

CHALMERS



Full Scale Test Case For Sailing Yacht Performance

Master of Science Thesis in Naval Architecture and Ocean Engineering

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This thesis is an attempt at evaluating performance of sailing yacht using full scale data as measured by regular onboard sailing instrumentation. Using standard sailing instruments connected to a computer, key performance data can be retrieved. Once processed, a database of performance can be obtained. Results of theoretical calculations from VPPs and DVPPs can be compared with reality for validation. It is proved that full scale performance data has become precise enough to be used scientifically.

This research has involved two sailing yachts, more than a year of sailing, a dozen of crew members, many advisors, family and friends. To all of you, thank you for your support, comments, help, friendship and understanding.

Maël GORMAND

The front page picture was taken on board “Le RM 1050” while going up the estuary of the Tagus, reaching Lisbon, Portugal. All rights are owned by LBDA and the crew of “Le RM 1050”.

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Abstract

The present master thesis investigates the possibilities of producing a full scale test case of the performance of sailing yachts. With such a test case, it is believed that instantaneous and absolute performance of sailing yacht evolving in real conditions can be investigated. An out-put of this study is the ability to validate a velocity prediction program with full scale data.

Through the use of a sailing yacht, a procedure for performance measurement at sea was developed. This procedure involves the use of on-board electronic instrumentation, displacement measurement and inclining test. A code is developed in Excel©, using VBA© to sort all the data gathered during the measurement campaign. The sorting of data involves the compilation of a database used for plotting the performance of the yacht in two different ways: the first to analyse the instantaneous behaviour of the yacht; the second to analyse the maximum potential performance the yacht can reach. The measurements can then be compared with simulations produced in the “same” sailing condition using a VPP. In this paper, two VPPs are investigated: SailSim© from SSPA AB and WinDesign© from the Wolfson unit at the University of Southampton. The first software has dynamical capabilities but was not used in the end for this research. The second one has only static capabilities and was used for the simulations in the present work. From the comparison between the measurements and the simulations, the quality of full scale data is established and the possibility to validate a VPP using standard sailing electronics is demonstrated. Further development is also suggested and further analysis involving full scale data is proposed.

In the present master thesis a universal method to record sailing yacht’s performance data at sea was developed. Then a code to process these data and sort them into a general database useful for further studies was built. It was proven that the quality of nowadays electronics make scientific studies possible. Finally it was demonstrated that standard velocity prediction programs can be validated by full scale data.

Keywords: VPP, DVPP, Yacht, Performance, Full Scale, Measurement

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List of Symbols and Abbreviations

a	Horizontal displacement of the pendulum during inclining test
\overline{BM}	Distance from the centre of buoyancy and the metacentre
B_{max}	Maximum Beam of a boat
CAD	Computer Aided Design
CAED	Computer Aided Engineering Design
CFD	Computational Fluid Dynamic
CSE	Computational Structural Engineering
d	Weight translation distance in inclining test experiment
DC	Direct Current
DSYHS	Delft Systematic Yacht Hull Series
DVPP	Dynamic Velocity Prediction Program
FEM	Finite Element Method
$\overline{GG_1}$	Shift of centre gravity location distance in inclining test experiment
\overline{GM}	Distance from the boat's centre of gravity and the metacentre
GMT	Greenwich Meridian Time
GPS	Global Positioning System
GUI	Graphical User Interface
IMS	International Measurement System
IP	Internet Protocol
IT	Information Technology
I_w	Second moment of area of the water plane area of the boat
l	Length of the pendulum for the inclining test
\overline{KB}	Distance from the keel to the centre of buoyancy of the boat
\overline{KG}	Distance from the keel to the centre of gravity of the boat
LoA	Length over All, the maximum length of a boat
LwL	Length on Waterline, the length of a boat at waterline level

Continued on next page

m	Mass of the weight used during the inclining test experiment
Mac	Macintosh computer (from Apple inc.)
$M_{Heeling}$	Moment on the sailing boat that force it to heel
$M_{Righting}$	Moment on the sailing boat opposing heeling
NACA	National Advisory Committee for Aeronautics
NMEA	National Marine Electronics Association
NOAA	National Oceanic and Atmospheric Administration
ODE	Ordinary Differential Equation
PC	Personal Computer
Rhino	Rhinoceros 3D v5.0 Wenatchee from Robert McNeel & Associates
SoG	Speed over Ground
SoW	Speed over Water
T_c	Draft of canoe body (draft of the boat excluding the appendages)
T_{max}	Maximum draft of a boat (including appendages)
USB	Universal Serial Bus
VCB	Vertical centre of Buoyancy, with respect to the waterline, positive downward
VCG	Vertical Centre of Gravity
VB	Visual Basic
VBA	Visual Basic Application
VMG	Velocity Made Good
VPP	Velocity Prediction Program
$\nabla_{sailing}$	Volume displacement of a boat in sailing condition
$\Delta_{lightship}$	Weight displacement of a boat in lightship condition
ρ	Density of sea water in $[kg \cdot m^{-3}]$
φ	Angle of heel achieved during the inclining test experiment

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- Mr and Mrs Eklund (owner and crew of “Vågvis”)
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Chapter 1

Introduction

1.1 Tools used in Naval Architecture

To better understand the importance of the work carried out during this master thesis, an insight at the art of naval architecture and its tools is necessary. Several techniques in use today in the design of sailing yacht will be discussed.

1.1.1 CAED design

Since the era of computers, many things have changed in the process of design. Before, drawing fair lines could take a month or more to an experienced draughtsman, now it takes only a couple of days with CAED. CAED stands for Computer Aided Engineering Design. This term covers various tools used by engineers and naval architects in today's world: Three dimension Computer Aided Design (3D CAD); Computational Structural Engineering (CSE); Computational Fluid Dynamics (CFD); Production planning; Velocity Prediction Program (VPP)...

Such tools have eased significantly the design process, leaving time for engineers to go deeper in their search for better designs. For example, 3D CAD, allows one to design a virtual hull in three dimensions and to know quickly its stability properties and its habitability. If going further into the design, it is possible to draw various details that ensure a better comfort on board. CSE (Computational Structural Engineering) software allows engineers to ensure that the hull or any other important structural element have sufficient strength throughout the boat's lifetime. CFD (Computational Fluid Dynamic) is used to optimise the shape of the hull and lower its resistance to motion. It is also used to "measure" the lift and drag resistance of the hull and different appendages in order to ensure the boat is well balanced, and

that it has sufficient steering capabilities or engine power. Production planning is a new era of CAED. With such a tool, it becomes easier to plan the production of the boat by better controlling orders and manufacturing processes; thus reducing the costs while optimising the production time. Though these tools are not used everywhere, their importance into the design process is continuously rising.

The last of these software is the Velocity Prediction program (VPP). VPPs are based on empirical studies and on sailing theories. This type of software is part of the subject of the present study.

1.1.2 Empirical studies and sailing theories

The art of naval architecture became slowly a science as people like Archimedes, Leonardo Da Vinci, Newton, Bernoulli, among others, started investigating flow patterns. Specially, in naval architecture, breakthrough was possible through the more specific work of Chapman, Froude and followers. In particular, systematic tank testing has allowed the derivation of empirical formulae describing the resistance to motion of a boat. Since the nineteen sixties, a systematic study on sailing boats parameters influencing the behaviour and performance of a boat at sea has been carried out at the Technical University Delft, in the Netherlands. The empirical formulae derived from their research together with sailing theories as derived by Marchaj and al, at the Wolfson Unit (University of Southampton, UK) or throughout different universities worldwide, have led to the derivation of general formulae that can be used to predict performance of sailing boats.

The sailing theories based on general mechanics and on fluid mechanics are, generally, too complicated to be used for engineering. The empirical formulae describing the same phenomenon but from a “practical” point of view makes engineering possible. However, the limitations are great on empirical formulae as only phenomenon inside the boundary of the study can be predicted to some accuracy. Even though, validation is necessary as, depending on the way the original experiment was conducted, significant deviation to the rule might be observed.

The typical tool to validate theories and empirical formulae is the towing tank, where a scaled model is towed in order to measure different forces like lift and drag. Eventually, as theories are refined with more experiments and better explanation of deviations to the rules, relatively accurate prediction of performance can be obtained mathematically (typically with VPP software). Other tools like CFD or CSE counteract the problems by making use of direct exact mechanical formulae and the computing power of computers.

1.1.3 CFD and CSE

CFD (Computational Fluid Dynamic), solves the Navier-Stokes equations of motion for a viscous fluid. CSE (Computational Structural Engineering), computes the stresses and strains in a solid. Each method requires large amount of computer power as they solve such equations for very small elements (either fluids or solids) dividing a larger volume. Applying external forces and boundary conditions, it is possible to determine to some accuracy the motions and stresses (as applicable) in any element of the volume. Thus, it is possible to determine the flow pattern around a rigid body, or the deformation of a rigid body, subject to external forces.

In naval architecture, both methods are of interest. While CSE can be used for predicting both the deformation of a rigid body and the flow patterns around a rigid body, CFD applies only to prediction of flow motion where it is known to be significantly more accurate. CSE can be used to model the deformation of a ship under wave loads. CFD can be used to reduce the resistance of a boat and optimise the flow entry in the propeller disk. It can also be used to optimise the shape of sails, keels and rudders in the particular case of a sailing boat.

While CSE is a good engineering tool for optimisation of sailing boat structures, CFD is still too expensive and slow to perform optimisation in small design offices. The use of tables or empirical formulae is still relevant for most of the boats of today as the design process is usually significantly quicker and the resulting designs performance sufficiently accurately predicted. The last kind of software available to a naval architect uses either empirical formulae or input from CFD software to predict the velocity a boat can reach.

1.1.4 Velocity Prediction Programs

Velocity Prediction Programs are the particular subject of the present work. This software uses the different tools available to a naval architect to predict the performance of sailing boats at sea. A paper by Peter van Oossanen^[3] published in 1993 gathers all the necessary equations and sources of information to make a proper VPP. This paper has been the starting point of most VPPs developed to date.

VPPs, as described in Van Oossanen paper, use parametric definitions of the hull, sails and appendages of a boat to solve either empirical or theoretical equations of motions, resistance and equilibrium. As a result, it is possible, if the parameters are within the boundaries of the studies defining the mathematical models, to calculate the speed a sailing boat can reach being given a particular wind strength and direction. Typically, VPPs give as an output,

polar curves that describe, for every true wind angle and strength, the speed the boat achieves. With such output, it is possible to adapt the design to suite particular needs like increasing the overall velocity made good (VMG), or getting a better reaching speed, etc.

VPPs have been developed in newer versions called DVPP (Dynamic Velocity Prediction Program). This second set of VPPs is different in that it can simulate the motion of the boat in waves instead of a static boat on a static sea, thus being dynamic. The interesting feature of this particular type of VPPs is that performance can be output for different sea states. Ocean racers but also ocean sailors would certainly appreciate sailing on boats that are faster or more comfortable at sea. It could also be important for designers to know what is the typical behaviour of their designs in a storm, etc. There is a large amount of possibilities with such dynamical software.

The main inconvenience of VPPs and DVPPs is their dependency on experiments. Such experiments are typically carried out on models in towing tanks or in wind tunnels. The accuracy of a resulting design is therefore depending on the accuracy of the experiment on a scaled model and on capacity of the scientist to isolate a physical phenomenon from other phenomenon that are usually coupled together in real life. As history has shown, engineers and scientist predictions are not necessarily validated when going to full scale. Giving a tool to engineers and scientist to validate VPPs is the main goal of the present master thesis.

1.2 Genesis of the project

The present project has originated from the conjunction of several unlikely events:

1.2.1 Voile Magazine, Fora Marine and M. Lombard

During the first year of my master of science degree, I met Stanislas Paillereau, who was involved in a contest organised by “Voile Magazine”, a French sailing magazine. Stanislas, together with Florian and Gregory had presented a project to answer the call from Voile Magazine: “What would you do with a Sailing boat for one year”. The three young students presented a project involving sailing around the Atlantic ocean for a year and keeping contact with children from a Hospital in Compiègne to give them dreams to continue their fight against long illness. The three friends wanted a fourth comer to make the life on board easier. That’s how they accepted me just before they received the confirmation from Bernard Rubinstein, the chief editor, that



Figure 1.1: The crew of “Le RM 1050” the day of departure in La Rochelle, Sunday 3rd of July 2005. From left to right: Florian Le Boulicaut, Stanislas Paillereau, Mael Gormand and Gregory Romain

they won the contest, in December 2004.

From there on, with Prof Lars Larsson, main supervisor of this project, it was decided to use this opportunity to perform measurements at sea on sailing boat performance. The naval architect of the sailing boat that was to be used, Mr Marc Lombard, was contacted, as well as the Shipyard, Fora Marine©.

All the stake-holders (Fora Marine, Voile Magazine, Marc Lombard, Lars Larsson) agreed on the project’s goal. Marc Lombard only placed one condition to the full use of his data: that none of the critical data like hull lines or key performance parameters could be published. This is understandable as “Le RM 1050”, the type of boat he designed and that was to be used by the winners, is a relatively new and successful design. “Le RM 1050” is presented in figure 1.2, in page 6.

1.2.2 Journey with “Le RM 1050”

The journey was to take the team from France to France visiting the following countries (see also figure 1.3, page 8):

- United Kingdom (The Scilly Islands, The Bermuda)



Figure 1.2: “Le RM 1050” sailing off the coast of Madeira the 5th of September 2005, two months after departure.

- Ireland (west coast)
- Spain (west coast, The Canarie Islands)
- Portugal (West coast, Madeira and The Azores)
- Morocco (Casablanca)
- Capo Verde
- Brazil (Amazon river)
- Fance (Britanny, French Guyana)
- Trinidad and Tobago
- Venezuela (Margarita, Los Roquès, Los Avès)
- The Netherlands (Curaçao)
- Panama (The San-Blas)
- Costa Rica (East coast)
- Belize
- Mexico (Yucatan coast)
- Cuba (La Havana)
- The Bahamas

1.2.3 SSPA and Chalmers

While the measurement part of the thesis was becoming clearer, it was still necessary to find a VPP. SSPA AB had developed one such software during its different involvement with the America's Cup in the late 90's early 2000's. Thanks to Professor Larsson and his contact inside the company, a copy of SailSim©, a dynamic velocity prediction program based on SimNon©, another in-house software from SSPA AB, could be obtained.

SailSim© was intended to be used for validation as it is a promising software (dynamic effects are taken into account in this software). Peter Ottosson from SSPA AB, helped on explaining how the software was developed and on how to use it. When it was discovered that SailSim© could not handle twin keel design like "Le RM 1050", he thought of some modifications that

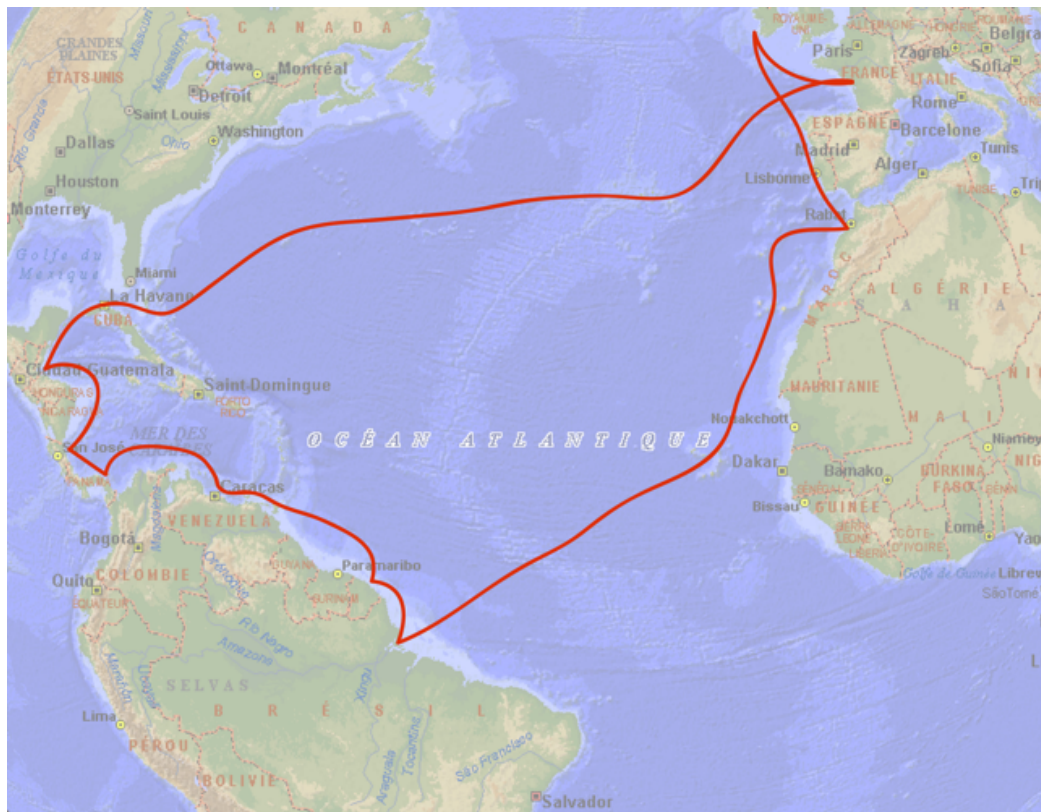


Figure 1.3: The journey of “Le RM 1050” from July 2005 to June 2006

could be given to the software's code to account for this specificity. However the modifications to the software were not done, due to a lack of time on SSPA AB's side.

