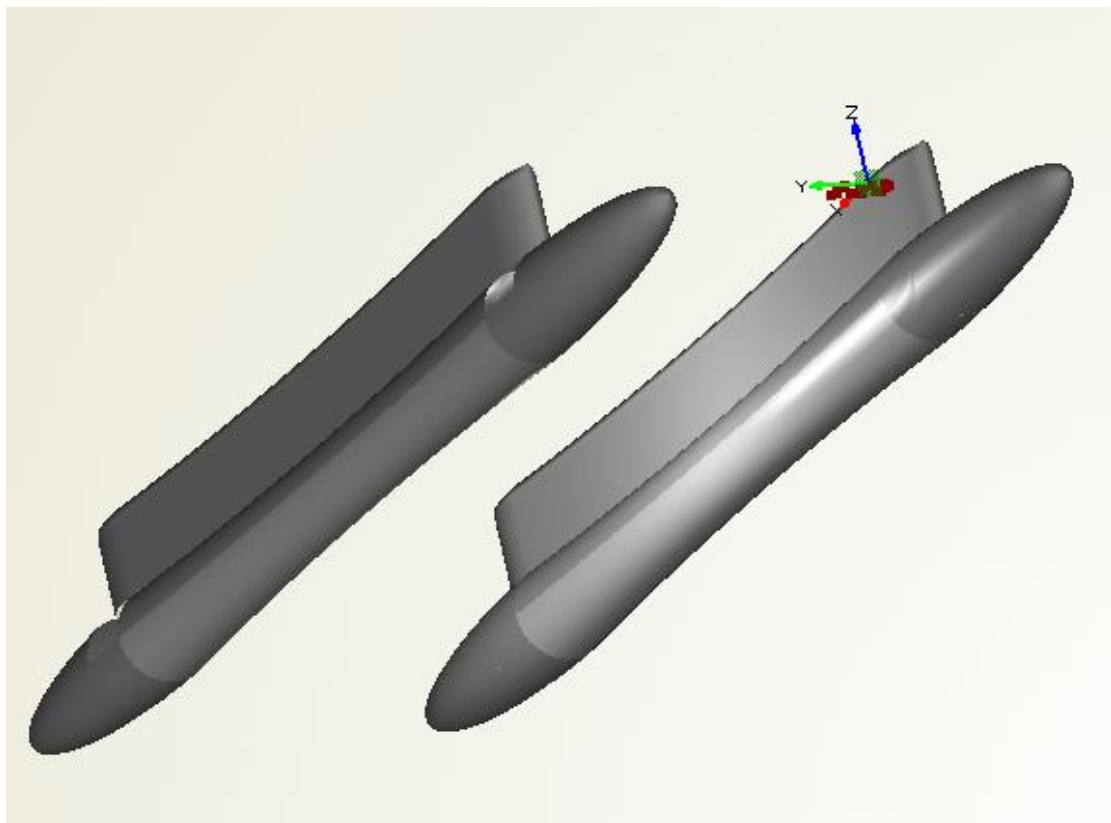


Figure 5.11 Best design for high speed(NSGA-II)

Regarding with the objective function we chose three best designs that have already been shown in the above diagrams (MOSA).

The first one is based again 80% at the low speed and 20% at the high speed and is as follows:

Design Variables			
Name	Value	Lower Bound	Upper Bound
parameters radmid	1.22298	0.65	1.35
parameters bstrut	1.64796	1.6	2
parameters lat_sep	6.76235	5	8
parameters lengthgon	52.7229	48	55
parameters Lgonnose	10.1429	7	12
parameters Lgontail	9.82434	7	12
parameters Lstrnose	3.05539	2	4
parameters Lstrtail	2.65535	2	4

Evaluations		
Name	Value	Is Objective
eval_R31_Kn	568.343	Yes
eval_R15_5Kn	119.691	Yes

Table 6 Parameter and evaluation values of mostly R155(MOSA)

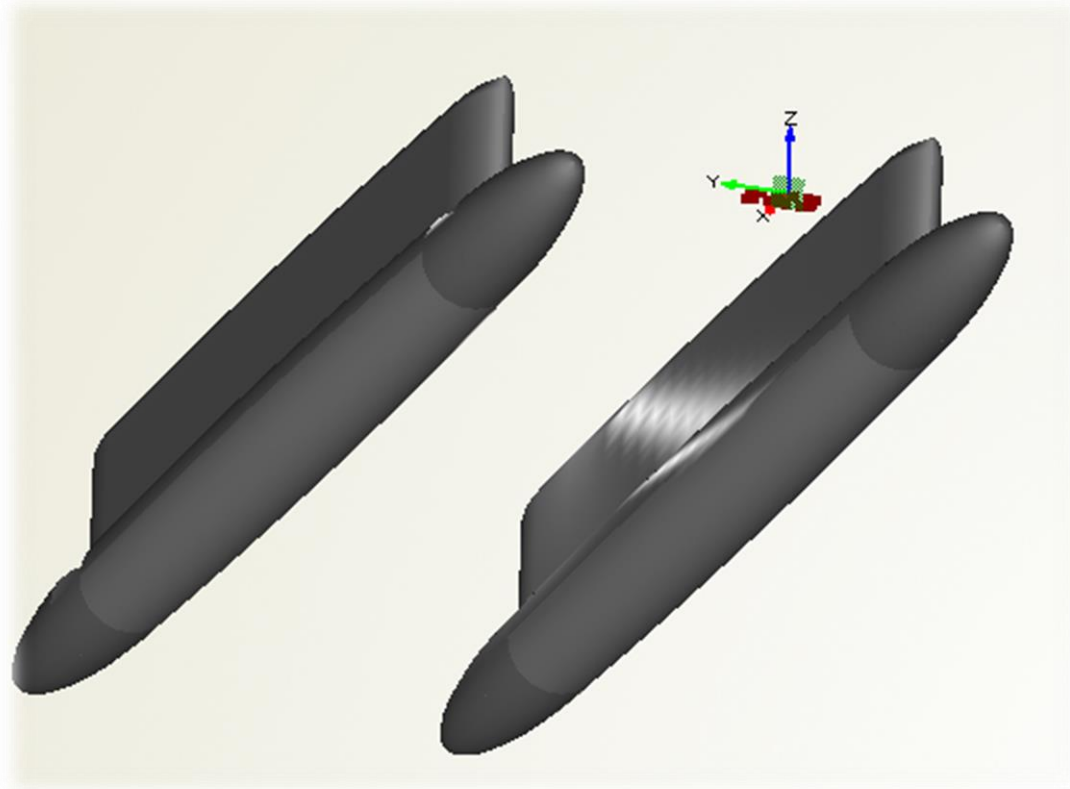


Figure 5.12 Best design for low speed(MOSA)

The second one is based again 20% at the low speed and 80% at the high speed and is as follows:

Design Variables			
Name	Value	Lower Bound	Upper Bound
parameters radmid	0.73966	0.65	1.35
parameters bstrut	1.6453	1.6	2
parameters lat_sep	7.77779	5	8
parameters lengthgon	54.6543	48	55
parameters Lgonnose	10.4367	7	12
parameters Lgontail	11.7423	7	12
parameters Lstrnose	3.0795	2	4
parameters Lstrtail	3.5526	2	4

Evaluations		
Name	Value	Is Objective
eval_R31_Kn	524.088	Yes
eval_R15_5Kn	169.567	Yes

Table 7 Parameter and evaluation values of mostly R31(MOSA)