The measurements recorded on board "Le RM 1050" had to be dropped during winter 2006-2007 and another more conventional boat was necessary to validate SailSim©.

1.2.4 Gabriel Heyman and Mr and Mrs Eklund

Gabriel Heyman, a Swedish naval architect, heard of the problems on this project. Contacted with the precious help of Nicolas Bathfield in spring 2007, he agreed on giving us his data on one of his designs and to contact the boat's owner to see if it could be possible to come on board and do measurements. Gabriel Heyman contacted Mr Eklund, owner of "Vågvis", a 60 feet sloop. Mr Eklund agreed to have us on board during one of his sailing journeys between Sweden and Denmark. Together with his wife, they hosted us on two occasions on board to measure the performance of Mr Heyman's Design. Gabriel Heyman agreed on lending us the material for "Vågvis" under the condition that critical data would not be published.

The journey with "Vågvis" involved a trip between Helsingborg and Copenhagen, and a second journey between Skillinge and Kalmar. The journey can be seen in figure 1.4, page 10. Details of the second journey can be better seen in figure 1.5, page 10. "Vågvis" can be seen in figure 1.6, page 17.

1.2.5 The Wolfson unit and WinDesign©

While the work with "Vågvis" was carried on during spring 2007, it became clear that SSPA AB could not, temporarily, give support on SailSim©. It was therefore necessary to obtain another VPP to prove that validation with full scale data was possible.

The Wolfson Unit at the University of Southampton was therefore contacted. They are well known for their research on yachts and yacht design. They developed a VPP (static version only) that is commercialised (unlike SailSim© which is only for internal use at SSPA AB). WinDesign©, the software from the Wolfson Unit, was therefore purchased by the department of naval architecture at Chalmers University of Technology.

In the end, WinDesign©, was the software used for validation in the present project.

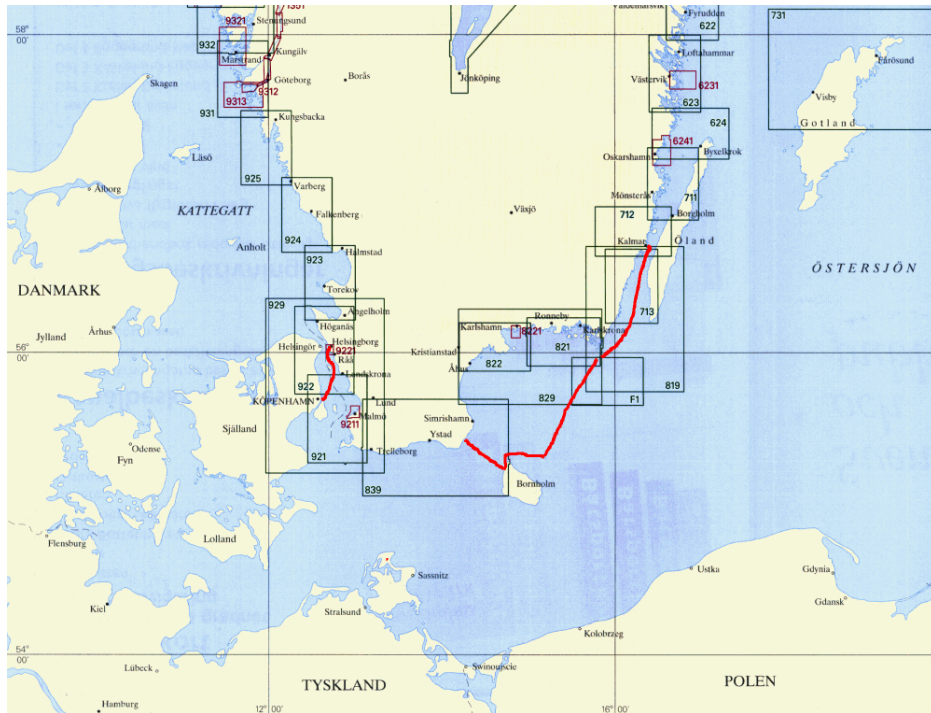


Figure 1.4: The journey with Vågvis in May-June 2007

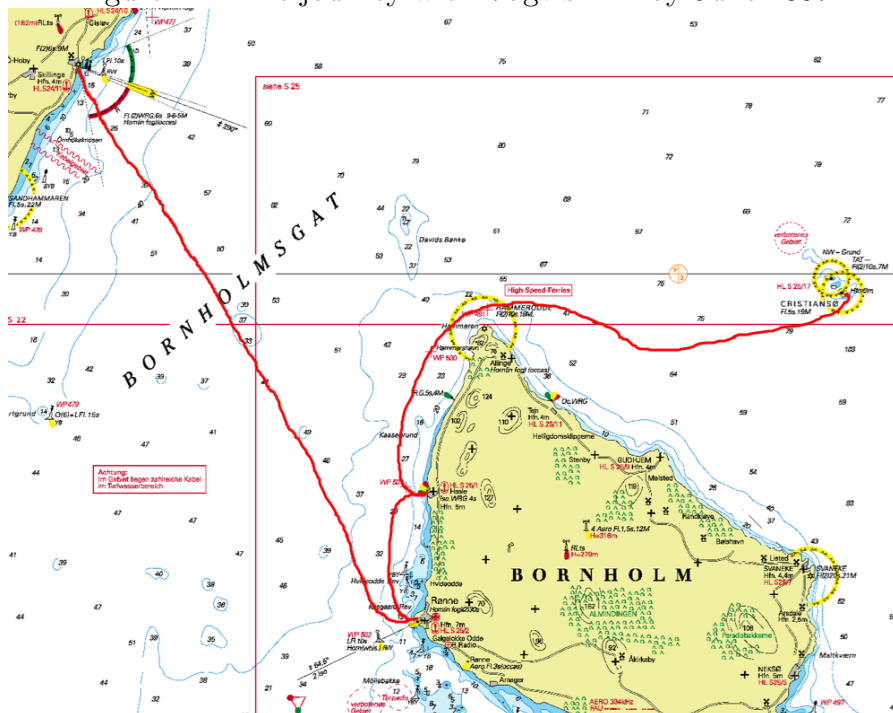


Figure 1.5: Detail of the journey with Vågvis on the island of Bornholm

1.3 Goal of this master thesis

This thesis will cover four different aspects related to some extent to velocity prediction programs and their validation. All these aspects were covered, but not all reached the expectation defined at the start of the project. The different goals are described as follows:

1.3.1 A procedure to measure performance of yachts

The first task was to determine the possibility of measuring the performance of a sailing boat at sea in an inexpensive manner.

The goal is to give anyone a way to measure the performance of his own boat, and also to help naval architects to assess the quality of their prediction by giving them a tool to measure the performance of their new boat design.

If the measurements are precise enough and if the data treatment procedure is careful enough, then, the polar curve that can be output to describe the performance of the boat at sea, should be accurate enough to understand either problems that occurred during the manufacturing process, or problems in the original conceptual design of the boat.

The idea of this work is to allow designers to create their own data base of true polar curves. They can use it as verification tools, or as a background for their future designs. The goal is also to help them assess the accuracy of VPPs and to help them integrate this new kind of tool in their design process.

1.3.2 The use of VPPs in the design process

In this project, VPPs are not exactly used for design but for reverse engineering instead. Starting from an original design and using it as an input to the VPP, we try here to get a result as close as possible to reality. This is latter explained and detailed in section 1.3.4, page 12.

But, even though the VPPs are not used for design, they are used nevertheless to obtain an accurate result that could very well be originated inside a design process. The data necessary to run two different VPPs (SailSim© by SSPA© and WinDesign© by the Wolfson Unit) were collected and used to produce polar curves. The limitations of each software were also investigated as well as their strengths and weaknesses, specially with regard to the first goal of this project.

1.3.3 A test case for various weather conditions

In this thesis, two VPPs were originally meant to be studied. A statical VPP (WinDesign©) and a Dynamical VPP (SailSim©). The interest of DVPP is that they allow evaluation of performance through “real” sea states that the boat is likely to encounter throughout its life. Validation of such a program becomes more difficult as testing a model in a wave towing tank is expensive. If one could produce accurate full scale data in different weather conditions, then validation of the prediction through real sea states could become possible.

Although this part of the project was well prepared, it turned out that realisation had to face serious problems. This has greatly altered the quality of the results. Anyhow, even though the results are not of sufficient quality to be studied as such, the experience obtained should provide a good start for a more extensive investigation.

1.3.4 Validation of a Velocity Prediction Program

The last goal of the project was to validate either a VPP or a DVPP with full scale data and investigate their accuracy in relation to what sailors do experience in reality. The ultimate goal of any scientific research is to understand reality in its complexity. However, to do so, it is necessary to isolate every aspect of the problem. In this way only, the mind manages to unravel the mysteries of nature.

But if breaking down a phenomenon to different small pieces is necessary, one should not forget that in the end, all the different laws that were found have to be assembled again into one masterpiece. This is the goal of a VPP: it uses all the different mathematical definitions of the motion and behaviour of a boat at sea, in order to predict the overall picture of its performance as a polar curve.

However, the masterpiece may not resemble the original picture. It happens that through our quest for understanding, sometimes, we mis-interpret facts and therefore derive the wrong equations. Validation is a key to make sure that the masterpiece is indeed accurate and a true picture of reality.

The last goal of the present work is therefore to validate the accuracy of a VPP, by the use of the polar curve created from full scale measurements. Though this work does not provide answers on discrepancy in the equations of the VPP (this is far beyond the scope of the present work), it helps pointing out where the problems occur.

1.4 Organisation of the work

During this thesis, several tasks were carried out at the same time. We distinguish the following subjects:

1.4.1 Literature and “tools” survey

Since the literature survey was not as successful as expected, no specific part will be dedicated to it. Special comments about literature will be inserted as needed throughout the present report. However, several points are worth noting:

Literature survey

The first quick insight into the literature survey shows clearly the lack of data on subjects related to sailing yacht performance. The original goal was to find either data or studies on the subject, and improve them. After extensive research hardly any papers were found on the subject.

The most interesting paper used for this master thesis is the paper by Peter van Oossanen on “Predicting the speed of sailing yachts”[3]. This paper is seen by many as the corner stone of every velocity prediction program. It derives or combines all the different equations of motion for a sailing boat known at that time. This paper was used to understand the mechanism of VPPs.

The second interesting book is “Aero-Hydrodynamics of Sailing” by C. A. Marchaj[1]. This book, also called “The Bible” by many naval architects, is the product of decades of research at the Wolfson Unit, at the University of Southampton. While the part about performance prediction is really short (a page), the rest of the book gives a very good insight on the workings of a sailing boat. This book was a good source of inspiration for this thesis because it describes a lot of different experiments.

Lack of information on performance

Even though the books and papers found, gave good insight into the subject, it would have been helpful to find more papers on the matter of sailing boat performance predictions or measurements. It is evident that many people in the yachting world do carry out a lot of research: competition is the main driver for most of the tremendous development that the yachting industry went through in the past decades. However, it seems like nobody really wants to reveal its findings, specially not naval architects or racing teams.

From time to time, some research can happen with teams that have a lot of experience, but often, the researchers are bounded on their publication by secrecy agreements. This is one point of the interest of this work as it is independent from racing teams. The only restriction concerns the data about the sailing boats used for the measurements. But people interested in further study can contact each architect for more information on their designs.

The tools survey

The literature survey included, in our case, a tool survey. The goal was to identify the most suitable tools for the present work, being given the particularities of the project. This was a much more fruitful study. If most of the solution were not kept for various reasons, it is worth noting that special recorder machine, sound Doppler velocity probes, laser Doppler velocity probes, among other solutions, were investigated. Accelerometers were also thought of, but not used as too weak on the long run for the particular scope of this project.

1.4.2 Workflow diagram

Figure 1.7, page 18, shows the procedure used to achieve the different goals of this thesis. There are mainly seven groups in this procedure, as can be seen in the flow chart:

1. A literature/tool survey was carried out
2. A strategy was designed in order to achieve the goals of this thesis
3. Measurement procedures were developed and assessed with feedback from previous measurement campaigns.
4. A code was developed with Visual Basic Application (VBA©) in order to process the measurements. The process was adapted to the specificity of each boat's electronic system.
5. Computer simulations were carried out based on the set up of the measurements.
6. A validation procedure was discussed and used to verify the possible validation of VPPs with reality.
7. Finally conclusions were derived from the present work.

1.4.3 Measurements

The second chapter of this work concerns measurement. This was a major part of the work in this project. The opportunity of using a sailing boat for long distance sailing over an entire year is seldom given to academics. Gathering of data was therefore of prime interest. Due to the prices of equipment and the remoteness of the journey, the decision was taken to study the performance of sailing boats, as no extra tools were necessary apart the standard navigation instruments.

Two boats were used for the measurements, each with its own specificities. Each particularity influenced the measurements. The boats will be presented. This chapter will describe and explain the different methods used to measure the performance of these sailing boats at sea. The different steps will be explained and criticise. The measurement part leads to the next chapter on data treatment:

1.4.4 Data treatment

The measurements being done, it was necessary to process the data in order to get an output useful for the target of the present work. Since the language of the instrumentation was not easy to use, it was necessary to build a code with Visual Basic© to process the data and retrieve the necessary information regarding the boat performance.

In this chapter, the way data was organised and the way to produce a polar curve from measurement are explained. Several plots representing the boats performance are presented.

This part of the work is by far the biggest in this thesis. This is due to the complexity of the NMEA language used by most marine instrumentation, and to the need to develop a code that could be further enhance in the future. This chapter will explain the code developed and some part of the development process. Further information regarding details on the code can be found in the appendices.

1.4.5 Computer simulation

Computer simulations were carried out in order to compare measurement data with results from a VPP or a DVPP. Two software were investigated:

- 1 SailSim© from SSPA AB
- 2 WinDesign© from the Wolfson Unit

The goal of the computer simulation is to prove that the results given can actually be compared with full scale data. The simulation had to be carried out using the “exact” measurements environmental input in order to get a proper comparison. Simulations were therefore carried out at a later stage of the present work. However, from the start, it was ensured that the simulations could be done correctly compared to the measurements, and specially to the type of boat used for the measurements. As such, SailSim proved incapable of handling the twin keel design of “Le RM 1050”, which led to the use of “Vågvis” for the measurements. Then lack of support in the simulation stage led to the purchase of WinDesign, another VPP, as will be described later. The simulations consisted in producing a numerical model of the hull and its appendages. Both boat’s architects gave a 3D CAD file on Rhinoceros 3D© in order to produce such numerical models. Then this numerical models were set to the actual conditions measured during the full scale experiments. The CoG and the displacement were systematically measured and used as input for the simulations. The numerical models were run in the same wind and sea conditions as during the measurements. The output, a polar curve, was produced and used in the validation.

1.4.6 Validation, discussion and conclusion

At last, the results from the full scale measurements and the simulations are compared. Based on a first assessment of the quality of both results, it is possible to determine the possibility of comparing full scale performance data to simulations.

Once this step is take, we can assess the accuracy of simulations compared to full scale measurements. With the comparison in hand, it is possible to validate the different VPPs used in the study based on their output polar curves data.

In the end, a discussion on the method and its output will be held. Weaknesses and strength of the presented work will be assessed and future developments or connected areas of research will be proposed, ending the present study.



Figure 1.6: Vågvis in Christiansø, Denmark during the displacement measurement. Notice the calm weather condition encountered.

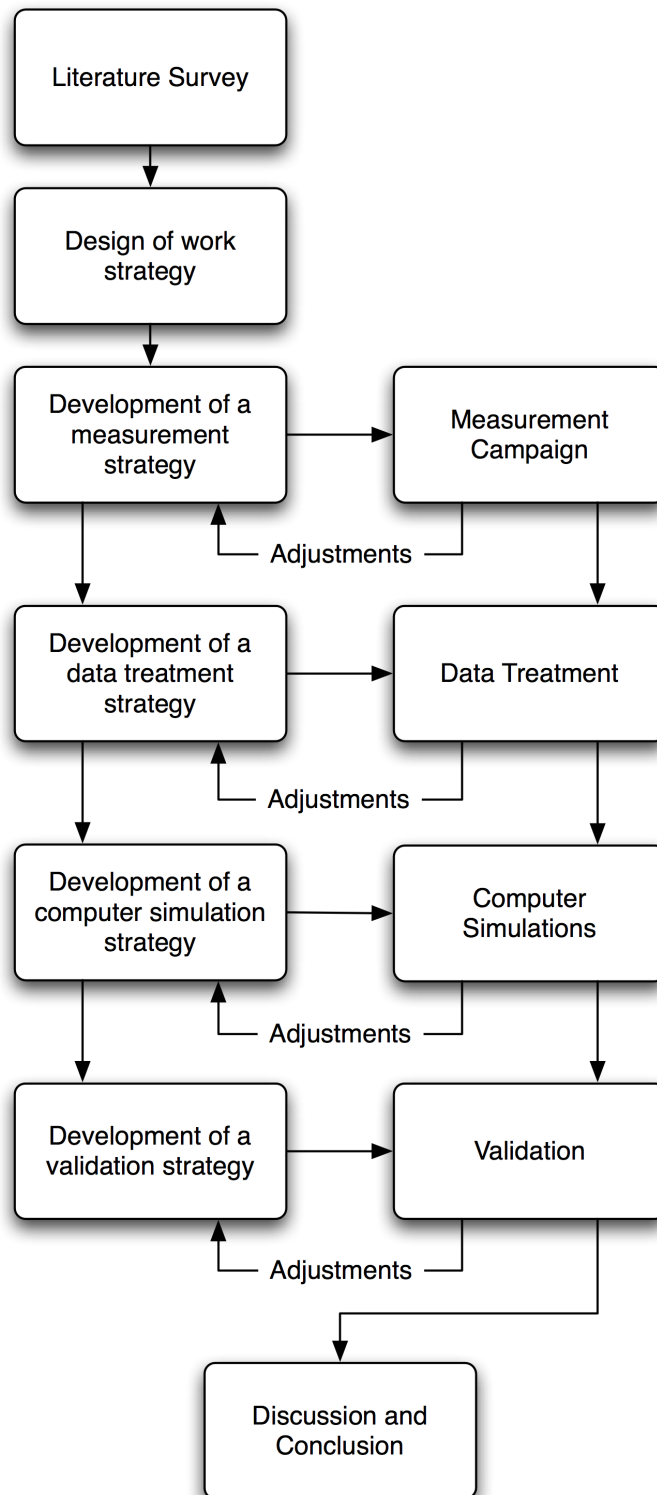


Figure 1.7: General Workflow diagram

Chapter 2

Measurements: theory, goal and set-up

2.1 Goal of the measurements

2.1.1 Create a polar curve database in still water and waves

The first goal of the measurements is to create a useful database of performance of a sailing yacht, both in waves and in still water conditions. With such a database, precious information can be gathered on the performance of a sailing yacht in static but also in dynamic condition.

If the static part of a yacht's behaviour is fairly well understood and modelled, the dynamic part is more critical (see [1] and [3]): scale effects and wind/wave/current interactions make its modelling difficult to validate. For example, it is impossible to scale a yacht's model to both the Reynold's number and the Froude's number. The first one governs aero-hydrodynamical effects while the second one describes the interface between air and water and their interactions.

When using full scale data, although interactions cannot be clearly identified and separated, the data are still precious to validate coupling of different numerical models. Indeed, the goal of every model is to describe reality. If most of the important physical effects are modelled and coupled together, then one should get a result close to the one obtained from a full scale measurement. The goal of the present work is therefore to set up a protocol to gather accurate full scale data in a useful manner for naval architects and other people interested in performance and behaviours of yachts at sea in order to perform their final validations.

The data collected need to be presented in a useful way. For that polar curves are the easiest mean of understanding the performance of a sailing yacht. In sailing yacht literature, polar curves have become a standard in presenting these performance. They usually show a line of achieved speed per wind strength. A radial plot is used (hence polar) with every angle representing the true angle to the wind of the sailing boat. The speed is presented as the distance for that particular angle between the origin and the speed line. In the present work, we will use polar curves to present the results. For ease of understanding, linear curves for each wind strength will be used as will be explained in chapter 6, from page 103 and onwards.

2.1.2 Full scale data measurement

To create the database in waves introduced in 2.1.1, page 19, we need to gather data on a full scale sailing yacht in its environment. This is the main part of the work carried out in the present thesis. Even though the measurement procedure and its implications were originally thought of as secondary, it quickly turned out to be the most important part of this research. The rest of the work is only possible when this part becomes successful. To make it successful, the use of two different sailing yachts was necessary.

Measuring performance of a full scale craft is a known difficult task. The fact that environmental elements cannot be controlled or difficultly measured without impact on accuracy, make such studies relatively rare in science.

In the present case, we can dissociate between two different needs:

- The need for average data
- The need for instantaneous data

A typical polar curve interesting to a sailor does not show maximum potential instantaneous velocities. These are usually obtained by a sailing boat under unlikely circumstances. Instead it shows time averaged velocities that can be obtained in a steady state. Therefore, the performance measured are to be averaged over a period of time long enough to consider the run as in a steady state. This way, impact of environmental instantaneous events becomes small, making the study possible in uncontrolled environment.

However, there is a paradox in the above demonstration: *to determine if a run is long enough to be considered steady, it is necessary to measure instantaneous environmental data over the entire run in order to determine the state of “steadiness” of the run and its magnitude.*

This paradox is important to keep in mind because on one side, the fluctuation of the instantaneous data do not matter, but on the other hand, their

accurate measurement is a key to a successful measurement campaign. The present work also aims at investigating the possibility of studying more instantaneous events like boat's dynamical reaction to wind gusts, etc. Such measurement requires more precise measurements than the ones typical sailing instruments could give in the past. However, with the advances of standard technology, it might be possible to get sufficiently accurate recordings to study such events. This will be a first attempt, though it will not be used for the main purpose of this thesis. The second major goal for measurement is to make full scale measurements viable for the validation undertaken in the present work.

2.1.3 Measurement procedure

To achieve the two goals mentioned in sections 2.1.1 and 2.1.2, page 19 and 20, a comprehensive measurement procedure has to be developed.

Such a procedure needs to cover the set up of means of records (i.e. instrumentation), as well as measuring of basic boat's properties (such as height of vertical centre of gravity (VCG) or displacement). Finally the performance data can be recorded.

The procedure is important in that it sets the boundaries of the study as well as the range of accuracy that might be expected. The procedure also ensures that all the necessary data for the study are indeed recorded correctly.

The procedure possesses a standard frame valid for all kind of boats studied. The frame has to be adapted to singular ships in order to take into account specificities of each boats such as electronic equipments on board, etc.

The "frame" will be presented in section 2.2, page 21 and onwards. It will then be presented from a practical point of view for the two different boats that have been used for the study:

1. "Le RM 1050", section 3.1, from page 37 and onwards
2. "Vågvis", section 3.2, from page 56 and onwards.

2.2 General procedure for measurements

For all types of boat, 7 steps needs to be fulfilled in order to perform a good measurement campaign. These steps are explained in sections 2.2.1 to 2.2.7 from page 22 and following.

The procedure is presented schematically in figure 2.1 page 22, where one can see the different locations involved by the different steps. Clearly one will quickly realise that many different locations are involved in the process

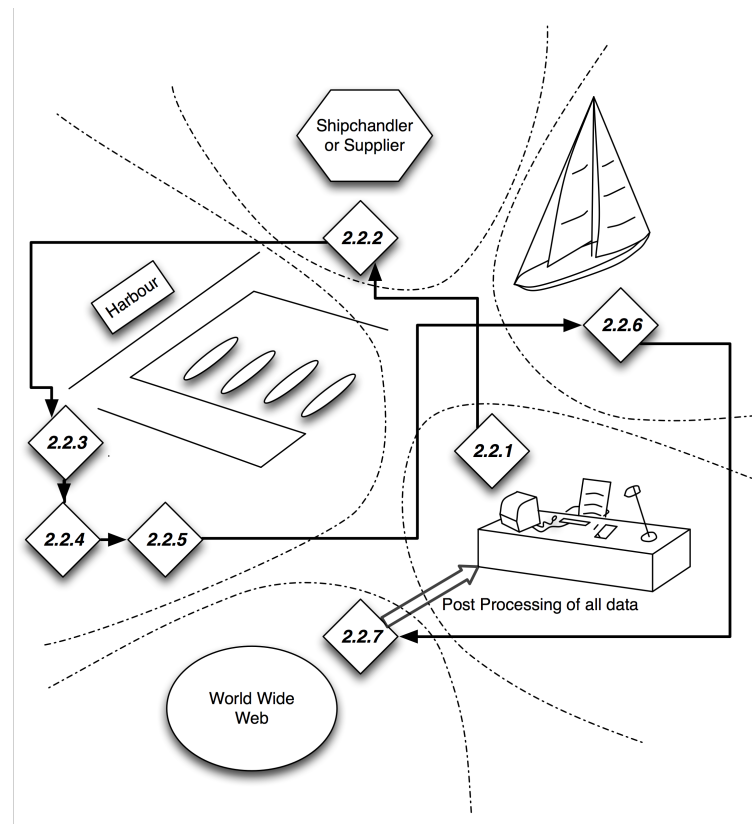


Figure 2.1: The measurement procedure contains seven steps, dispatched over five main locations. The numbers refer to the different sections describing each stage in the report)

of a measurement campaign. Being located close to the harbour where the boat is, and close to the measurement area, will be a major key of success.

2.2.1 Preparation of the work and data to be recorded

The first step of the framework is to identify all the data that have to be collected in order to successfully reach whatever goal is pursued. In the present case, we are interested in assessing the performance of sailing yachts in their natural environment. We therefore need to ask ourselves what are the data that are absolutely necessary for reaching our goal. We can also wonder what else can be done to improve accuracy or if we can achieve other goals at the same time. Often the same data can be applied to several types of studies. Recording one extra piece of information could make other studies possible at a small extra cost. Thus by widening the range of the recording,

better use of data can be done. Since we all know how hard it is to gather full scale data, this subject should not be neglected.

All these considerations need a strong theoretical analysis of the studied object (in our case, a sailing boat). The theory allows determining what is going to be useful in the study and what is not. However, practice also proves that we often underestimate some parts of the study while other parts are overlooked. Experience (and therefore the back-and-forth analysis of the work from theory to practice), is an important element to ensure that the final goal can be met. This implies that the researcher has to regularly re-evaluate his procedures and the quality of his work. Does it has enough data to reach his goal? Is the quality of the data good enough? How can you do better? These key questions allowed good progress in the present work. The final result presented here, is the fruit of several re-assessment of the working procedure. As a result, several types of data necessary for this study have been identified. They are here presented in two families: the automatically and the manually recorded data.

Data electronically recorded

These data are recorded via the on-board instrumentation system intended originally for navigation. These systems can be as simple as being just a GPS giving only the speed over ground (SoG), or as extended as giving accelerations of the boat as well. Typically, for the present research, four instruments are of prime interest:

The Loch-meter that provide the Speed over Water (SoW)

The Anemometer that provides the apparent wind speed and angle to the ship centre line

The GPS that provide the Speed over Ground (SoG), the true heading (i.e. of the true course on the ground seen by a satellite), and the precise time

The Autopilot that provides the rudder angle and the magnetic heading (on modern autopilots)

Once the electronic data sources have been identified, they can be further assessed in how to collect them. This is introduced in section [2.2.2](#), page [24](#).

Data recorded manually

Some of the data cannot be recorded automatically without using expensive equipment. Instead, careful measurements by hand can usually give accurate

enough results. Hull displacement, height of the centre of gravity (through an inclining test), type of sails used, etc have to be assessed. However, if these measurements require a careful procedure, the equipment necessary is relatively simple and consists mainly of a long enough piece of string and a weight (to make a pendulum) and a precise ruler. This will be further presented later in this section 2.2.4 and 2.2.5, page 27 and onwards.

2.2.2 Electronic instrumentation

To perform the automatic data collection, onboard instrumentation can be used. Depending on the size of the unit, the electronics available can vary drastically. Nevertheless for boats ranging from 6-7m to 25m, instruments such as loch-meter, anemometer, sound-meter, or nowadays GPS can usually be found. These sets of electronics usually use the standard language developed by the National Marine Electronics Association: standard NMEA0183. This standard sets a communication language used by marine electronics. It defines how data have to be organised, named and sequenced. This allows instruments to “communicate” between one another or to the outside world. Thanks to this harmonisation of the marine electronics, it is possible to retrieve and “understand” electronics data.

The first question that needs to be answered for all cases, is: how to retrieve the data? Using a multiplexer¹, the data transmitted by all the instruments can be sent to a computer and recorded for further processing. This way, using both the NMEA 0183 language and a multiplexer connected to a computer, all the instruments necessary for automatic data collection can be recorded and later processed. The NMEA 0183 language is more specifically assessed in section 4.1.1, page 73 and onwards.

Also, it is important to keep in mind that each brand of instruments has its specificity when it comes to the language used. For example, RayMarine© or Garmin© instruments output information in a slightly different manner than the standard that needs to be translated. The multiplexer software translates some of the data but not all of them and not for all brands, as will be discussed later. The researcher has, therefore, to be careful with the data he/she collects and make sure he/she understands all the data transmitted by the instruments used.

When it comes to the electronics, after investigating what we can retrieve and how to retrieve it, the quality of the data collected, or the rate of data

¹A multiplexer is a device that collects output from several electronic devices, put them into a sequence (typically on the basis of first-in-first-out), and send them through a single channel to another multiplexer (being a computer in our case) where it can be split back for different uses.

retrieved have to be investigated. Some solutions have poor data transfer rates and only few data can be recorded, thus shortening drastically the boundary of the research. Other solutions may become very expensive, etc. To reach the goal of the research, both the data rate of the instruments and the multiplexer have to be investigated carefully. If instantaneous data are to be recorded, then data rate of at least one hertz, have to be achieved in order to capture inertial impact on the performance. However, if such data is not necessary, then cheaper, older electronics might as well be sufficient. Electricity and electronics are serious matters. Collecting properly electronic data also implies electronic skills to plug the instrumentation correctly. As has happened on one occasion, mis-preparation can lead to dangerous electronic short-cuts endangering not only the recording, but also the unit (see section 3.1.7, page 50 or section 3.2.6 , page 66 for example). It is important to study the systems on board before setting-up the data collection system. Electric shocks, electrical shortcuts, etc. can endanger both the people on board and equipments. To ensure that problems can be solved quickly, different options of connectivity and their implications have to be assessed. This is part of preparation work and can help reduce miscellaneous problems and hazards during the campaign.

The specificity of each boat used in this research will be described in sections 3.1.2 for “Le RM1050” and 3.2.2 for “Vågvis”, pages 38 and 57 respectively. The multiplexer used for measurements on board both boats is a ShipModul 42-USB from Customware BV. This multiplexer allows connection of up to 4 instruments via electronic cabling (DC12V-5mA, typical of electronic devices). It possesses 4 outputs for plugging to other electronic devices, and one output-input interface using USB connection. The multiplexer has an internal data filtering system in order to avoid overflow of the outputs. The multiplexer comes with a software providing the possibility to record data on a computer and control the automatic filtering. The software works both on Windows© based computers and on Macintosh©.

2.2.3 Preparation of the boat

Before any recording of measurements, the boat has to be prepared. Preparation includes the following tasks:

1. check the output language of the electronics on board and the output electronic connections
2. check how to connect the instruments to the multiplexer

3. check if the multiplexer software can translate or record all the necessary data
4. check if the batteries have a sufficient power capacity for the system
5. plug the multiplexer and the electronics together
6. check the state of the sails, sheets, etc, on board
7. check the state of the hull (if dirty, needs to be cleaned, etc)
8. check where are located the major movable weights on board and if they are well fixed
9. check the level of fluids in the different tanks
10. set the instruments
11. plug the computer and check that the software runs properly
12. prepare a measurement procedure to check the accuracy of the measurements by hand

Most of these stages are self explanatory. A boat needs to be ready to take the sea whether measurements have to be performed or not. Some other steps are necessary for the accuracy of the measurements, though they are of less importance for normal sailing. For example, it is recommended for obvious reasons to do the measurements with a clean hull and new sails. This is not always possible and some VPPs allow corrections for such cases (less efficient sails, higher roughness for the hull, etc).