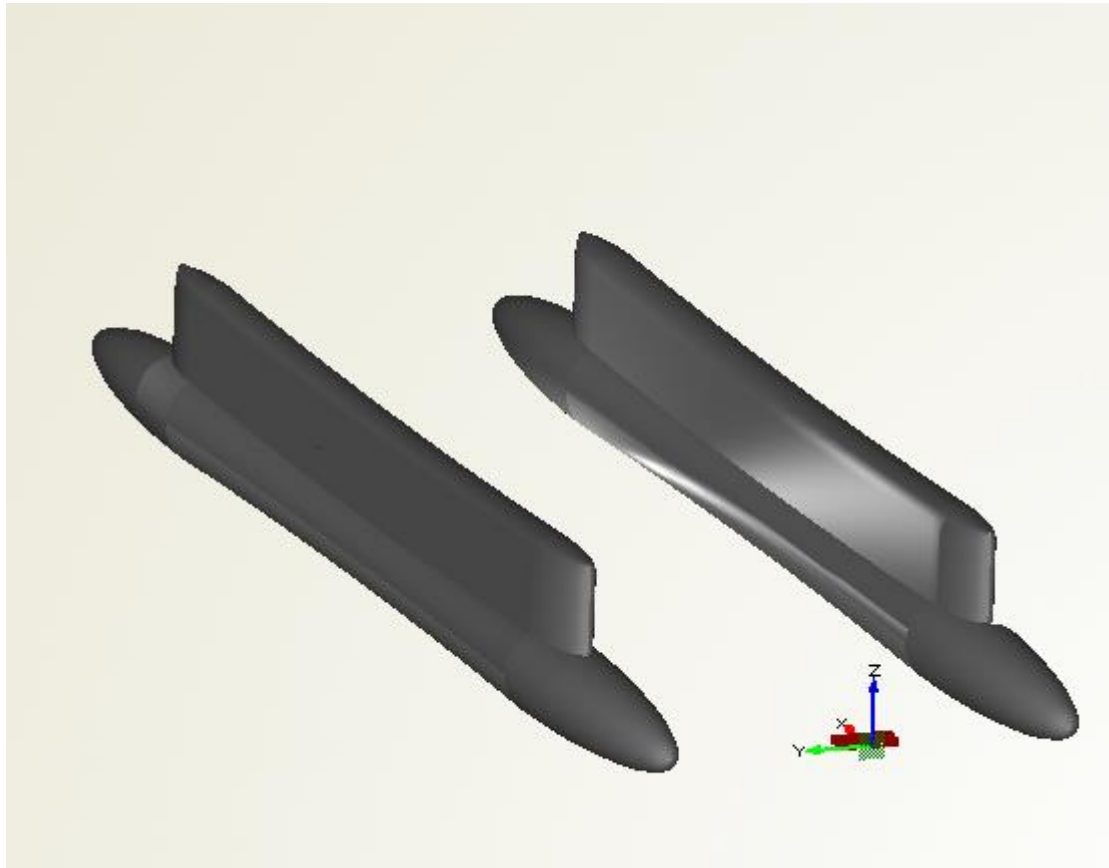


Figure 5.13 Best design for high speed(MOSA)

The third one is based again 50% at the low speed and 50% at the high speed and is as follows:

Design Variables			
Name	Value	Lower Bound	Upper Bound
parameters radmid	0.969248	0.65	1.35
parameters bstrut	1.61779	1.6	2
parameters lat_sep	7.88281	5	8
parameters lengthgon	52.4578	48	55
parameters Lgonnose	9.11432	7	12
parameters Lgontail	11.2759	7	12
parameters Lstrnose	3.98236	2	4
parameters Lstrtail	2.74392	2	4

Evaluations		
Name	Value	Is Objective
eval_R31_Kn	541.209	Yes
eval_R15_5Kn	138.55	Yes

Table 8 Parameter and evaluation values of best equal (MOSA)

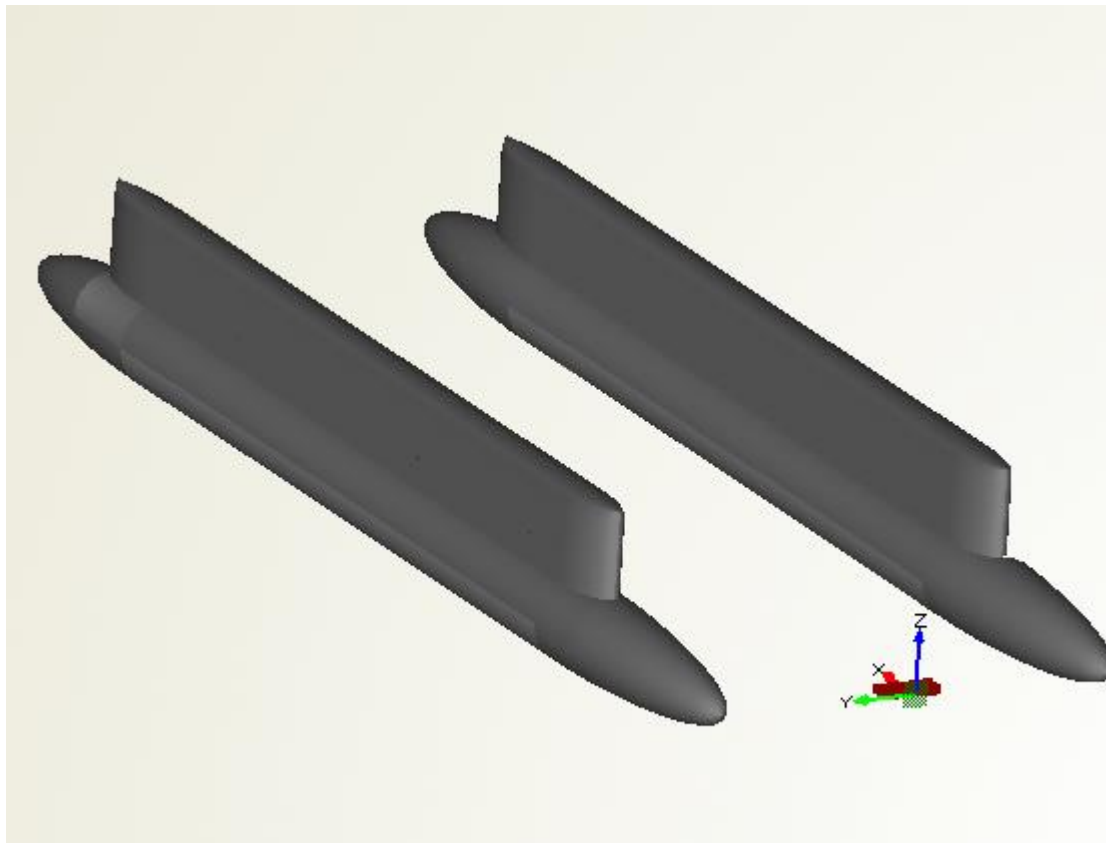


Figure 5.13 Best design for moderate speed(MOSA)

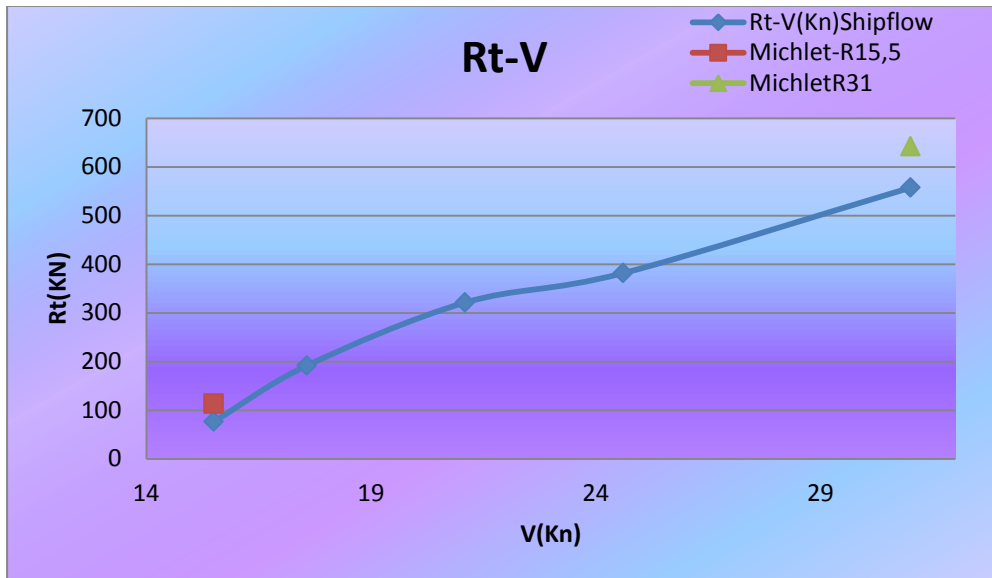
5.7 VALIDATING RESULTS WITH SHIPFLOW

Taking into account that the MICHLET is a very fast code that calculates the total resistance within seconds for a range of speeds , a validation of the results was needed to be fulfilled. So SHIPFLOW had to be introduced. There is no need to run again optimization with SHIPFLOW as this would take a lot of time and computational power. That was the reason that was decided to extract the best designs from FRIENDSHIP FRAMEWORK, alternate to a form that is understood by SHIPFLOW and run them again to check the results. At this point we should state that this was not an easy job as the best designs refer to a particular speed. So the CFD code had difficulties in giving objective results for the range of speed needed. For example the best design for the low speed had very good results for speed of 15,5Kn but also gave us poor results for the speed of 31Kn.

The only solution was to change the gridlines at SHIPFLOW configuration. With some iterations correcting gridlines the results were far more better but again not absolutely cogent.

Here are presented the results of the SHIPFLOW for each of the five best designs from MOSA(the three presented above, the best for the low speed and the best for the high speed). At each of the best designs some intermediate speeds were also calculated in order to create a typical resistance curve (at least for a small range of speeds).

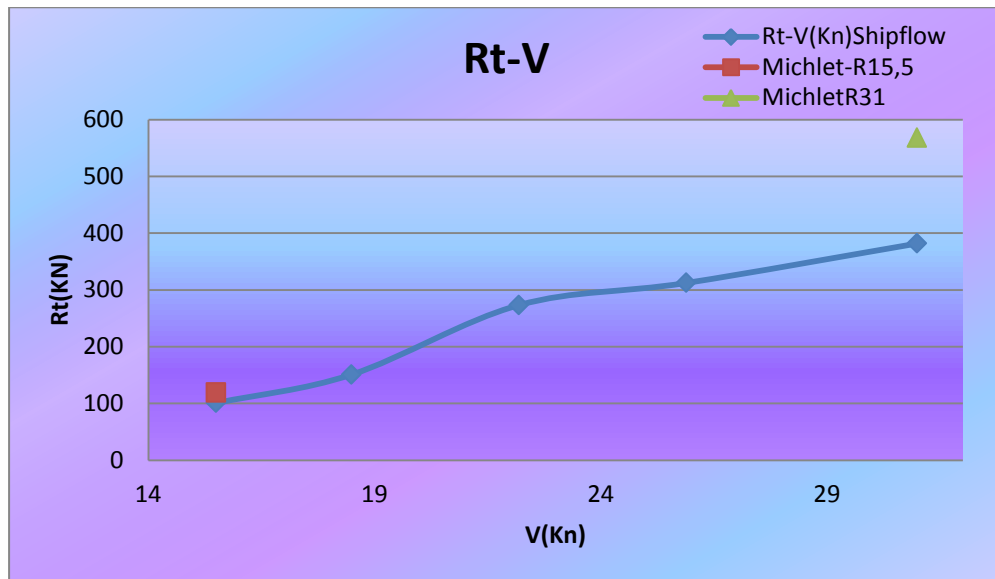
- **Best R155**



Graph 19: Rt –V (Shipflow)

For the best design at the speed of 15,5 Kn we can notice that there is a convergence to the codes at this speed but as it raises divergence is inevitable. That is why at the high speed SHIPFLOW did not converged to a C_w it created high waves and the iterations stopped by the program itself.

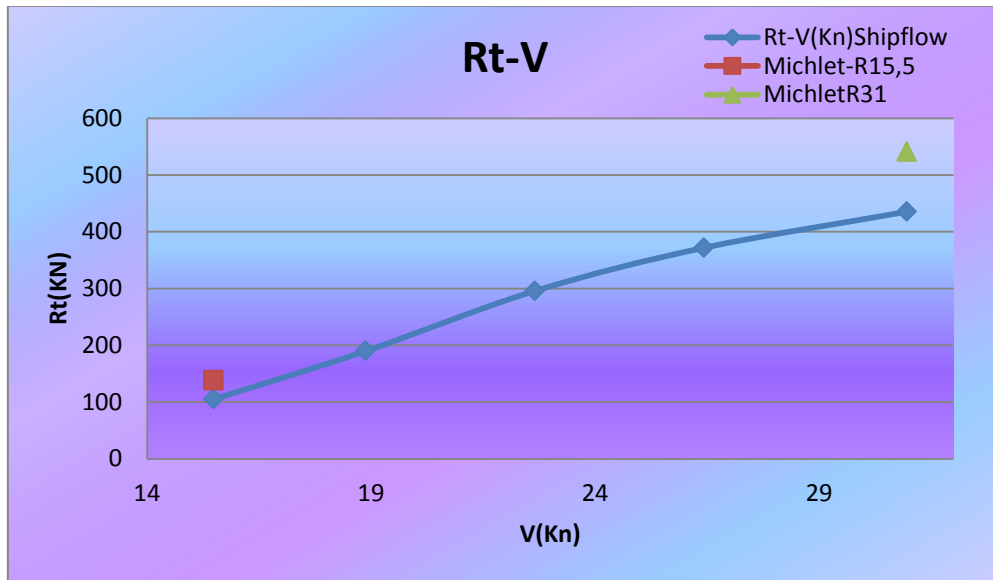
- **BestR155(mostly)**



Graph 20: Rt –V (Shipflow)

Here we can see exactly what was mentioned to the previous design but obviously to a greater scale. Again convergence at the low speed and divergence at the high one. The reasons still the same.

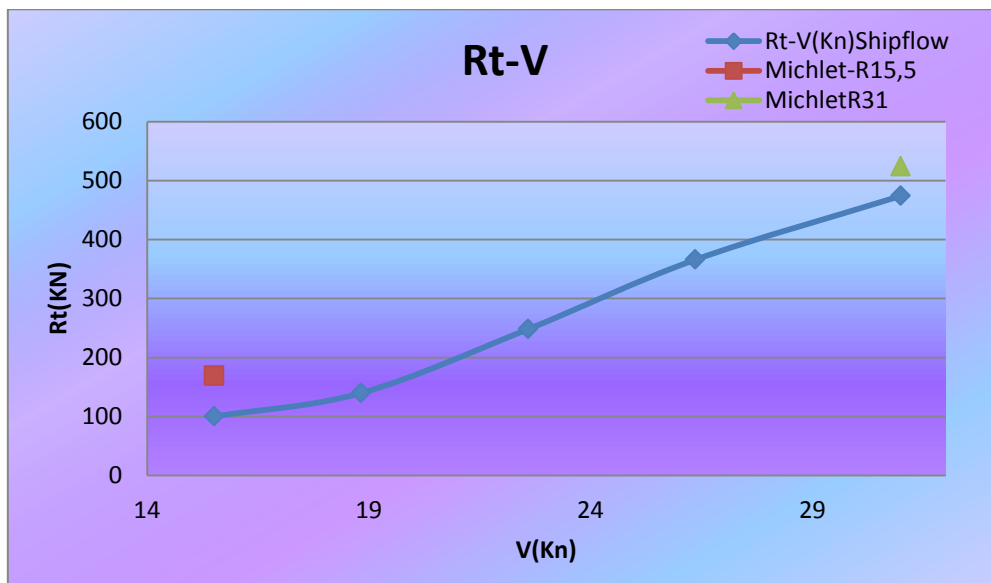
- **Best equal**



Graph 21: Rt –V (Shipflow)

At the best design for both speeds the above phenomenon is starting to moderate. For example at the high speed SHIPFLOW ran more iterations for the previous designs. Again we cannot extract safe results but at least we have something to base on.