Compatibility of the electronic instruments, the multiplexer and the computer is very important and must be checked carefully. It is also very important to ensure that the instruments or other devices give the ability to record all the necessary data for the analysis planned. The particular sentences transmitted by the instruments will be later detailed in section 2.2.7, page 34.

Preparing the boat also means looking into where and when to collect data. The “where” depends on the type of data (deep/shallow water; main direction of the wind/waves, etc.), and the “when” depends on the data itself (what is the actual sea and weather states, ect.). Knowing in advance what kind of weather we are looking for can help retrieving the right data at the right quality. However, this implies that the boat for the measurement and the crew are available at all times, which is not always the case. For other circumstances, knowing the weather forecast the day of the measure is a

minimum, for both safe sailing, but also to help getting a clear idea of the conditions encountered.

At last, preparing the boat is mainly preparing its crew. A trained crew will execute clear manoeuvres and make the campaign successful. Unprepared crew will signify approximate procedures and low quality data. A trained regatta crew should always be favoured as these crews tend to be efficient sailors, able to sail fast and smooth. However, this is not always possible. In any case, clear explanation of the goal to the crew is key to a successful campaign. A good skipper can help improve procedures and ensure that the crew performs to the best.

2.2.4 Hull displacement

Measuring the displacement of the hull is very important. The performance of the boat during the measurements is directly linked to the displacement. It is not possible to compare the performance of a boat at two different drafts: the wetted surface, the centre of gravity, the centre of buoyancy, the moment of inertia and the moments of gyrations (among other properties) become all different. Therefore, if full scale measurements are to be compared with the results of a VPP, for example, then one must ensure that the displacement on both the record and the simulation, are the same.

In the present work, the 3D CAD drawings were provided. Using naval architecture design software such as FreeShip©, Rhino 3D©, and others, it is possible to calculate precisely the volume below the surface, and therefore retrieve the displacement of the boat at the time of the measure.

Prior to any measurement, the displacement of the boat should be recorded. To do so, one can measure the height from the top of the freeboard and the flat sea surface at 4 different locations:

- the foremost point on the hull
- the aft-most point on the hull
- the out-most portside of the hull
- the out-most starboard of the hull

Only three of the points are necessary, but the fourth one makes checking errors possible. As for all sailing boats, the hull constantly keeps itself in the upright position. This means that moving a weight on board will result in a change in hull heel and trim angles. Therefore, the simple weight of the person measuring the displacement on board will introduce an error in the assertion of the boat's displacement. This is less true for bigger boats (due

to the fact that the weight impact becomes negligible), but very important for smaller ones. Also one thing to consider is the accuracy of the CAD model with regards to the built hull. It is common sense to accept that the hull will always bear significant differences with its original numerical definition. Assessing the difference could be a good advantage to assess the resulting error between the numerical model and the full scale hull. However, this might be a complicated task for a full scale yacht and requires large or complicated means of measurements. Another approach would be to evaluate the impact of a potential error on the measurements. This way, one can get an idea of the severeness of not measuring precisely the difference between the drawings and the real boat. If the error is, anyway, negligible, then we can assume that the displacement as calculated from the drawings is a good enough approximation.

During the measurements of the displacement, the errors have to be assessed. The sources of errors are waves, oscillation of the boat, displacements of weight on board and precision of the height measurement. For both yachts used, an error calculation will also be provided.

2.2.5 Inclining test

Measuring the displacement is of no use if the centre of gravity of the unit is not located at the same time. The VCG is one of the most important properties used to define equilibrium, and therefore the performance of a sailing boat.

There is a standard measurement procedure to evaluate the height of the VCG for ships. It consist in measuring the angle of inclination of the hull with regard to a pendulum, when the hull is subject to the shift of a significant weight on board.

The height of the centre of gravity will depend on all the loads present on board, the strength and direction of the wind and as well as on the presence of mooring lines or waves at the place and time of measurement. It is hard to find a location and the weather condition to perform accurately an inclining test as even a small breeze can put the boat in a small but significant oscillatory motion.

The inclining test procedure performed in this thesis is based on lecture notes from C. O. Larsson et Al. [4] at Chalmers university of technology.

Using a pendulum of known length, a ruler to measure either the heel angle or the transverse displacement of the heeled boat and a defined weight to shift on board, it is possible to calculate the height of the centre of gravity of the unit. This experiment is shown in figure 2.2, in page 29. The calculation procedure is derived from the first principles of ship stability:

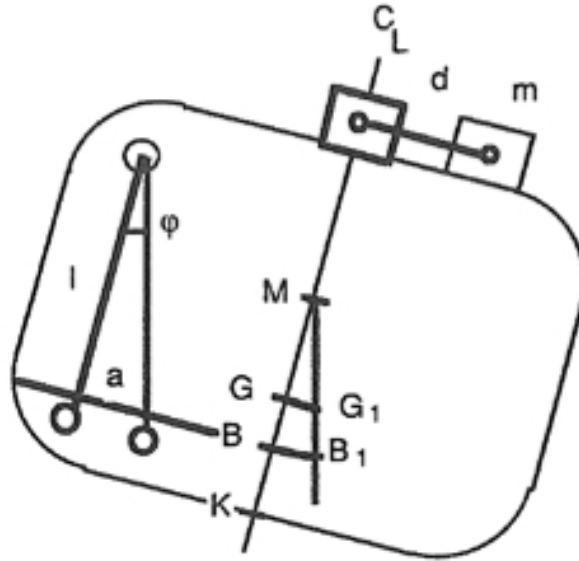


Figure 2.2: Inclining test procedure

- The inclining test start from a state of static equilibrium and an even keel situation. A mass on centreline is then moved to either port side or starboard. As a result, the boats heel to that side and reaches a new static equilibrium (as shown in figure 2.2, page 29).
- In the new state of equilibrium, from Newton's first law, we get the principle of moments: to reach a static equilibrium, the moment of heeling must be equal to a restoring moment:

$$M_{Heeling} = M_{Righting} \quad (2.1)$$

- In the inclining experiment, the heeling moment is generated by the mass m moved a distance d from the centreline. The righting moment is caused by the shift of the centre of gravity $\overline{GG_1}$ related to the unchanged mass of the boat $\nabla \cdot \rho$:

$$M_{Heeling} = m \cdot d \quad (2.2)$$

$$\nabla \cdot \rho \cdot \overline{GG_1} = M_{Righting} \quad (2.3)$$

$$\Rightarrow m \cdot d = \nabla \cdot \rho \cdot \overline{GG_1} \quad (2.4)$$

$$\Leftrightarrow \overline{GG_1} = \frac{m \cdot d}{\nabla \cdot \rho} \quad (2.5)$$

- Using a simple geometric relation, as can be seen in figure 2.2, $\overline{GG_1}$ can be expressed in term of the heel angle φ and the height \overline{GM} (i.e. the distance from the centre of gravity to the boat metacentre):

$$\tan(\varphi) = \frac{a}{l} \quad (2.6)$$

$$\overline{GG_1} = \overline{GM} \cdot \tan(\varphi) \quad (2.7)$$

$$\overline{GM} = \frac{\overline{GG_1}}{\tan(\varphi)} \quad (2.8)$$

$$\Rightarrow \overline{GM} = \frac{\overline{GG_1} \cdot l}{a} \quad (2.9)$$

- Combining equations 2.5 and 2.9 , we get:

$$\overline{GM} = \frac{m \cdot d}{\nabla \cdot \rho} \cdot \frac{l}{a} \quad (2.10)$$

Where:

- \overline{GM} is the distance from the metacentre to the centre of gravity of the boat
 - m is the weight moved on deck
 - $\nabla \cdot \rho$ is the total weight of the boat including the moved mass m
 - d is the distance between the original and final location of the weight
 - l is the height of the pendulum used to measure the heel angle of the boat
 - a is the transverse distance traveled by the pendulum during the test
- From figure 2.2, page 29, we can define the distance \overline{KG} (the height of the centre of gravity from the keel, also known as VCG) that we are looking for, in terms of \overline{KB} (the height of the centre of buoyancy from the keel), \overline{BM} (the distance from the centre of buoyancy to the metacentre) and \overline{GM} (defined in equation 2.10):

$$\overline{KG} = \overline{KB} + \overline{BM} - \overline{GM} \quad (2.11)$$

- The distance \overline{BM} is the metacentric radius. It is defined in term of the second moment of area of the water plane area I_w and the displacement of the boat ∇ (see C.O. Larsson [4] for the mathematical demonstration):

$$\overline{BM} = \frac{I_w}{\nabla} \quad (2.12)$$

- The distance \overline{KB} (the height of the centre of buoyancy) can also be expressed in term of the draft of the canoe body T_c and the VCB:

$$\overline{KB} = T_c - VCB \quad (2.13)$$

- Finally, combining equations 2.10, 2.12 and 2.13 into equation 2.11, we can derive the height of the centre of gravity from the boat based on the data measured during the inclining test:

$$\overline{KG} = VCG = T_c - VCB + \frac{I_w}{\nabla} - \frac{m \cdot d}{\nabla \cdot \rho} \cdot \frac{l}{a} \quad (2.14)$$

The height of the pendulum is of significance. If the height of the pendulum is too small, the displacement of the bottom of the pendulum will be too small to measure accurately. A small breeze or other environmental effects can give rise to small oscillation of the boat during the measurement. If the induced inclination is of the same order of magnitude as the inclination due to the shift of weight, then the error will be too important for the test to be conclusive.

In general terms, the higher the pendulum, the greater the accuracy. Also, we can see that the heavier the weight relative to the displacement of the boat, the greater the accuracy.

On most sailing boat, unless using specially built tools, it is hard on a rigged boat to have more than 2m height clearance for a pendulum. Let us try to figure out the error in \overline{GM} height for a 1cm measurement error on a 10cm displacement measurement for a 10t displacement boat where a weight of 100 kg was shifted 1 m to either port side or starboard.

We have:

$$m = 100kg \quad (2.15)$$

$$\rho \cdot \nabla = 10t \quad (2.16)$$

$$d = 1m \quad (2.17)$$

$$l = 2m \quad (2.18)$$

$$(2.19)$$

Using equation 2.10 for three different values of a , we get:

$$GM- = \frac{100 \cdot 1}{10000} \cdot \frac{2}{0.09} = 0.222 [m] \quad (2.20)$$

$$GM = \frac{100 \cdot 1}{10000} \cdot \frac{2}{0.1} = 0.200 [m] \quad (2.21)$$

$$GM+ = \frac{100 \cdot 1}{10000} \cdot \frac{2}{0.11} = 0.182 [m] \quad (2.22)$$

$$(2.23)$$

And we can calculate the relative error resulting from this:

$$Error = \frac{0.222 - 0.2}{0.2} = 11\% \quad (2.24)$$

An error of 11% for a measurement error of only 1 cm, is not insignificant. If the height of the pendulum is increased, the accuracy can be greatly improved. This calculation has to be kept in mind during the rest of the procedure.

2.2.6 Sailing procedure and measurements

To perform the measurements at sea correctly, the researcher and the yacht's crew need to know precisely what to do at sea. They need to know where to go, when, and how to sail in order to reach the goals of the study. The sailing procedure is necessary to ensure minimisation of errors during the recordings. First some parameters have to be evaluated when considering the location of measurements. Events like tide or current can greatly influence the quality of the results and therefore, have to be assessed prior to any measurements. When considering the measurements themselves, the way the data are collected will make it easier and more efficient to produce a full polar curve with the lowest error. To do so, the crew needs to make sure they have proper sailing conditions to do the recording. They also have to ensure that the way they perform the measurements is the simplest and the most reliable. For example, to record performance of a yacht from upwind to downwind is difficult: it is hard to keep a sailing yacht upwind or very close to the wind without initial speed; currents have also a strong influence on recordings as the current is impossible to separate from leeway with classical instrumentations.

A typical procedure of measurement would be:

1. Identify the currents and tides typical on the future site of measurement, using regular current charts
2. If tidal current is an issue, then determine the time frame for measurements with the lowest tidal current (tidal current varies over time and would induce large errors)
3. On site, measure the strength and direction of the current. Proceed to several measurements to make sure the current is stable (unstable current would make it impossible to do the measurements accurately)
4. proceed to the first set of recordings:

- (a) from a steady downwind position, slowly sail upwind either to portside or to starboard
 - (b) stay at each interesting sailing angle over a period of time long enough to get a good average measurement (between 5 to 20 minutes, depending on the accuracy sought, every 5° to 15° angles as necessary)
 - (c) go as close to the wind as possible when going upwind. If feasible, try to reach a completely upwind state
 - (d) repeat the exact same procedure on the other side
 - (e) repeat all the previous steps once or twice for each sailing condition investigated, in order to reduce errors to the maximum
5. between each polar measurement, an assessment of the current strength and direction is strongly advised. Over a period of time of two-three hours, the current properties might have changed significantly.

The recording has to be done over the entire polar range (i.e. first from downwind to upwind on portside, then from downwind to upwind on starboard). Then the recording can be post-processed to get an accurate polar curve.

Once all the measurements are done (and we can see now that a single proper measurement takes at least six hours), comparing the current properties measured before the measurements and after it, will give a first insight on the quality of the measurements. To measure the strength and direction of the current, only two practical ways have been found. It is impossible to measure the current accurately when under sail. This is due to the fact that the “drifting” vector is composed of both the current (external to the sailing boat) and the leeway. The leeway side force is generated by the hydrodynamic appendages as soon as the boat starts to sail. As soon as the sails are up, this component will take importance and will make it impossible to determine the current.

Here are two methods to estimate the strength and direction of the current:

1. The boat can be left to drift for a long enough period of time without sails. The drift direction and strength can be recorded by the GPS and should represent the main current, though the wind blowing the boat away will introduce an error that might be of serious significance if the wind strength is important. It might also be impractical or dangerous to leave the boat drifting over a period of time long enough to get a good measure.

2. The boat without sails can be sailing with the engine. The drift can be recorded using the difference between the SoG and the SoW. Here too, the wind might introduce an error as it will “push” the boat away in a particular direction. However this error can be minimised by running upwind and then downwind (that way, the wind component can be neglected), or in any two perfectly opposite directions. Magnetic deviation of the compass has to be taken into account, but is usually well established and shouldn’t induce significant errors.

The procedure is presented in figure 2.3, page 35.

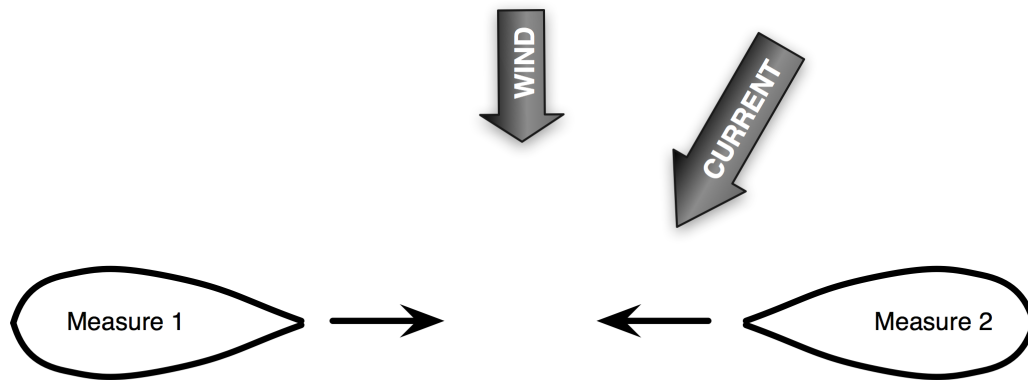
2.2.7 “External” recordings

Some of the data that are important for assessing the performance of sailing boats are hard, expensive or impossible to measure at sea: wave heights and period for example. During the present research, the main external data required were the waves properties, i.e., significant wave height, frequency and direction. These data are necessary to ensure that the same “waves” are used by both the simulations and the measurements.

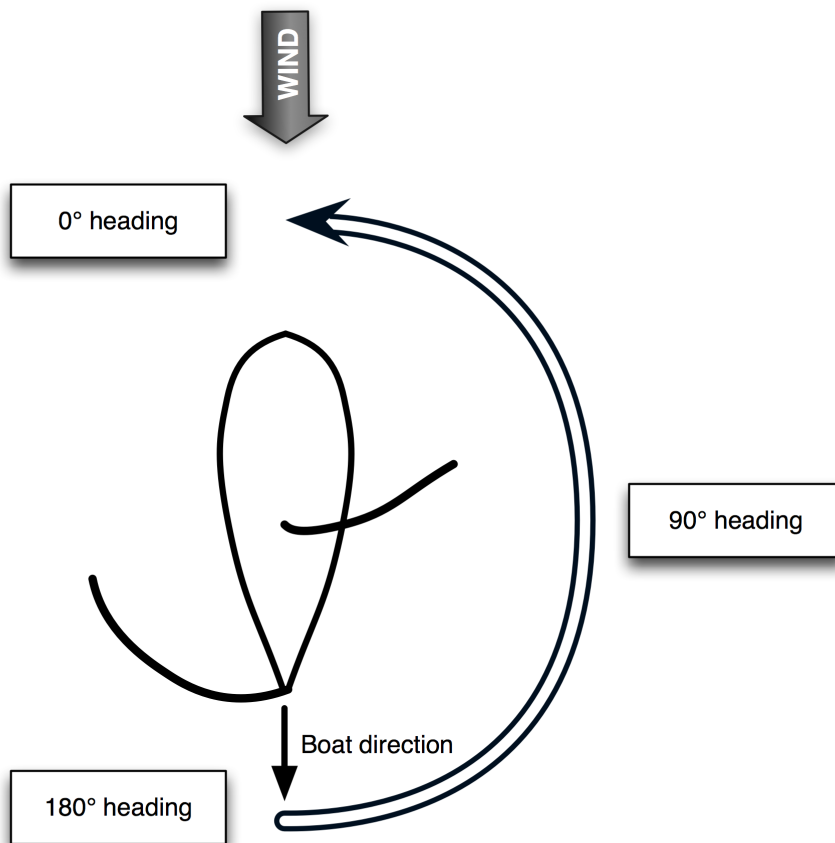
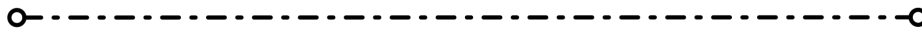
During the past hundred and fifty years, wave heights and frequencies were logged by sailors with notable errors. Accuracy arrived only with the era of weather satellites. Measurements with satellites have proven to give good accuracy for wave frequency, direction and height. However, because it is not always possible to actually observe an area due to clouds over the earth, meteorologist have developed advanced programs to estimate the weather along the oceans. These predictions are now given for 12, 24, 36, 48 up to 72 hours upfront. These estimations are reset every 12 hours with wave measurements taken by buoys dispatched along the major oceans and major sailing routes. These buoys record the major weather properties: pressure, temperature, wind speed, current speed, wave heights and frequencies, etc. These data are used as input in the new model run for the next 12 hours predictions.

Although weather predictions used to be erratic at the beginning, with the increase in super-calculator power and better satellite and buoy measurements, the accuracy have risen up and is now very good up to 48hrs.

Certain weather forecast authorities like the National Oceanic and Atmospheric Administration (NOAA) of the United States of America, provide on their website the wind, waves, current, atmospheric pressure and temperature prediction for most of the oceans of the planet. Their data are free to download on a daily basis, but access to older data can be more complicated. For up to 72hrs predictions, if you send an email, with the area of sailing as



First and last step of the procedure: measuring current



Second step of the procedure: polar curve measure first on Portside, then on Starboard or vice versa

Figure 2.3: Sailing procedure

the subject, you get the data back (under the GRIB format). Other companies in Europe also provide data for more localised sea like the Mediterranean or the Baltic sea.

Retrieving these external data is essential for two reasons:

1. Sailors need to ensure the severeness of the weather before sailing and to prepare their sailing. Going out in a clear sunshine unaware that a severe storm is on its way is just dangerous if not suicidal. For the research, knowing what type of weather lies ahead can help deciding if it is worth going out to do the measurements or not. For example, if a long series of measurements in different conditions is to be done, then one might realise that the exact same weather has already been encountered and that it is worth waiting a bit more to get a different one.
2. Second, once the measurements have been done, it is important to be able to check observations and to know exactly what weather was really encountered. This way, one can ensure that all the needed information for the research use is available and correct. For example, in the case of the present study, it is important to run the simulations with the same boundary conditions as for the measurements.

It might be that other external recordings are necessary for a different type of research. Once again, with the use of all the theoretical knowledge available, the researcher ensures that all the data he needs can be retrieved on time: missing data means often to start all over from scratch.

After introducing our working procedure, we are now going to see how it was applied to both units used in this research.

Chapter 3

Measurements: first and second campaigns

After defining the measurement procedure and framework, they are applied to the yacht used for the measurements. Getting a sailing yacht for measurements is not an easy task or not as easy as one might think. Nevertheless, in the course of this research two yachts were used. The types of boats, their characteristics, the preparation work and the measurements done on board are described in the sections of this chapter. “Le RM 1050” is presented in section 3.1, page 37; “Vågvis” is presented in section 3.2, page 56; Finally, future recommendation on measurements are discussed in section 3.3, page 68.

3.1 Measurements with “Le RM 1050”

3.1.1 General characteristics of the boat

“Le RM 1050”, the sailing boat that was used in the first part of this thesis work, is a sloop of 10.5m in length with hard shines, twin keels and a single rudder. It is made of plywood with epoxy reinforcement. The general structure is light with few bulkheads and wide volumes. The beam is large and the rudder deep. It can lay on its twin keels and rudder at low tide. The keels are tapered “L-shaped” with bulbs to lower the centre of gravity while keeping a shallow draft. The rig is fractional to allow the Genoa or jib $n^{\circ}1$ to pass the shrouds without blockage and be trimmed closer to the mast. The rigging for a baby jib is in place and can be used in case of heavy weather conditions.

“Le RM 1050” is an easy to sail, safe sailing boat. The hard shines make it

very comfortable to sail as it oppose an extra drag force to small oscillatory aero-hydrodynamical forces. Globally, it carries relatively large amount of sail area for a leisure boat, but it doesn't have racing capacities at such. The wide aft it exhibit makes her hard to go close to the wind. Below 45° to true wind, she becomes slow. However, for the same reason, she goes well when going downwind.

The main characteristics of "Le RM 1050" are:

LoA	=	10,47	[m]
Lwl	=	9,50	[m]
B_{max}	=	3,95	[m]
T_c	=	0,41	[m]
$\nabla_{sailing}$	=	5,65	[m ³]
$\Delta_{lightship}$	=	4700	[kg]
T_{max}	=	1,6	[m]
[KeelBallast]	=	1800	[kg]
[RudderDepth]	=	1,4	[m]
[MainSailArea]	=	36	[m ²]
[GenoaArea]	=	34	[m ²]
[BabyJibArea]	=	16	[m ²]
[SpinnakerArea]	=	75	[m ²]

Other data were available for the present work but are not presented here on explicit request from the naval architect of the boat, Mr [Marc Lombard](#). For more details on the boat itself, its performance or its fabrication, the yard, [Fora Marine](#), can also be contacted.

3.1.2 Instrumentation available on board

"Le RM 1050" was a sponsored boat. As a result, the equipment was not specifically chosen for the present work, but provided by one of the sponsor of the project, [Plastimo SA](#). Plastimo wanted to introduce a new product to the French market for which they had exclusive dealing rights: [NavMan](#). NavMan is a company from New Zealand specialised in navigation electronic equipment.

The set of electronics on board is schematically presented in figure [3.3](#), page [42](#) and included the following:

Multi 3100 a screen that groups data from the Depth-meter and the speedometer.

Wind 3100 a screen that groups data from the anemometer and the weathercock.

G-Pilot 3100 a screen that groups all data from the auto-pilot system

Autopilot 3100 a screen that controls the autopilot system

Tracker 5500 a screen that regroups all data from other instrument and the GPS and is used as a chart plotter

Masthead instruments that include the anemometer and the digital weathercock

Depth sounder a sonar based sounding device that detect the depth of sea up to 50m

G-Pilot Course Computer a computer device that calculates the autopilot instruction necessary to steer the boat, based on wind, GPS and magnetic compass data.

Gyrocompass a digital compass used by the course computer of the autopilot system for steering the boat with regard to the magnetic north.

Rudder sensor a incremental-decremental sensor attached to the rudder stock that detect the exact rudder angle. It is used by the course computer of the autopilot system for steering the boat.

Speedometer a digital sensor based on a free spin wheel measuring the instantaneous speed of the boat. It measures the flow speed near the bottom of the hull (instrument placed sufficiently forward and sufficiently away from the hull to measure the flow outside of the boundary layer).

NavBus an electronic in-house multiplexing system that allows all instruments from NavMan© to be connected together. This system uses a closed proprietary language.

Shipmodule 42-USB a NMEA0183 compliant multiplexer device from Customware b.v. that allow gathering 4 instruments as input and 4 instruments as output. The device is equipped with a USB port both in input and output mode to connect to an external computer.

In the above list only the multiplexer is not from NavMan©. All the other equipment were designed to be used as any sailing instrumentation. These instruments used an in-house system to communicate with each other called

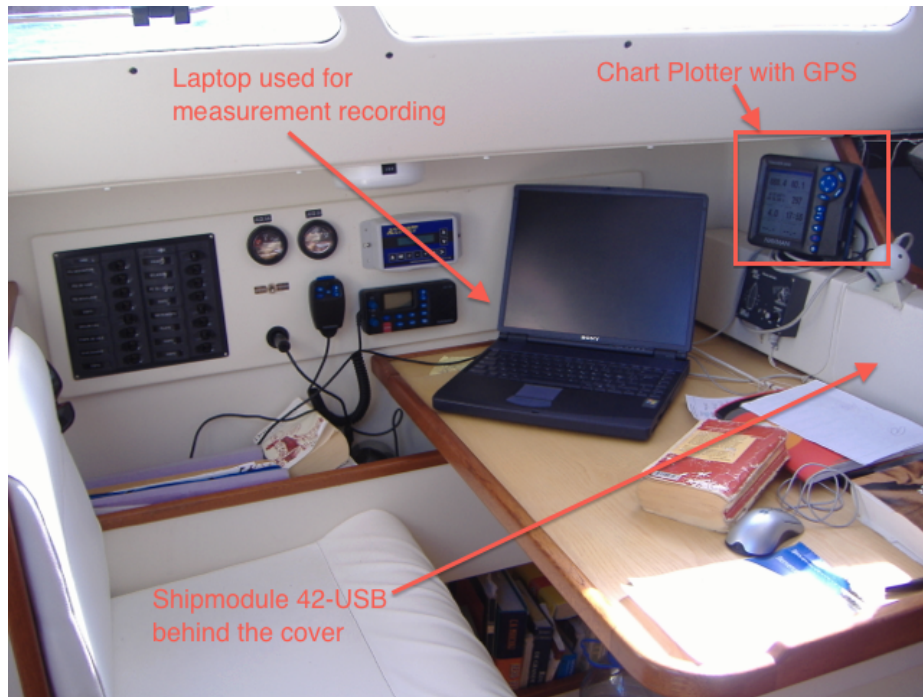


Figure 3.1: Picture of the chart table of “Le RM 1050” with the chart plotter, the laptop used for measurements and the location of the multiplexer

the SeaTalk system. These instruments also complied to the NMEA0183 norm from the National Marine Electronics Association (NMEA). Because this standard was used by this electronics, it was possible to plug a multiplexer also complying with this norm to output data from all instruments to a computer. We used both a Macintosh and a PC to collect data over the course of the project.

The chart plotter, the GPS, the computer and the multiplexer are located at the chart table and can be seen in figure 3.1, page 40. The screens relaying sailing information are located in the cockpit and can be seen in figure 3.2, page 41. Finally, the course computer and the gyro-compass are located in the storage cabin behind the bathroom.

3.1.3 Instrumentation set-up

The following sections describes in more details the exact set up of each instruments:



Figure 3.2: Picture of the cockpit of “Le RM 1050” with the speedometer/sound-meter, the autopilot, the electronic weathercock and the compass.

Speedometer

To set up the speedometer, it is first necessary to ensure that the free rotating wheel under the hull, is clean from seaweed and free to rotate ; that the instrument (on the screen of the Multi 3100) indicates a null speed in absolute still water while the boat is not moving.

Then, when sailing in a sheltered area with no current, the boat has to reach maximum constant possible speed with the engine and without sails: the higher the speed, the more accurate the set-up; the more constant, the less error due to averaging. The GPS gives the accurate speed over ground which can be set-up as the instantaneous sailing speed of the boat. It is important that there is no current in the area of the set up. Tidal or river current can induce large errors. Also, GPS speeds are typically average as it is a speed calculated from two different exact locations. If the instantaneous speed of the boat is constant enough, then we can use that speed as an instantaneous speed. The set-up have to be checked at least three times during the operation to minimised errors coming from the GPS.

The best no current situation over one year of sailing was encountered offshore, 3 days of sailing south west of Capo Verde; the GPS was giving a

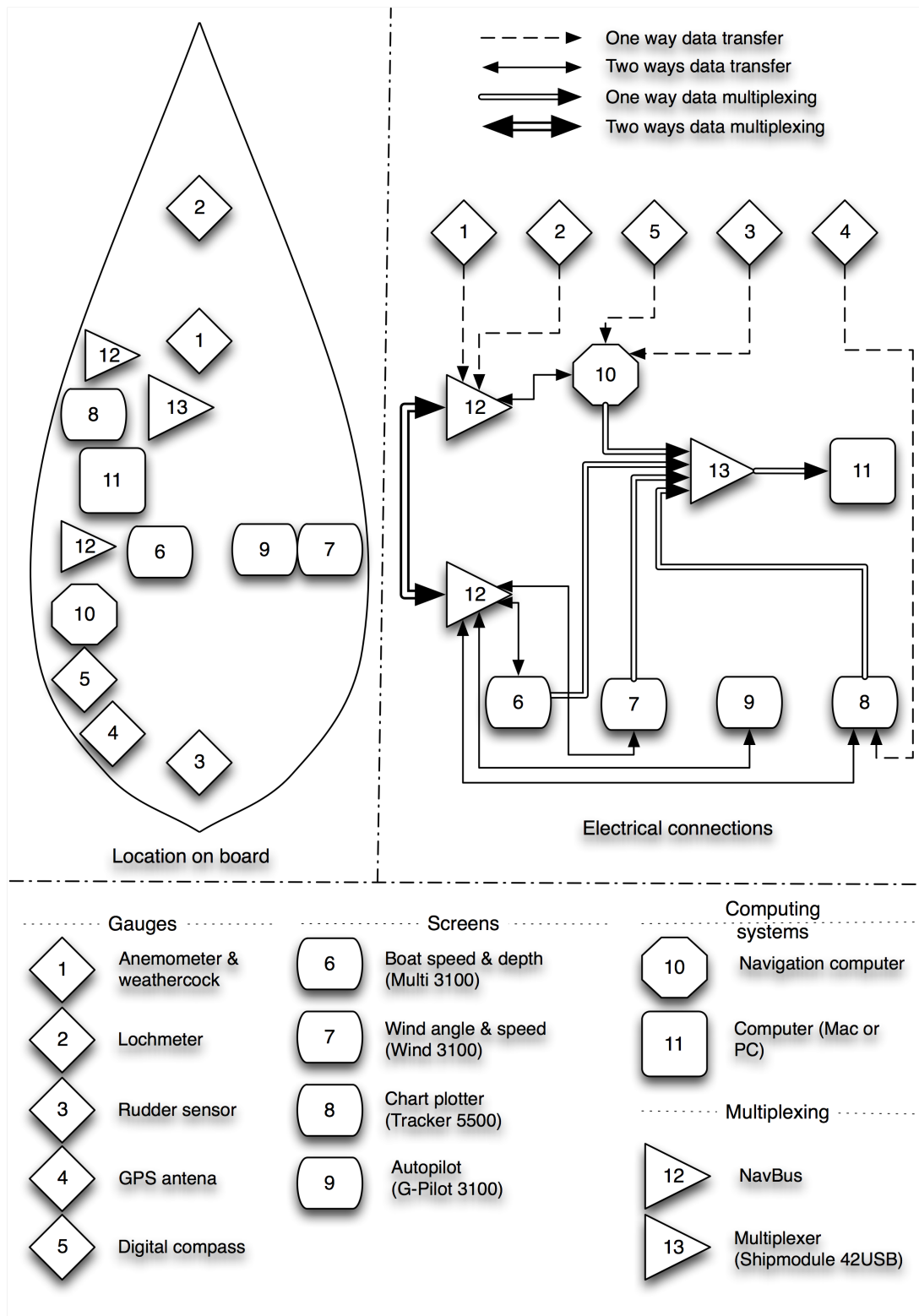


Figure 3.3: Location of instruments on board and data connections on board "Le RM 1050"

constant speed of 0 knots and there was absolutely no wind.

To ensure absolute perfect accuracy this set-up has to be done regularly and the speed checked before any measurement campaign. Over the one year of sailing with “Le RM 1050”, this set-up was performed twice:

1. in “La Rochelle”, just before leaving for the first leg of the journey, in June 2005
2. approximately 300 nautical miles south west of Capo Verde, during a no wind no current condition and after changing the entire set of electronics (see section 3.1.7, page 50).