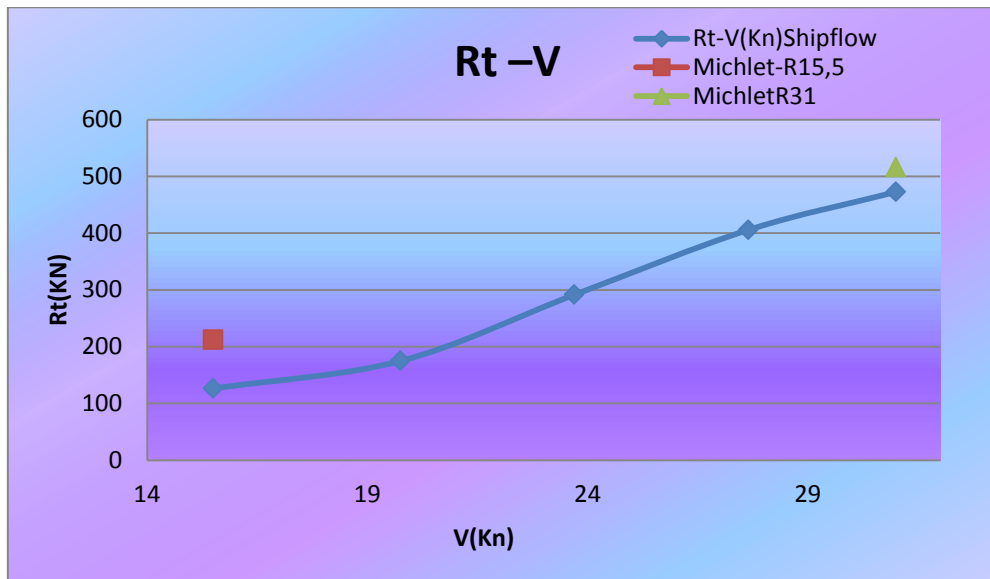
- **BestR31(mostly)**



Graph 22: Rt -V (Shipflow)

At this design we witness another phenomenon of the previous. SHIPFLOW stopped running because it finished the iterations but it did not achieved convergence. This happened at both speeds.

- **Best R31**



Graph 23: Rt -V (Shipflow)

At the best design for the high speed we can observe that SHIPFLOW diverged at slow speed(stopped by iterations) but converged at the high speed(the reverse phenomenon for the first two designs)

Generally we can say the SHIPFLOW always underestimated the total resistance by the aforementioned ways. A number of 25 runs were made to SHIPFLOW(five designs for five speeds each). The runs that did not converged(they had their iterations stopped by the program) had their gridlines changed and ran again. This procedure stopped when almost every run was successful (at least they stopped by the iterations , not by the program).

The last but not least that has to be mentioned is that indeed there is a deviation regarding to the two programs. Happily this deviation is smaller where the SHIPFLOW converged and greater where it diverged. Something that makes perfect sense. Unfortunately as we already said SHIPFLOW underestimate the total resistance(hence the wave resistance, as the friction is calculated by ITTC and is the same for both programs). This cannot be explained at the boundaries of this diploma thesis but the answer may lies at the code of each program itself or at the nature of the problem proposed (Swath is a special kind of ship)

5.8 SINGLE OBJECTIVE OPTIMIZATION

At this point a parenthesis should be opened. As mentioned above at the multi-objective optimization the parameters are usually contradictory. With the optimization problem as stated above two single objective optimizations were accomplished in order to explore how are our parameters vary when our goal lies only at the slow or only at the fast speed. In this case we get released from the contradictory parameters, and as a result we can get even better results for every single speed. Something that has to be referred at this point is that the parameters has been changed regarding with the DOE for each speed in order to find the most optimized design.

The results for the low speed are as follows:

Attribute	Active	Active	Active	Active
Name	radmid	bstrut	lat_sep	lengthgon
Scope	parameters	parameters	parameters	parameters
Reference				
Lower Bound	1.3098817	1.2029114	6.3324331	48.581598
Upper Bound	1.394844	1.7732662	7.9900816	54.907286
Feasible Designs: 100 %				
Mean Utilization Index				
Mean	1.3672608	1.4303257	7.1136922	52.289363
Sample Standard Deviation	0.023126318	0.18454454	0.53927478	1.6649619
Error-free: 100 %	100%	100%	100%	100%

Active	Active	Active	Active	Objective
Lgonnose	Lgontail	Lstrnose	Lstrtail	eval_R15_5Kn
parameters	parameters	parameters	parameters	
8.0001221	8.1429465	2.0036011	2.0925917	88.519615
11.921447	11.990112	3.9407645	3.9968566	129.17532
9.7884778	10.385024	2.8438083	3.0692282	108.45801
1.0975768	1.1819188	0.58581424	0.59472115	10.064888
100%	100%	100%	100%	100%

Table 9 Boundaries of parameters and evaluations

It is obvious that if we guide the parameters at their optimal values the results we take are far more than satisfying. Here we can see that the total resistance for the best design for the slow speed can be reduced even more and catch a value up to 88KN. So if we decide that the we finally run at the speed of 15,5Kn we then have ready our optimized Swath

Now if we change our minds and switch at the high speed the results are again very promising, as the total resistance can be reduced at 503KN:

Attribute	Active	Active	Active	Active
Name	radmid	bstrut	lat_sep	lengthgon
Scope	parameters	parameters	parameters	parameters
Reference				
Lower Bound	0.55036622	1.2133822	4.06421	45.18555
Upper Bound	1.3452148	1.9986725	7.9600214	54.61181
Feasible Designs: 100 %				
Mean Utilization Index				
Mean	0.89846467	1.5064738	6.3460274	51.186514
Sample Standard Deviation	0.20462446	0.20149471	0.88438823	3.0189991
Error-free: 100 %	100%	100%	100%	100%

Active	Active	Active	Active	Objective
Lgonnose	Lgontail	Lstrnose	Lstrtail	eval_R31_Kn
parameters	parameters	parameters	parameters	
4.2846418	4.8666819	2.2353552	2.6805524	503.36764
9.9779355	10.987396	5.8653544	5.9942016	869.72263
7.3947091	8.3407384	4.0433937	4.4778151	580.03324
1.5475152	1.516371	1.046406	1.0115519	72.39357
100%	100%	100%	100%	100%

Table 10 Boundaries of parameters and evaluations

5.9 Comparison of AQ3 with AQ

Since this diploma thesis started with the data of the Passenger Ferry Aegean Queen (AQ, [13]), a comparison of the herein obtained resistance results should be made with those of AQ. So from the resistance curve of AQ the total resistance was found for two significant speeds. All results are compared at the following table:

Rt(KN)	AQ (tests)	AQ (predictions)	Best R155	Mostly R155	Best equal	Mostly R31	Best R31
<i>For the speed of 15.5 Kn</i>	250	260	113	119	138	169	212
<i>For the speed of 31 Kn</i>	645	565	642	568	541	524	516

Table 11 Compared results of AQ & AQ3

Table 11 compares the total resistance data of AQ(test results and numerical predictions) with the total resistance data of AQ3 (the best five designs as resulted from the optimization and presented at an earlier part of this diploma thesis) . As explained before:

Best R155 is the best design for the low speed ,
Mostly R155 is the best design for mostly the low speed,
Best equal is the best design for both speeds,
Mostly R31 is the best design for mostly the high speed,
Best R31 is the best design for the high speed.

From table 11 it is obvious that the models proposed here are much more efficient than AQ.

In this comparison however some important factors should be mentioned:

- The predicted values of AQ at the high speed proved much smaller compared to the experimental values, whereas the comparison at low speed is much better. This is attributed to various non-potential flow phenomena, like flow separation, but also the change of the mean draft and trim of the vessel that was not accounted for in the theoretical predictions..
- AQ had a constrained lower hull(gondola) and strut to fit the engines. This increases the total resistance of AQ compared to an unconstrained optimized design. AQ3 instead does not require this adjustment due to the fact that by the technological improvements of diesel engines of same power, they now fit in much lesser space (see characteristics of MTU engines, e.g. 20V 1163 TB73).

6. Conclusions

The work presented herein, demonstrated the applicability of an advanced technology ship design approach using parametric design tools for optimization at the conceptual design phase.