On top of these set-up, the hull was entirely cleaned four times over the entire course of the one year journey. Each time, the wheel of the speedometer was cleaned and the accuracy of the instrument checked carefully. The accuracy of the system was also verified on each leg by the crew. With experience sailing the boat suspicious speed indications could be spotted and the set-up corrected.

Anemometer and Weathercock

Subject to external elements, the anemometer and the weathercock have to be set-up regularly. Like for the speedometer, one has to ensure no object are obstructing the wheel nor the weathercock.

When in absolutely perfect head wind, the control screen (Wind 3100) can be used to set the wind direction to 0° . The easiest way to do so is to anchor the boat or to moor it by the bow only and let it come head wind on its own. Then, the weathercock can be accurately set.

For “Le RM 1050”, the present set-up turned out to be relatively difficult as she was always oscillating when moored only with one line or anchored. It is suspected that the wide stern might be interacting with the wind to create sufficiently big vortex aft to actually trigger and feed these oscillations.

For the anemometer, the set-up is somewhat easier. Most of the harbour actually measure and give the exact instantaneous wind speed at mast height. This measurement is relatively accurate and this type of instrument is usually quite stable over time. The height of the measurement can be an issue for boats with very tall masts. The wind profile in the boundary layer might change significantly. However, the height of the mast of “Le RM 1050” is usually within the range of the masts used for measurements in harbours.

When a clear reading can be made from the reference instantaneous wind speed in the harbour, this value can be set into the system.

GPS and Chart-plotter

The GPS is a self setting system. If a problem in measurement is found, the entire set has to be changed. It means that the computing unit calculating the exact location via data collected from satellites, is out of order.

On a more practical ground, the set up of the GPS and the chart-plotter that gives its information, consists mainly in making sure the electrical connections are correct. It happened several times that short-cuts provoked the temporary loss of the GPS instrumentation (causing some serious threat to the boat once, as the GPS got out of order while landing on the Scilly Islands in the UK, at night. The Scilly Islands are famous for their traitorous coast line). Once again, the quality of installation of the instrumentation is critical...

Gyro-compass

The Autopilot system is equipped with a Gyro-compass in order to automatically steer to a particular heading if wanted. This compass was located inside the equipment room, sufficiently far away from other metallic equipments. To set it up, one has to make sure it gives the same direction as the main compass once this one has been checked. The gyro-compass is set via the screens control of the auto-pilot (Pilot 3100).

Rudder sensor

The rudder sensor placed on the rudder stock has to be free to move. One has to ensure no objects can interact with it. The set-up is done at sea via the on-screen instruction from the Pilot 3100 screen. It asks first to sail on the engine without sails in a perfect straight line (in direction of a fixed point very far away on horizon) to set up the absolute 0deg rudder angle, then sail to maximum port side, then to maximum starboard (beware of excessive speed during the turn). Then the rest of the autopilot set-up can take place. What is important to remember here is that 0deg angle for the rudder is the angle necessary to keep the boat going in a straight line. This means that if the boat has, when sailing on the engine, a small tendency to go to either port side or starboard, the rudder has to have some angle of attack to compensate the imbalance. This means that technically, at 0deg, the rudder can actually have an angle of attack. This irregularity depends mainly on the way the yacht was manufactured, and even the best built boats can exhibit a small imbalance.

Depth sounder

The depth sounder is normally not used for the present study. However, the data are output from the system like all the other data and can be exploited if desired. It can be noted that at shallow draft the performance of a boat are different from performance at larger drafts. If shallow draft investigation are sought, then the use of the depth sounder is necessary. To set up this instrument, at even keel, we use the manual sound present on every sailing boat. The sound, is made of long string marked every metre, with a lead at one end. The lead is dropped into the water and let free to dive, until it reach the bottom. The height of the water can then be measured from the lead up to the last point of wet string, or to the freeboard, if the freeboard height is known. This procedure has to take place when the sea state is perfectly flat. Small waves can introduce a significant error.

Once the depth is know it can be set on the “Multi 3100” screen that also control the depth sounder settings.

NavBus

The NavBus© system is a in-house multiplexing system from NavMan©. The output from each instrument connected to the NavBus©, is sent to all the other instruments that can make use of it, or not. It allows the autopilot’s course computer, to sail according to GPS way points, or to sail with regard to the wind, as required, etc. The problem of this system is that the data sent are encoded in a proprietary language that NavMan© refused to share. It was also impossible to connect a computer directly to the NavBus© system: the system is only designed for NavMan© instrumentation.

Shipmodule 42-USB

The Shipmodule© is a multiplexer, like the NavBus©, but this time, from the third party company Customware bv, from the Netherlands. This multiplexer complies with the norm NMEA0183. It was set up to retrieve data from the Muti 3100, the course computer, the GPS and the Wind 3100. The data are then output to an external computer. The multiplexer, like the rest of the electronics works in Direct Current (DC). The plugging procedure of the multiplexer involved connecting the positive electronic cables of each of the instruments to each input of the multiplexer and to connect the other cables to a ground. The multiplexer can then be plugged to the general electrical DC power source of the boat. Last step is to plug the USB out-put/input port to the computer, and set this one up, as will be seen in

next section. The electrical connections between the instruments and the multiplexer are presented in figure 3.3, page 42.

Computer

The computers used on board were a DELL running with Windows Operating System (OS), and an Apple Powerbook running with MacOSX. To read the multiplexer information sent through the USB port, both computers required drivers that were provided by Customware bv on their website. The driver came on the PC with a set-up software and a filtering monitor system¹. On the mac, originally, this software was not available. Hence, on the mac, it was necessary to use GPSNavX, a navigation software, to be able to retrieve the data from the multiplexer. The multiplexer software was made available at a later time for both the Mac and the PC.

The monitoring function allowed recording all the data sent by the multiplexer in a window instantaneously. These data could then be copy-pasted into a text file and saved for later processing. One of the downsides of this method is that, if the computer would come to crash before the data could be copy/pasted into a text file and saved, all data were lost. This situation happened several times with the PC, never with the Mac (the PC was quite old and the mac brand new). However, this was the simplest solution found to collect data. Otherwise, it would have been necessary to develop a dedicated software for data collection, or buy an expensive "off-the-shelf" solution.

3.1.4 Inclining test

The first unit of the "RM 1050" series was thoroughly investigated in 1998 when she was first put afloat. An inclining test was performed by the architect, the yard and the French maritime authorities. Design loading conditions were kept up to date during all the evolution of the series. The last major modification in the design altering the VCG was introduced in 2003. Data are presented in table 3.1, page 47.

For the present unit, the yard didn't perform any inclining test before delivery as it is not required for slightly modified sister ships in France. During the one year journey, it was originally thought that an inclining test would take place before every long journey. However, it proved difficult to do the measurements for several reasons:

Experience: The lack of experience of the crew in doing an inclining test

¹i.e. a system to control the filtering of data right from the multiplexer in order to reduce the amount of data sent to the computer in case of poor data transfer rate

Table 3.1: Height of the Centre of Gravity for different cases for “Le RM 1050”

Case	Displacement [kg]	LCG [m]	VCG [m]
Lightship	4798	5.21	0.121
Min Sailing	5003	5.30	0.162
Max Sailing	7041	5.30	0.257
Max with options	7487	5.41	0.268

was a major issue. The difficulties were underestimated at first and the proper documentation was not taken on board. As a result, when the right weather conditions occurred, no reliable measurement could be done.

Weather: calm enough weather was seldom encountered during the journey. Over the route taken, most of the harbour of anchorages were always subject to wind, waves or strong current of some kind. Apart of the harbour in La Rochelle before departure and arrival, calm enough conditions in harbours were encountered only once in the Bermudas Islands.

Not having a precise series of inclining test was a major draw-back to all the campaign. It will be further explained in section 3.1.7, page 50.

3.1.5 Displacement

Displacement was measured at several occasions on board. Each time the procedure was the same and involved the following steps for the measurer:

1. make sure that the rest of the crew was off board, the boat in sailing condition (with tanks and stores supplied as for sailing during the measurements) and that the boat was either moored or anchored with little or no wind and no movement
2. measure the distance from average water level to the freeboard at the most forward point of the hull (bow)
3. measure the distance from average water level to the freeboard at the most port-side point of the hull
4. measure the distance from average water level to the freeboard at the most starboard side point of the hull

5. measure the distance from average water level to the freeboard at the aft-most point of the hull (stern)
6. correct the measurements for the error induced by the arm lever of the measurer
7. make an estimate of the increase in displacement for the rest of the crew

The main problem when measuring the freeboard height is the height and frequency of the waves when doing the measurements. Waves of 10cm height can induce a 10cm error. The measurements usually always relied on the experience and judgement of the measurer. Wind was also a major problem as it triggered oscillations of the boat, therefore reducing the accuracy of the measurements.

The displacement measurements featured the same problems as for inclining test: wind, waves and current have been reducing drastically the possibility to do the measurements. However, some measurements were performed and are presented in table 3.2, page 48. For a quick comparison, the minimum and maximum displacement of the boat in design conditions are $5003[\text{kg}]$, and $7487[\text{kg}]$, respectively.

Table 3.2: Freeboard Height Measurement for “Le RM 1050”

Date	Bow [m]	Stern [m]	Portside [m]	Starboard [m]	Displacement [m^3]
20060219	1.245	0.555	1.068	1.020	6.944
20060319	1.190	0.530	1.120	0.995	7.879
20060628	1.480	0.615	0.965	0.965	4.144

3.1.6 Measurements recorded

With “Le RM 1050”, 7 measurements were recorded:

1. NMEA log test 1.txt
20050917, from 17h52’41” GMT to 18h01’08” GMT;
2. NMEA log test 2.txt
20050917, from 18h01’25” GMT to 18h04’01” GMT;

3. NMEA test 50 deg.txt

20051002, from 15h36'32" GMT to 16h05'44" GMT; Test in the Canary Islands

4. loic_barre_va_spygv.txt

20051015, from 17h32'51" GMT to 17h45'12" GMT; Loïc Trompette helming downwind with spinnaker and full main sail in opposite direction

5. regulateur_barre_va_gengv.txt

20051016, from 03h08'10" GMT to 03h15'59" GMT; Speed regulator helming; Genoa and main sail fully out; going downwind

6. 20060315(mesures).txt

20060315, from 16h38'14" GMT to 16h49'19" GMT; 1 reef in mainsail, genoa fully out; speed regulator helming; hydrogenerator in the water during measure; 2°-3° heel angle to portside (starboard to windward); hull is dirty

7. 20060319(mesures).txt

20060319, from 18h32'15" GMT to 18h53'38" GMT; Automatic pilot on; around 15°-20° heel angle; hull was dirty and the dinghy was towed behind the boat; 10-30cm of waves coming from wind direction; sailing in sheltered shallow waters (coral reefs)

The first two measurements were a simple test of the equipment. Before being able to do this first measurement, it took some time to figure out the way to connect all the electronics together without short-cutting vital instruments such as the GPS, etc. The lack of tools after departure also meant that it took more time to fix all the problems encountered. Lacking tools were often hard to find or expensive to purchase. Once all was connected satisfactorily, these two measurements were performed to ensure that instruments were working properly. Since departure, beginning of July, two month and a half had already past...

Three measurements were done during the month of October. This time, the measurements were aimed at clarifying the measurement procedure. These measurements were done before the data process code was developed. It was still believed that the code would be relatively light and an analysis could be performed quickly to evaluate the quality of the measurement and hence, correct the measurement process while still at sea. These measurements were therefore not extensive. Soon after that measurement, the electronics went

out of order. It took one month to get a new set of electronics. Because the electronics was changed during the week before departure from Capo Verde to Brazil, it was not possible to set all the system correctly. The measurements had to wait.

Over the five following month, the author tried developing a data process code with two different languages (i.e. Python at first, and then Objective C). These developments turned out to be catastrophic: too complex code; difficulty to handle a complicated database; problems with major bugs, etc. The last two measurements done in Mars 2006, were a new attempt at gathering good data. This time, more attention was paid to details, and though no inclining test was done, displacement was measured accurately close to the measurement date.

Soon after these last measurements, the electronics went out of order partially again. Critical data could not be gathered anymore, thus, turning this measurement campaign into a pointless story.

3.1.7 Problems encountered

During this first measurement campaign, a lot of problems were unforeseen. From the lack of micro-electronic welding tools, to failing electronic systems due to sea water ingress, or from difficulties to get good weather conditions for simple measurements to the crew focussing on going through bad weather safely, making good measurements proved everything but simple.

Dedication and distance

One of the first problem that was encountered was the fact that the main goal of “Le RM 1050” and its crew, was not to make a scientific measurement campaign, but to travel around the Atlantic and write articles for a sailing magazine. The life on a sailing boat can be relatively dull. Everyday is like the next and notion of time disappears. All long distance sailors know this fact. Before one realises, six month, one year are gone.

Furthermore, the fact that the boat was far from reach before departure, made it impossible to prepare specifically the boat. Due to delivery delays, the multiplexer could not be installed on board and tested before leaving La Rochelle. All the electrical connections and the resulting problems had to be taken care of at sea. Once on the journey, finding the proper tools and solving the encountered problems turned out complicated. For example, finding the micro-electronic cables necessary to plug the multiplexer to the rest of the instruments was hard. It was achieved in the end by purchasing a telephone cable in a supermarket in the suburbs of Vigo, Spain. Then, to

connect all the electronics, the cables had to go through bulkheads, in middle of the sheath of electric wires, and around many corners. Without a proper sheath guide, it was extremely hard and it took several attempts over the coming month to achieve it.

Another problem of remoteness is that it is hard to communicate with knowledgeable people when facing a problem. Delays of several weeks to several months can be observed, slowing the entire campaign down. If far away from base over the main course of the campaign, It is fair to say, that what cannot be foreseen by experience or knowledge before departure, will jeopardise the entire success. Special care is therefore to be placed in minimising the miscellaneous that distance can create. For example, after one month on board sign of failure into the electronics could be noticed: it took four month to get the new sets from the manufacturer, because these sets had to be sent to harbour where we would be sure to be at the present time of delivery (if delivered after the departure of the unit, it would take often weeks of sailing just to come back to the harbour and retrieve the equipment; if delivered too long before expected date of arrival, the chances of the parcels disappearing increased dramatically). This meant four month were measurements could not be performed because some of the critical data could not be retrieved.

The success of a measurement campaign rely into its preparation. If, before starting the campaign, it could have been possible to install all electronics on board and go for testing, most of the problems could have been solved before leaving the harbour. The measurements could have started on the very first day of the sailing journey (rough weather from “La Rochelle” to “Galway”) and good data could have been collected to achieve the goals of this thesis. However, the boat being in France and the author in Sweden, this was not achieved.

Weather

Weather plays a great role for the accuracy of the entire measurements. One needs calm weather to make inclining tests and displacement measurements, but at, the same time, stronger weather to collect useful data in all kind of weather conditions.

This two necessities are of course contradictory: it is very hard to find a perfectly sheltered place where to perform the inclining test and the displacement measurements, and yet, be able to reach a sailing area where the weather conditions would be severe enough to measure performance in strong weather prior to changes in location of centre of gravity or displacement. Over the course of the measurement campaign with "Le RM 1050", these conditions were not often encountered.

Another problem regarding weather condition is the ability to get access to accurate weather data. In Europe or North America, this is not such a problem. Most of the coast lines are equipped with many weather buoys and the weather predictions at 24 hours are usually very accurate. The problems starts when we get out of these areas. The rest of the atlantic relies on a few measurements and satellite pictures. Over smaller regions, weather charts can be significantly off and since there is few buoy measurements, it is difficult to estimate the error and thus reach an accurate estimation of the actual weather conditions on board. Visual observations are known for their inaccuracy and can't be used reliably either.

An attempt was made at retrieving weather prediction charts daily using a server based in France. The wind, wave, pressure and current charts are available from the NOAA website as "grib" files and are published every six hours for the next 36hrs. These predictions are usually quite accurate for the North hemisphere. The automatic program that was set up on the server was supposed to collect these charts every six hours and store them on the hard drive of a computer located in France. This way, it would have been possible to use these weather charts to get a gross estimates of the weather that was encountered on board. The log book of the boat could have been used to give a rough estimation of the quality of the weather charts compared to the actual weather encountered.

The server based in France collected the charts for the first 10 days, then crashed. Nobody, home, where the server was located had the ability to fix the bug and get it running again. There was no way to remotely control the computer to get it up and running again as it was located on a private network with multiple variable IPs. This technique could easily work in theory, but it is important that a person knowledgeable in IT is left on land with the task of maintaining the server and ensuring that the data are correctly collected on a daily or weekly basis. Otherwise, getting access to data from the different agencies like NOAA, is probably possible. It might be hard though as these agencies are usually big and not necessarily keen on giving their data a posteriori.

Electronics

As already mentioned in section 3.1.2, page 38, the electronics were not chosen for its reliability, but imposed upon the crew. It turned out that the electronics on board was of very poor quality. Navman©, the electronics supplier, was specialised into land electronic equipment and the set available on board was their first mass production attempt at marine electronics. The electronics was relatively well design from a user's perspective and easy

to handle/connect to the rest of the instrumentation. Measurements, over the course of time when the instruments were working, seemed reasonable and reliable. Only few small variations were observed and were easily corrected, like for the gyro-compass, that had to be checked and retuned every now and then². The rest of the instruments seemed to give accurate data whenever compared with the weather data available or, with instrumentation available in various harbours throughout the journey.

However, the Navman© instrumentation suffered one major default: the control screens, that also include the computing electronics, were not truly watertight.

After only three weeks sailing (from La Rochelle to Ireland, in rough weather), the electronics started to present the first signs of failure. The screen’s display started flickering. Then it started to be difficult to use some buttons. After that, the screen’s display went off and later on, even exporting the data from the instruments to the external computer didn’t work anymore.

By the end of the second month of sailing, the speedometer was out of order, quickly followed by the anemometer screen the next month and the autopilot control screen. By the time the crew reached Madeira, all the external screens had to be changed. It is worth noting that sea water ingress meant that all the components of the electronics inside the casing would eventually be affected by the rusting effect on their fine wires.

Due to the difficulty of reaching a sailing boat going around the Atlantic, it was quite difficult to make up an arrangement to collect the new electronics. In the end, in front of the amount of money that represents such a quantity of electronics, it turned out safer to ask one of the friend of the crew that was to join the board in Capo Verde, for the crossing to Brazil, to carry it with him in his luggages. Electronics was therefore, only changed in Capo Verde, a couple of days before leaving to the transatlantic crossing. However, due to very tight schedule and the difficulties in preparing the boat for the journey, the relatively late period the crew was to start the crossing (middle of November 2005) and weather conditions, it was not possible to set the electronics before leaving. The settings were done at sea a couple of days after departure in a day with absolutely no wind nor waves (which was quite depressing for the crew...).

At the end of the three weeks crossing of the Atlantic (21 days to reach Bèlèm in Brazil, from Capo-Verde), the electronics started again to show serious signs of failure. By the time the crew reached Trinidad, several screens

²The gyro-compass was located inside the port-side aft cabin. This cabin was used as a storage room with, specially, access to batteries, tools, etc. The amount of metals in the direct surrounding and the fact that these metals were sometimes changing place, could explain the need to recalibrate the device regularly.

went out of order. The supplier refused to give a new set of electronics, which meant that the return crossing of the North Atlantic was done without any wind nor speed indication. Only the GPS was still working by then. The best measurement that could have been performed on this sailing trip were on that last leg. The crew met strong weather with 35 to 40 knots established wind and strong sea. The boat was sailing in close reaching with three reefs in the main sail and the baby jib up, going at more than 12 knots on GPS. Unfortunately, because most of the electronics was out of order, it was impossible to record that run, or to know how much current contributed to that speed.

Electrical connections

One of the major problem with electronic equipment is their sensitivity to connexions and set-up. For example, the crew encountered a loss of GPS while landing on the Scilly Islands at night. It seemed to be due to improper connexion of the multiplexer. On board “Le RM 1050”, an electrician did all the plugging of the NavMan© instrumentation, but he did not have time to incorporate the multiplexer into the system because it was delivered too late (couple of days before departure). The connecting, therefore, had to be done by the crew with the few tools available on board. Before the Scilly Islands, the electronic wires (very thin) were just inserted and screwed into connections holes. However, the sea environment rusted the wires very fast as they were not coated with zinc. It took two month to find and buy an electric welding machine to correct that problem.

There was another problem linked to the wires not being coated: diameter of wires. On an electrical system, it is often the case that several different types of wires have to be connected together for various reasons. In the present case, some of the electronic wires had to be connected to wires of bigger diameter for power. The connection becomes relatively sensitive as it may happen that wires miss-connect simply because their diameter is too thin compare to the diameter of other wires. If zinc coating is used instead, it is possible and recommended to weld the wires together in order to prevent such inconvenience (that might lead to scary ending, as seen during the Scilly island landing episode).

Miscellaneous

There are a lot of other problems that have been encountered during this project that have to be mentioned, at least partially.

A sailing boat being a complex machine, there are a lot of small things that

can go wrong on board and that will induce delays or problems during a measurement campaign. It can be as insignificant as a pulley or a rope breaking, but can also be more serious, like when the board lost all GPSs while landing at night on the Scilly Islands.

Over a year of sailing, we realised that a boat requires a lot of regular maintenance. For instance, the winches had to be greased every three months, and the sails required some patching because of the effect of the sun and wear problems when in contact with the shrouds. Because of a design problem at the head of the mast, we had to cut the last 2m of the main sail’s halyard four times over the course of the journey. If we would not have had a 10m extra rope length on the halyard, we would have had to change this expensive rope in the middle of the journey, thus, probably meaning delays or immobilisation of the boat (specially if a proper rope supplier doesn’t exist in the surrounding).

Another encountered problem was the anti-fouling. It’s bad quality meant that after two months of sailing most of it was gone. It meant in practice that we had to clean the hull by hand from seaweed every second month over the rest of the journey. Since this is quite an intensive and hard labour, it was difficult to perform it every now and then. It was taking a full day of work to one person with a snorkel to clean the entire hull and appendages. Working in waves was much harder and dangerous, thus limiting the amount of time this action could be performed.

There are many other events that slowed the measurement campaign, but it would be pointless to mention them all. The reader has to understand, once again, that on such a long journey things rarely goes to plan. There are dozens of problems that will need to be assessed to make the campaign successful. The closer the team from a single base well provided with all kind of services, the easier it will be to be successful. As will be shown in section 3.2, page 56, experience and a better preparation up-front of the campaign increase drastically the chances of success of the campaign.

3.1.8 Problem induced by simulations

After the campaign with "Le RM 1050" was ended, the measurements were to be compared with VPP simulations. The software used at that time was the one developed by SSPA AB, SailSim. However, it turned out that SailSim could not simulate the specificities of a twin keel sailing yacht. Dagger boards, pendular keels, etc. were all included in the software’s capabilities but not twin keels. Even if the measurements would have been perfect both in quality and in quantity, it would have been pointless to compare them with results from simulations. To make the simulations work, many assumptions

would have been needed, jeopardising the quality of the output. This will be later explained in more detail in section 5, from page 93 and onwards.

This reason combined with the relatively poor quality of the measurements performed over a year of sailing, pushed forward the necessity of a new measurement campaign with a more conventional boat and a simpler software. The new boat was found thanks to Mr Heyman, and was named “Vågvis”. The second campaign is described in the following section.

3.2 Measurements with “Vågvis”

The measurements with Vågvis were performed in two times:

1. The first time was on the 24th of May 2007, during a short sailing trip between Helsingborg, in Sweden and Copenhagen in Denmark. That day, the electronics was plugged to the system for the first time, and different set-ups were tried. Then an inclining test and a displacement measurement were performed. Finally, the sailing capabilities of the unit were discovered.
2. The second measurement series took place during a sailing journey between Simrishamn (Sweden), Bornholm (Denmark), Christiansø (Denmark), Utklippan (Sweden) and Kalmar (Sweden), from the 8th to the 11th of June 2007. During that journey an electrical and a driver problem arose with the multiplexer. They were solved in Bornholm, for the electrical connections, and in Christiansø for the driver. The measurements were recorded during the last day of sailing, on the 10th of June, between Utklippan and Kalmar.

3.2.1 General characteristics of the boat

“Vågvis” is a 60’ long One-Off design from Gabriel Heyman, finished in 2004. She was designed as a cruiser-racer sloop to be single-handed by her owners, Johan and Sol-Brit Eklund. She presents a convenient rig with either a self-tacking jib or a genoa in front and a fully battened main sail. The water entry line of the hull is fine and the centre of flotation relatively aft for such a unit. She behaves very well at sea. In particular, I was impressed how fast she gather speed and how sensitive she feels when steered, even though she displaces about 22 tons.

The structure of Vågvis is very light and relatively flexible. The formed hull is made of honeycomb sandwich, and the mast is in carbon fibre. The boat

is equipped with a single keel and a single rudder. She has all the comfort you can expect on a boat this size and is equipped with a bow thruster for ease of manoeuvring in smaller harbours.

The main characteristics of ‘Vågvis are presented below:

LoA	=	17,61	[m]
LwL	=	14,38	[m]
B_{max}	=	4,84	[m]
T_c	=	0,89	[m]
$\nabla_{sailing}$	=	21,32	[m ³]
$\Delta_{lightship}$	=	21850	[kg]
T_{max}	=	2,20	[m]
[KeelBallast]	=	7300	[kg]
[RudderDepth]	=	1,88	[m]
[MainSailArea]	=	86,34	[m ²]
[GenoaArea]	=	89,66	[m ²]
[BabyJibArea]	=	51,19	[m ²]

3.2.2 Instrumentation available on board

“Vågvis” was equipped with RayMarine© instrumentation for the anemometer, the weathercock, the speedometer, the auto-pilot and the course computer. The chart-plotter/GPS was from Garmin©. These instruments were partially connected together with proprietary communication systems and partially using the NMEA-0183 norm.

To retrieve the data from the instruments to a computer, the same multiplexer as for the first campaign was used (Shipmodule 42-USB from Customware bv, see section 3.1.3, page 45 for description).

Connecting all the instruments to the multiplexer was complicated. First of all, all the RayMarine equipments were connected together via a proprietary communication system called SeaTalk©. The SeaTalk© system does not allow for exporting data with the NMEA-0183 norm. Instead, each individual instrument had to be plugged-in on their special NMEA-0183 ports and directly connected to the multiplexer inputs. Connecting the instruments directly would have required to open many panels, to install lengthy cables throughout the boat, and only four instruments in total could have been plugged. During the second campaign, due to the lack of time, such a procedure was not possible.

Thankfully, most of the instruments were sharing data with the course computer from the auto-pilot system. A newer version of the multiplexer’s driver

allowed reading and translating most of the SeaTalk© data into NMEA-0183 standard, though not all of it (for example, it was impossible to output rudder angle data). The most important data could be retrieved through the SeaTalk© output of the course computer if plugged correctly. However, the GPS data were not available through this output. But the course computer was connected to the chart-plotter using a NMEA-0183 output/input system. Bridging the chart-plotter connection to the multiplexer allowed to retrieve this missing data. With two connections only, almost all data could be captured.

The electrical connections between instruments and their layout on board are presented in figure 3.4, page 59.

3.2.3 Instruments set-up

Anemometer and weathercock

“Vågvis” was prepared at the beginning of the season by the shipyard where she is stored for winter time. Since all the rigging was removed for winter and placed back onto the hull, the anemometer and the weathercock were set again by the yard. The stability of such instruments over time made it unnecessary to reset them before measurements could take place. Off course, their accuracy was still checked before the measurements were performed.

Speedometer

For the speedometer, the set-up was checked before the measurements were recorded and was corrected for a minor error. The set-up was done in an attempt to sail while there was no wind whatsoever. It was easy to verify that there was no current, nor any speed nor any wind at the time. All the screens were therefore set to null. Later on, a slight breeze allowed to sail and make the measurements. This situation will be further described in section 3.2.6, page 66.

Autopilot and course computer

The autopilot and the course computer system had one interesting data to output: the rudder angle. However, due to the set-up of the electronic system and the policy of RayMarine, the autopilot system manufacturer, it was not possible to retrieve this data through either the NMEA-0183 output of the course computer, nor through the SeaTalk system. The autopilot and the course computer were therefore only used to get access to the data transferred through the SeaTalk system. Figure 3.4 page 59 shows the system's

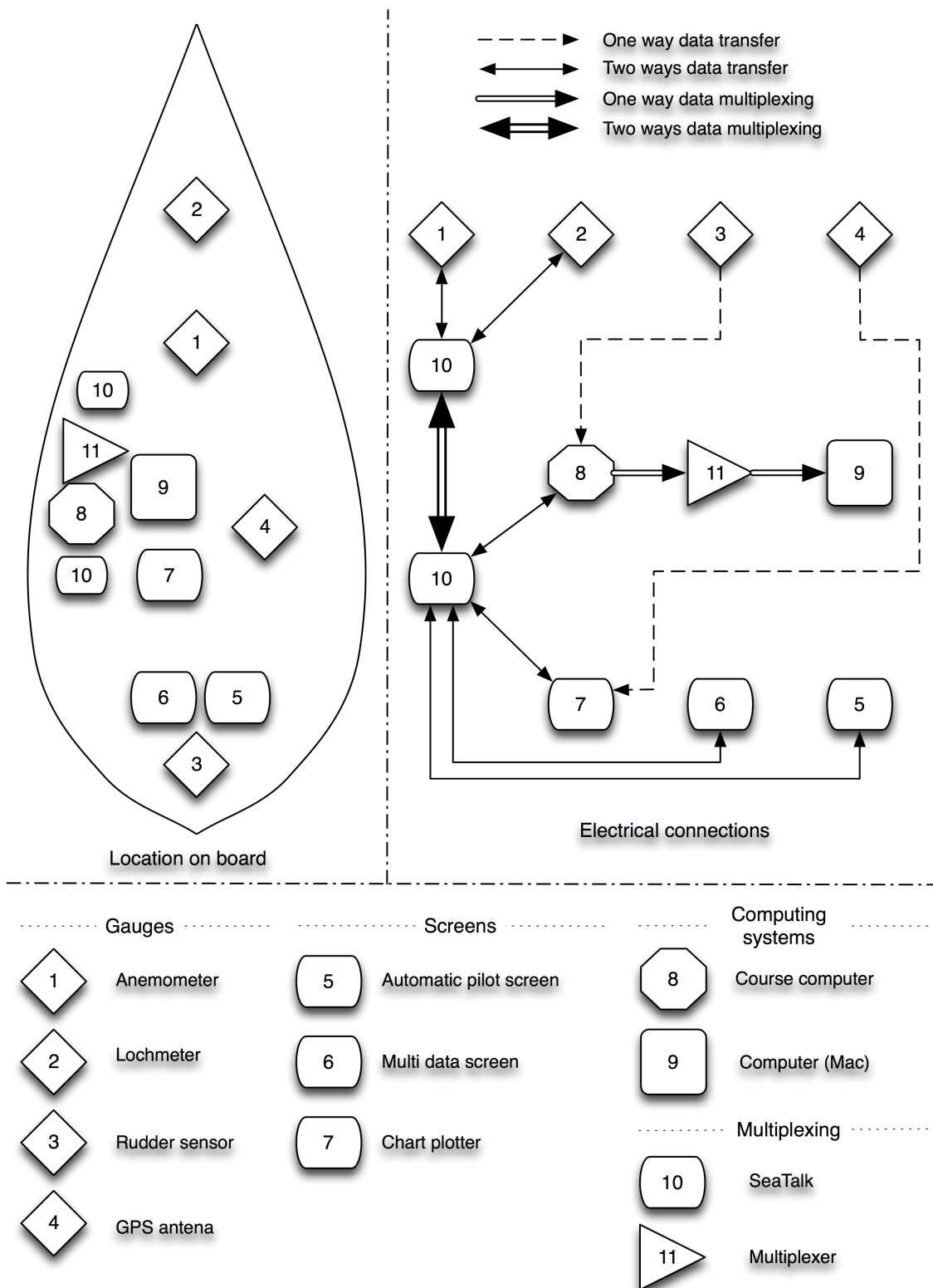


Figure 3.4: Location of instruments on board and data connections on board "Vågvis"

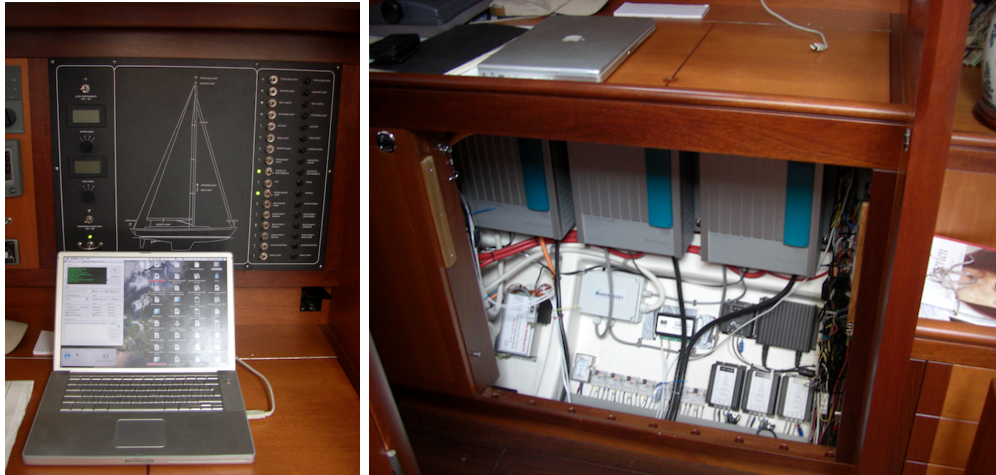


Figure 3.5: Chart table with computer and multiplexer inside the electronics compartment under the chart table on board “Vågvis”

connections used to retrieve these data. Figures 3.5, 3.6 and 3.7, pages 60, 61 and 62, show the system as it was set-up in the electronics compartment under the chart table inside the boat.