The preliminary design phase of Swath has been realized, utilizing parametric modeling tools in the FRAMEWORK of simulation-driven design.

In this case study, it has been achieved to build up a robust optimization model. Several sub-systems have been developed in order to cover many aspects of the design optimization problem that compose a fully automated package regarding the design of a novel, unconventional catamaran.

The core of this method is found in the fully parametric model, which is applicable to a wide range of global dimensions and local characteristics, retaining its fairness of shape and feasibility of its properties. It is generated using the tight coupling of the computer aided engineering tool FRIENDSHIP-FRAMEWORK, and the computer workbench MICHLET, (and the flow solver SHIPLFLOW).

Since the designer has developed all the subsystems and has carefully examined the interaction and dependencies that occur between the different factors, an extensive parametric variation study was undertaken in order to explore the feasible boundaries of a multi-dimensional design space. The final stage of multi-objective optimization, led by two Genetic Algorithms provided many favourable designs with rather competitive characteristics compared to existing ships of the same type and range, and other conceptual designs.

Regarding the investigated design concept, it was shown, that a special type of ship, a Swath, that is fully unconventional and without a parallel midbody has advantageous characteristics regarding powering demands from all aspects as shown above.

The greater advantage of all this coupling is time. There are so many design-optimization packages most of them trying to achieve as much precision as possible. The concept of this thesis is not precision but time. After the design process it can give the first results within hours without any special computer powering.

So the contribution of this thesis, while examining the overall work is as follows:

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- Development and application of a robust and very fast global optimization method for Swath design.
- Adoption of the method within one program (FRIENDSHIP FRAMEWORK) that is used for the geometrical modeling, simulation and optimization, using only MICHLET as an external software.
- Analysis of design variables sensitivities and use of them as design directives for a quick dimensioning during the preliminary design.
- Initial, global optimization of a Swath using the MOSA and NSGAI algorithm.
- Promising results of Swath design

Still, there are many unexplored regions. In order to achieve a greater degree of holism and improve the decision making process at the preliminary phase, more aspects of the ship design problem have to be integrated in the automated optimization process.

It seems that the multi-discipline task of ship design enters a new era, where the naval architect and the designer will have to embrace a totally new perspective. Parametric modeling and simulation-driven design have the potential to change radically the traditional way of thinking and acting in marine industry.

Finally some future perspectives are presented below for further work:

- Taking into consideration all these more work can be done when focusing more at the design process including all hydrostatic characteristics ,stability and damage stability and so on.
- Designing and optimizing the structural part of the vessel for least weight , better moments of inertia etc.
- Exploring the seakeeping characteristics especially at high speeds and rough seas, utilizing stabilizing fins.
- Economic and technical study with statistical data and risks assessments, adjusting the inner space in order to maximize the capacity of passengers and cars.
- Searching for a special type of propeller with better efficiency, studying simultaneously the wake around it.
- Converting the Swath to Slice and comparing the two types.
- Getting away from the conventional catamaran- Swath design and keeping this special hull form for more hulls so that wave resistance for some of the hulls can be greatly diminish.

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APPENDICES

APPENDIX A - TriSwath

The aim of this annex is to optimize the placement of individual hulls in a multihull configuration, in order to minimize wavemaking. No attempt is made here to optimize the shape of individual hulls. For a general multihull vessel, these are coupled tasks, but we consider here only a special case where they are uncoupled.

The name of the three-hull designed is TriSwath and the geometry is the same as the Swath designed at this diploma thesis but scaled by a factor of 0.66 in order to keep the displacement fixed at 1000t. The formation of the vessel is like an arrow and the placement of the individual hulls is as follows:

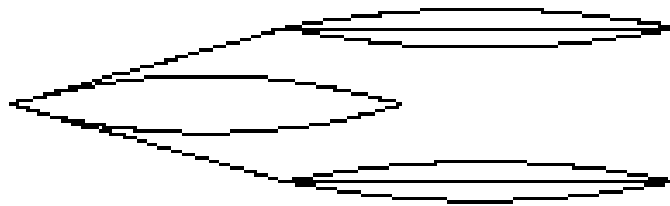


Figure A.1 TriSwath hull placement [19]

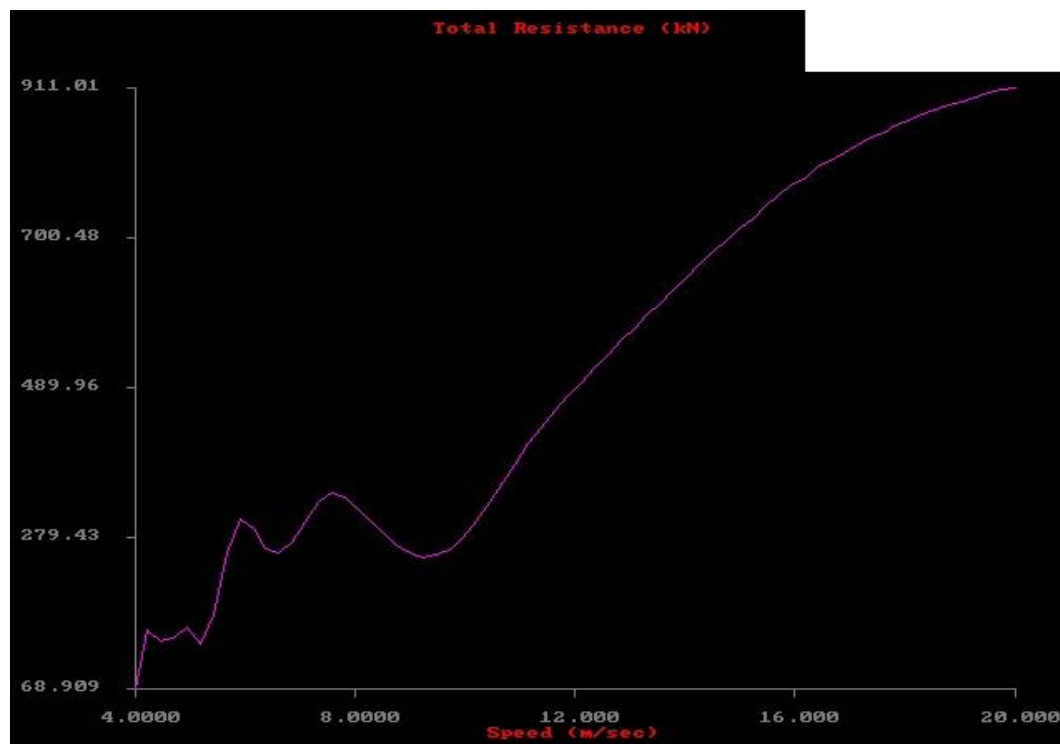
The above geometry was designed at FRIENDSHIP-FRAMEWORK and a DOE ran. As stated before the form of the hull did not touched but only the placement. That left only two parameters to explore. The lateral and the longitudinal separation. So Sobol algorithm was utilized with these parameters and evaluations the total resistance at the same speeds as the AQ3.

Attribute	Active	Active		
Name	lat_sep	long_sep	eval_R155_tri	eval_R31_tri
Scope	parameters	parameters		
Reference				
Lower Bound	3.15625	10.3125	155.25453	593.13305
Upper Bound	12.84375	29.6875	480.06862	947.44427
Feasible Designs: 100 %				
Mean Utilization Index				
Mean	7.9727746	19.983428	266.73609	829.11038
Sample Standard Deviation	2.8790697	5.7531561	72.029338	65.041477
Error-free: 100 %	100%	100%	100%	100%

Table A.1 Boundaries of parameters and evaluations

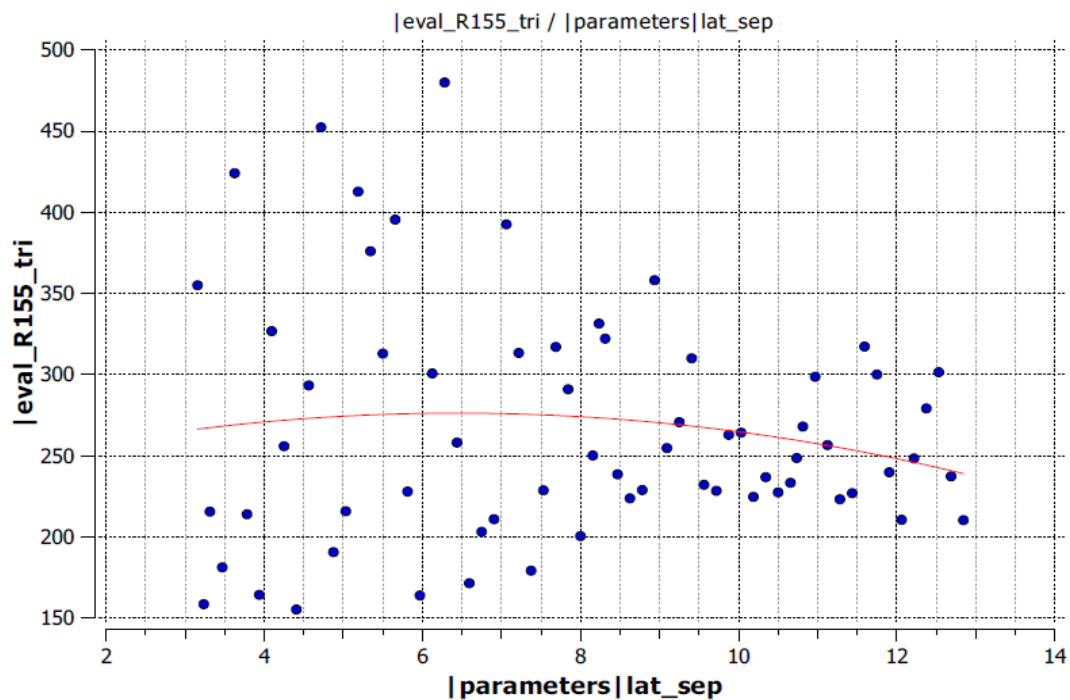
As we can see it is close to the best optimized values from AQ3. And this without a form optimization. Moreover it must not be forgotten that obviously the wetted surface is more than AQ3 something that means increased friction resistance. But the most interesting and promising at the same time is that the speeds we assumed is a random(the same as AQ3). At these exact speed the resistance curve does not present a local minimum(unlikely it is near a local maximum). So if a it is about to create a new model and we have the right to adjust the speed we need to run the results are awesome.

The resistance curve is as follows (from a random model of the Sobol results):



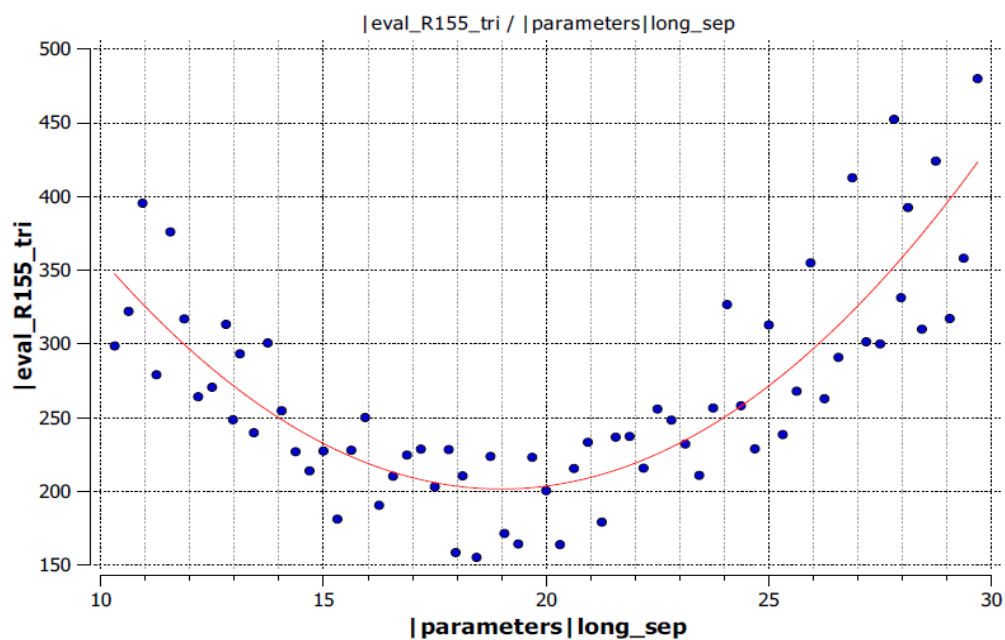
Graph A.1

Finally the trends of the longitudinal and lateral separation are presented:



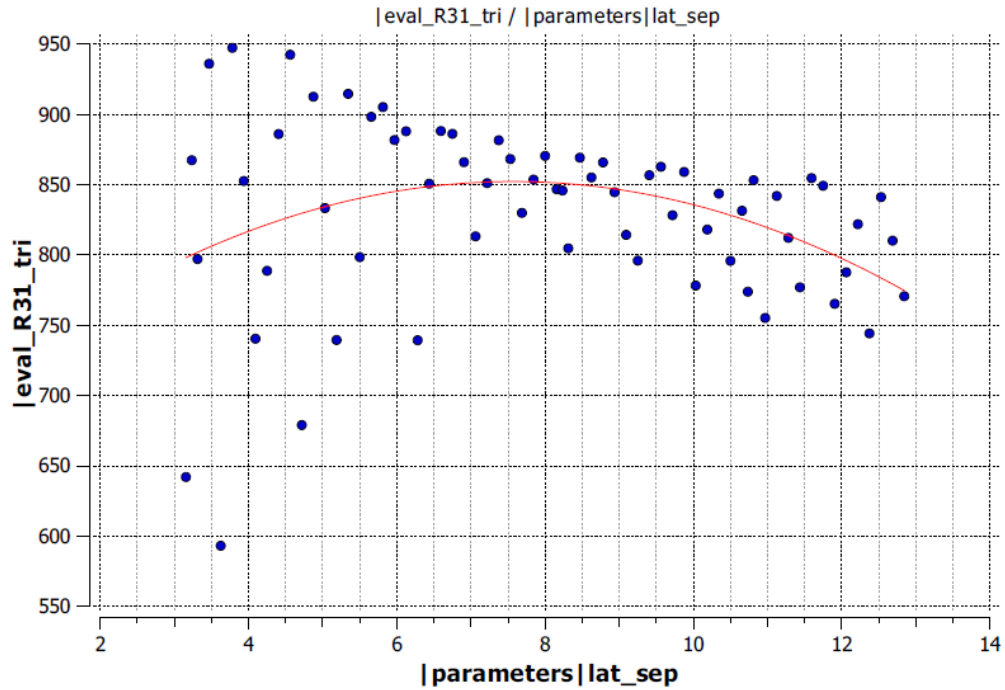
Graph A.2

The trend of the lateral separation here is not so obvious although as the parameter increases the R_t for 15,5Kn is stabilizing.



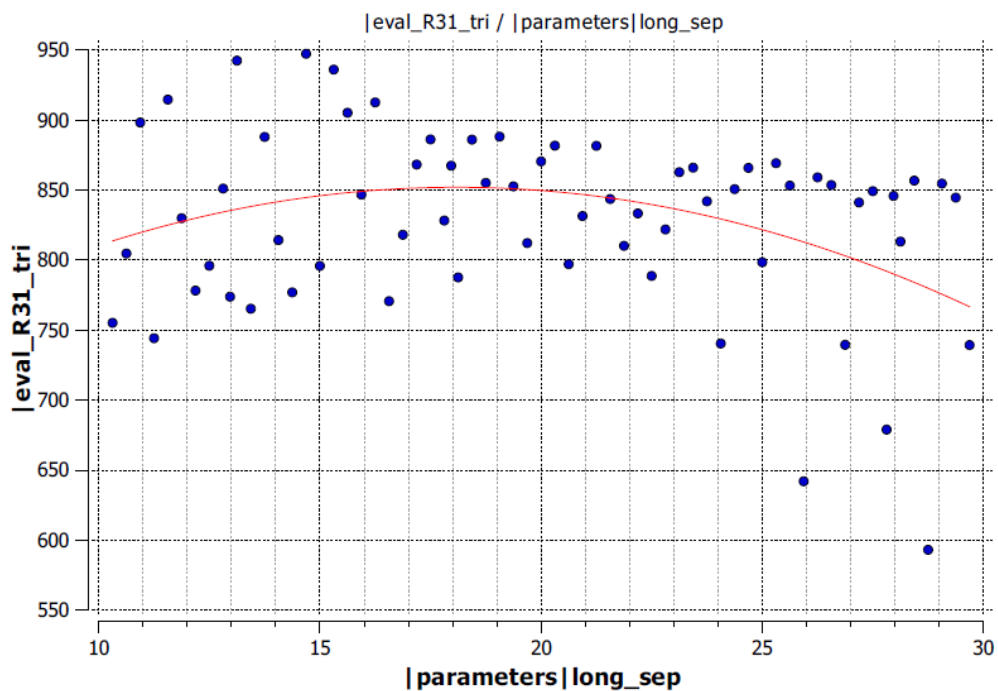
Graph A.3

It is obvious at the diagram that the least R_t for 15,5Kn is for parameter value of 17-21m



Graph A.4

The lateral separation for the high speed seems to be almost the same with the low speed. Just the scatter extends to a lesser degree. Again the trend is not so obvious.



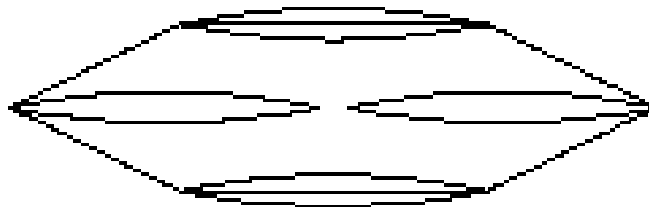
Graph A.5

Not the same with the low speed, although R_t at 31 Kn seems to decrease at the greater values of the longitudinal separation.

APPENDIX B - DiamondSwath

The aim of this annex is again to optimize the placement of individual hulls in a multihull configuration, in order to minimize wavemaking. No attempt is made here to optimize the shape of individual hulls. For a general multihull vessel, these are coupled tasks, but we consider here only a special case where they are uncoupled.

The name of the tetra-hull designed is DiamondSwath and the geometry is the same as the Swath designed at this diploma thesis but scaled by a factor of 0.5 in order to keep the displacement fixed at 1000t. The formation of the vessel is like an diamond configuration while all hulls are identical. The placement of the individual hulls is as follows:



DIA

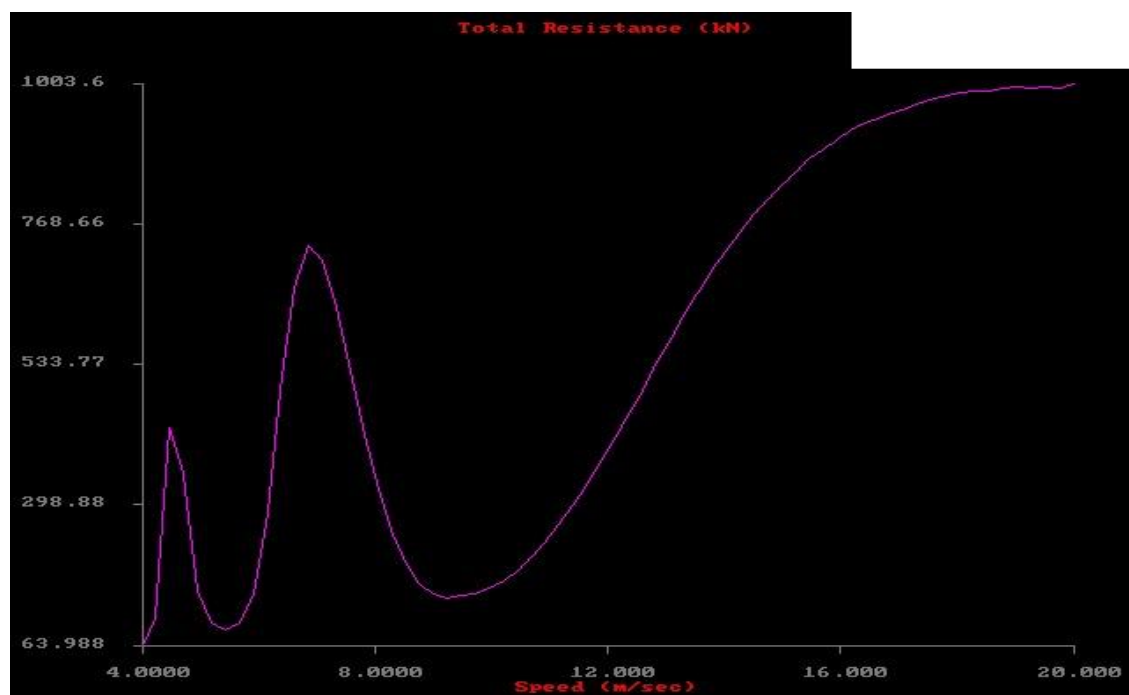
Figure B.1 DiamondSwath hull placement [19]

The above geometry was designed at Friendship-FRAMEWORK and a DOE ran. As stated before the form of the hull did not touched but only the placement. That left again only three parameters to explore. The lateral separation, the longitudinal separation and the longitudinal separation of the last hulls behind the others. In order for the optimization to be least complex the third parameters was considered as the longitudinal separation multiplied by two. So Sobol algorithm was utilized with these two parameters. Evaluations were again the total resistance at the almost the same speeds as the AQ3 slightly changed the slow one.

Attribute	Active	Active		
Name	lat_sep	long_sep	eval_R18	eval_R31
Scope	parameters	parameters		
Reference				
Lower Bound	3.1875	10.78125	136.20971	525.27443
Upper Bound	14.4375	34.609375	808.48636	1012.3346
Feasible Designs: 100 %				
Mean Utilization Index				
Mean	9.0392442	23.108648	428.74786	888.01159
Sample Standard Deviation	3.2231614	7.0096717	236.74881	113.50315
Error-free: 100 %	100%	100%	100%	100%

Table B.1 Boundaries of parameters and evaluations

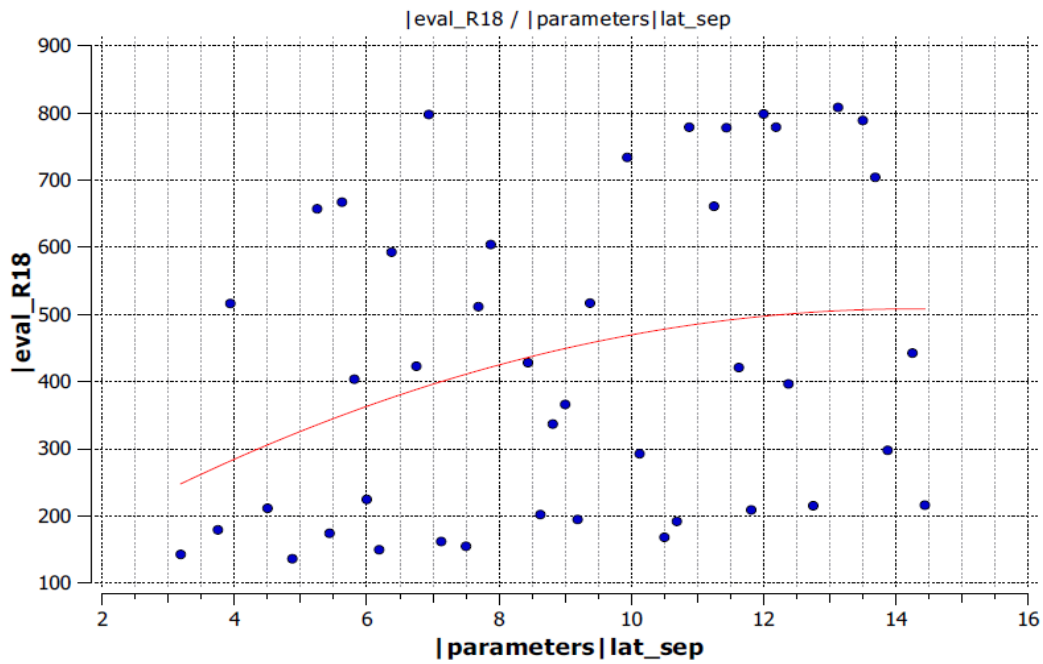
The results here seems to be more promising as the total resistance was reduced even more (without a form optimization). And it is easily understood that the friction resistance is far more greater. But now indeed we are to local minimum of the resistance curve (as stated below). Anyway the evaluations can also be diminished more.



Graph B.1

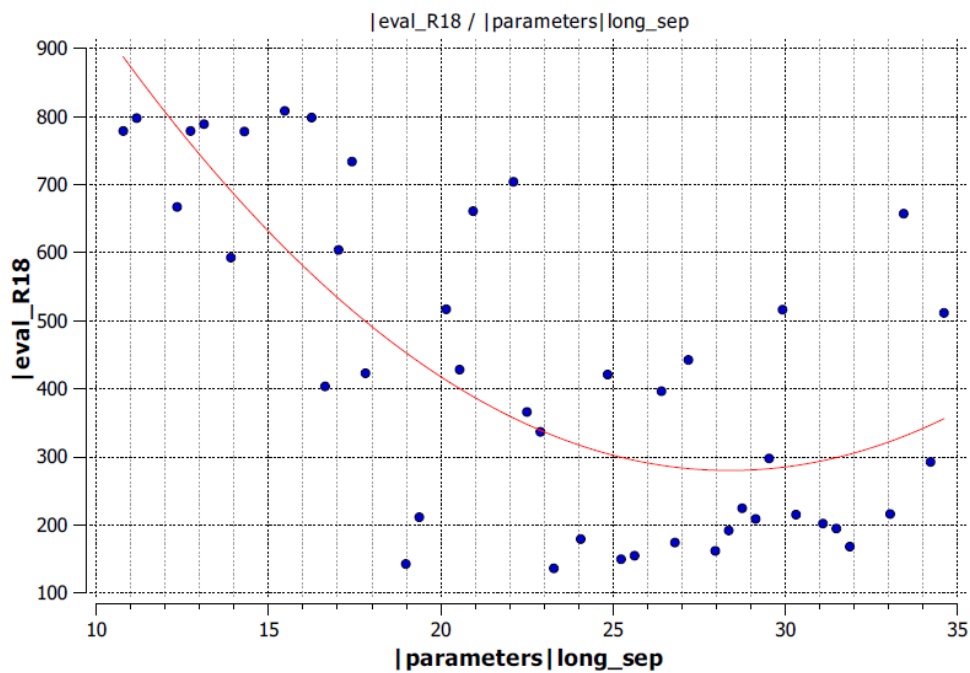
Finally the trends of the two parameters are stated below:

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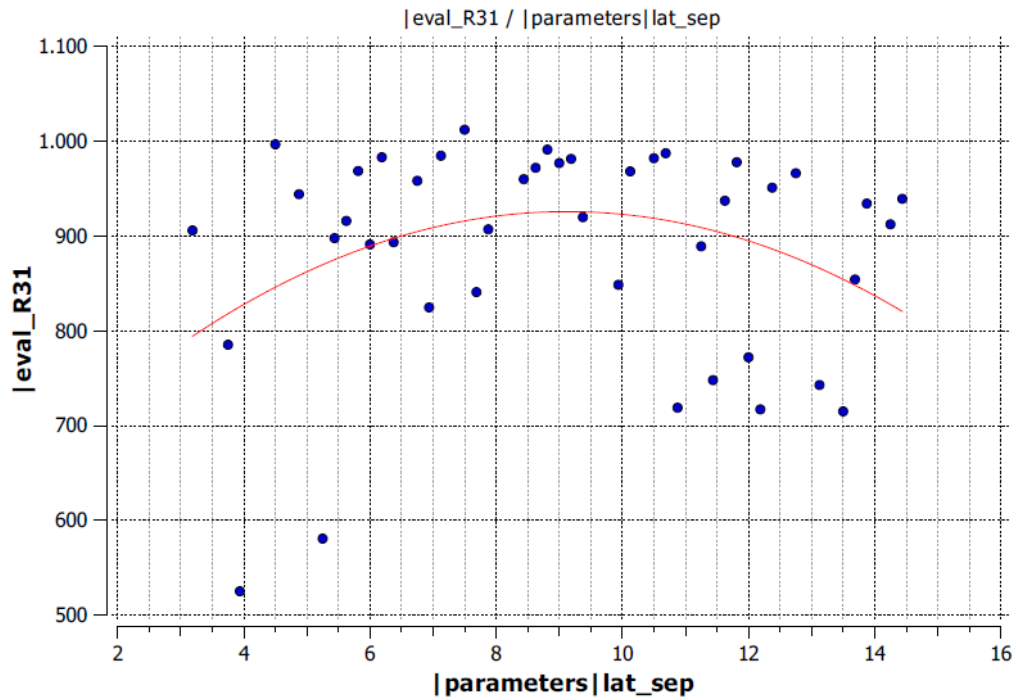
Graph B.2

Lateral separation seems to decrease for diminished total resistance at 18Kn



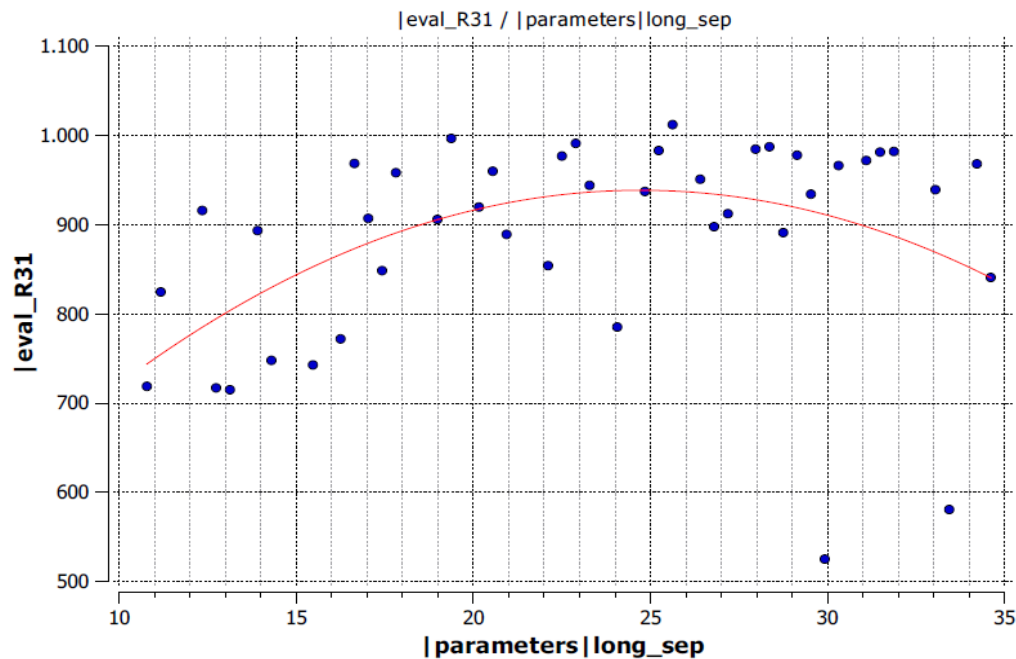
Graph B.3

Longitudinal separation tends to be around 25 m for least total resistance at 18 Kn.



Graph B.4

The trend here is not so obvious but some good designs and their values give a hint.



Again without being obvious the least total resistance for the speed of 31 Kn seems to be at very low or very high longitudinal separation values.

Graph B.5