3.2.4 Displacement

For Vågvis, the displacement was measured twice: once in Helsingborg, once in Christiansø.

In Helsingborg, the conditions of measurement were not very accurate due to too high waves inside the harbour. However, the measurement in Christiansø was very good thanks to a high pressure weather over the Baltic sea. The sea was perfectly flat, with absolutely no wind, in what we can call a mirror state, as can be seen in picture 1.6, page 17.

From these measurements, presented in table 3.3, page 63, a displacement can be calculated from the CAD drawing. This is, off course an estimate. Nothing can prove us that the hull was built exactly as is represented on the CAD drawing. However, the error can only be smaller than measuring the weight of the unit with a crane. A crane will only be precise to about a tenth of a tone, while if a careful yard manufactured the yacht, geometrical error are usually small.

We can assume that the measurement performed on the 10th of June is the most accurate due to exceptional conditions that day. The displacement measurement is very important because, if performance results are to be compared with simulations, it is very important that the same displacement

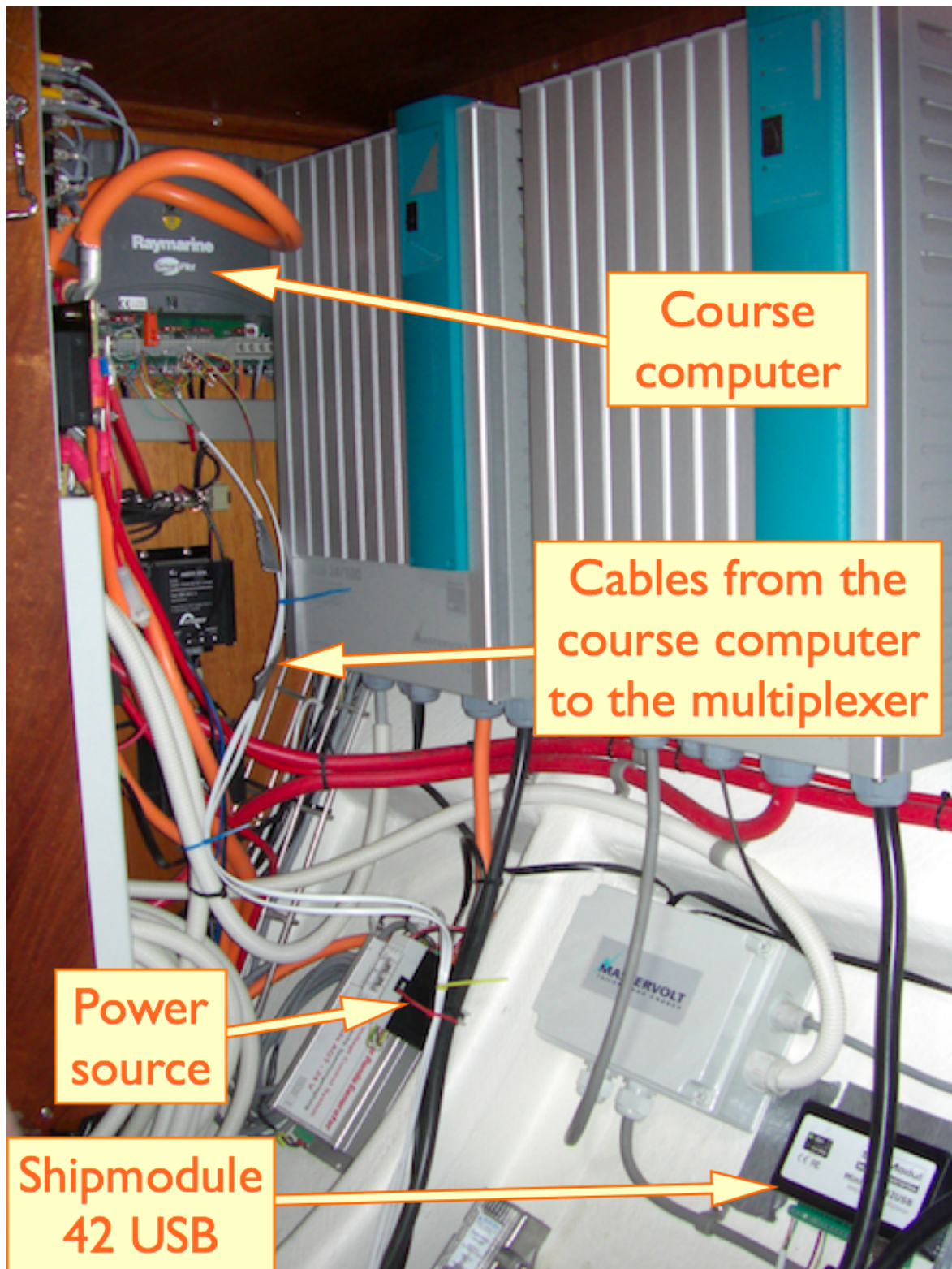


Figure 3.6: Electronics compartment under the chart table

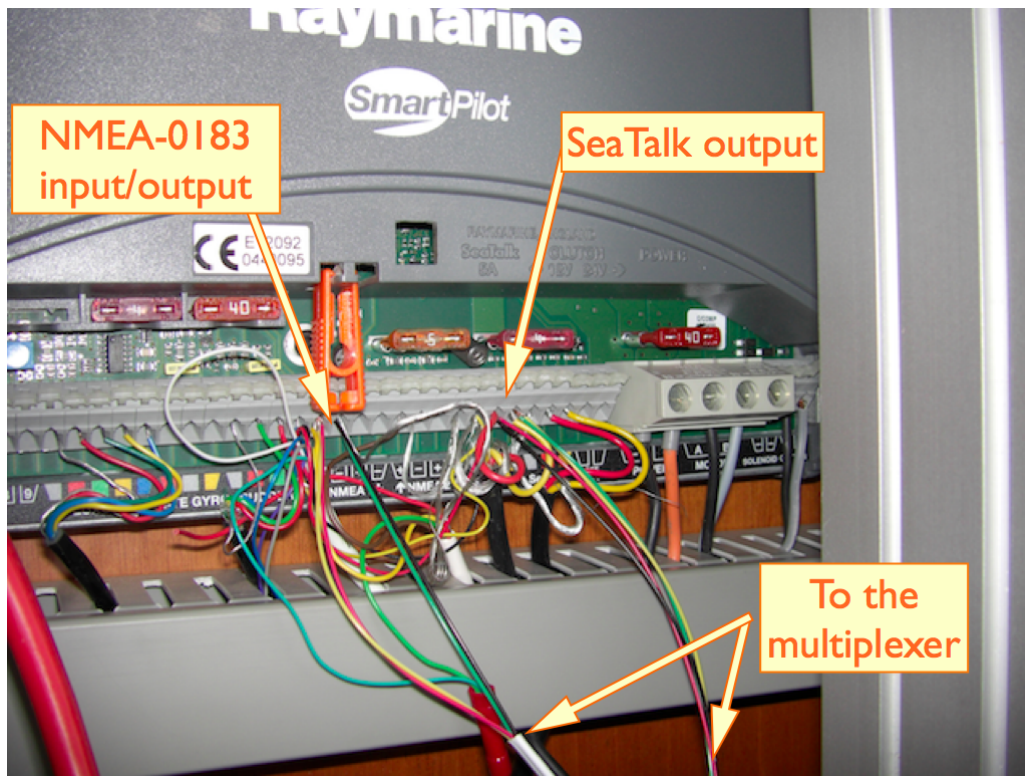


Figure 3.7: Details of the electronic connections on the course computer

is used.

It was assumed that the density of water was $1.012\text{kg}/\text{m}^3$ in Helsingborg and $1.005\text{kg}/\text{m}^3$ in Christiansø. The difference in density is taken into account for the calculation of the weight displacement.

3.2.5 Inclining test

The inclining test was performed on the 22nd of May 2007, in Helsingborg (Sweden). The boat was in the marina of the city. The mooring was set loose for the test. To perform the test, a pendulum was set inside the boat. Its length was set to the longest possible from roof to floor. The movable mass was placed on deck and was composed of Mr and Mrs Eklund and myself, grossing about 215kg . The crew was move from the attachment point of the shrouds on port side to centreline, 2.15m away, approximately. For the displacement of the boat, we used the data from the first measurement in the displacement table (table 3.3, page 63) as it is the closest to average of the displacements measured that day (the average is $22.6024[\text{m}^3]$). The

Table 3.3: Freeboard Height Measurement for “Vågvis”

Date	Bow [m]	Stern [m]	PS [m]	SB [m]	∇ [m^3]	Δ [kg]
20070522-1	1.820	1.475	1.455	1.475	22.6085	22880
20070522-2	1.800	1.470	1.450	1.465	23.0584	23335
20070522-3	1.835	1.500	1.475	1.505	22.1402	22406
20070610	1.813	1.490	1.475	1.490	22.5944	22707

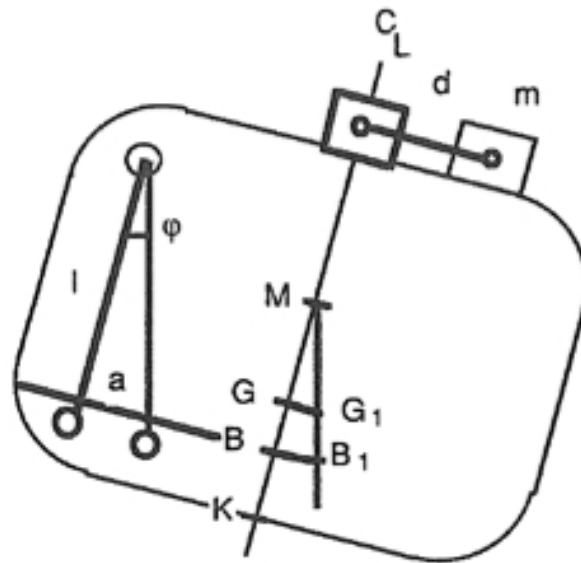


Figure 3.8: Inclining test procedure

data collected from the experiment are presented below. The names of the variables refer to section 2.2.5, page 28. Figure 3.8 is a reminder of the set-up of the experiment. The variables used in the following calculations are presented in the figure.

We have:

$$\begin{array}{llll}
 l & = & 2.325 & [m] \\
 a & = & 0.030 & [m] \\
 m & = & 215 & [kg] \\
 d & = & 2.150 & [m] \\
 \nabla & = & 22.609 & [m^3] \\
 I_w & = & 41.119 & [m^4] \\
 T_c & = & 0.895 & [m] \\
 \Delta & = & \nabla \cdot \rho = 22.609 [m^3] \cdot 1012 [kg/m^3] = 22880 & [kg] \\
 VCB & = & 0.393 & [m]
 \end{array}$$

Using equation 2.14 derived in section 2.2.5, page 28, we have:

$$\overline{KG} = T_c - VCB + \frac{I_w}{\nabla} - \frac{m \cdot d}{\nabla \cdot \rho} \cdot \frac{l}{a}$$

The distance \overline{KG} is also known as the VCG , the Vertical Centre of Gravity of the boat. If we solve with the values from the inclining test, we get:

$$\begin{aligned}
 \overline{KG} &= 0.895 - 0.393 + \frac{41.119}{22.609} - \frac{215 \cdot 2.15}{22.609 \cdot 1012} \cdot \frac{2.325}{0.03} \\
 \overline{KG} &= VCG = 0.755 [m] \\
 VCG - T_c &= 0.755 - 0.895 = 0.140 [m]
 \end{aligned}$$

From the inclining test, the VCG is located 0.140m below waterline. The VCG calculated via the list of weight by the Naval Architect, Gabriel Heyman is at 0.043m below waterline. The difference between the two values can be explained by the difference of displacement between the measured boat and the theoretical value, but also by error in the measurement during the inclining test.

We assess these sensibilities by calculating the VCG for an error in the displacement measurement of $\pm 1cm$ and an error in the inclining test measurement of $\pm 1cm$. The calculations are the same as for the inclining test. The results are presented with their key data in table 3.4, page 65.

As can be seen in the results of the sensitivity study, an error of $\pm 1cm$ in the displacement has a small influence on the height of the VCG. However, an error of $\pm 1cm$ on the inclining test measurement has large implications

Table 3.4: Inclining test sensibility study for “Vågvis”

Name	Measure	∇_{-1cm}	∇_{+1cm}	BC_{-1cm}	BC_{+1cm}
l [m]	2.325	2.325	2.325	2.325	2.325
a [m]	0.03	0.03	0.03	0.02	0.04
m [kg]	215	215	215	215	215
d [m]	2.15	2.15	2.15	2.15	2.15
∇ [m^3]	22.609	22.197	23.020	22.609	22.609
I_w [m^2]	41.119	40.809	41.392	41.119	41.119
T_c [m]	0.895	0.885	0.905	0.895	0.895
Δ [kg]	22880	22464	23296	22880	22880
VCB [m]	0.393	0.390	0.396	0.393	0.393
KG [m]	0.755	0.738	0.769	-0.028	1.147
VCG [m]	0.140	0.147	0.136	0.923	-0.252
BM [m]	1.819	1.838	1.798	1.819	1.819
VCG error [%]	-	-8	0	-580	285

on the VCG height calculations. To lower the error, and as demonstrated in 2.2.5, page 28, we should have used a longer pendulum.

We now calculate what error in the measurement has to be made to obtain the same VCG as in the list of weight. We assume for that, that the VCG is 0.043m below waterline and calculate backwards towards the measurement a . Re-organising equation 2.14 we obtain the following:

$$a = \frac{l \cdot d \cdot m}{\Delta \cdot \left(\frac{I_w}{\nabla} + VCG - VCB \right)} \quad (3.1)$$

Using the following data, we have:

$$\begin{aligned} l &= 2.325 & [m] \\ m &= 215 & [kg] \\ d &= 2.150 & [m] \\ \nabla &= 22.609 & [m^3] \\ I_w &= 41.119 & [m^4] \\ VCG &= 0.043 & [m] \\ \Delta &= 22880 & [kg] \\ VCB &= 0.393 & [m] \end{aligned}$$

$$a = \frac{2.325 \cdot 2.15 \cdot 215}{22880 \cdot \left(\frac{41.119}{22.609} + 0.043 - 0.393 \right)}$$

$$a = 0.032[m]$$

As can be seen from equations 3.1, an error of 2mm in the measurements would have been enough to get the same VCG height as in the list of weight. During the experiment, a much longer pendulum should have been used. It would have reduced the VCG height error significantly. However, a long pendulum is harder to use on board and accurate measurements becomes more complicated. Here, a mistake of one or two millimetres have lead to a difference of up to 9.7cm in the height of the VCG compared to the list of weight. The measurement itself was accurate to about two - three millimetres. We can therefore conclude that the true VCG height during the measurement was located somewhere between 0.043m and 0.252m below waterline.

3.2.6 Measurements recorded

With Vågvis, two sessions of measurements were performed, the first one on the 22nd of May and the second one from the 8th to the 11th of June. From the first one, no results came out as it took time to set the instruments correctly and that several problems had to be solved. The second session was a success with good quality measurements.

During the first attempt, a misconnection of the multiplexer on the electronics short-cut the system resulting in the loss of all instrumentation. The problem was resolved by unplugging the multiplexer from the boat instruments. Due to the length of the journey, no other attempt was done at sea. However, before leaving the board, it was ensure that with proper connections, the system would work.

The second session of measurement was done in four days. The first day, the author was picked up by Mr and Mrs Eklund in the early evening in Simrishamn. Due to the relatively strong wind and the necessity to sail to Bornholm quickly before the night, the crew took-off directly. An attempt at connecting the instruments was done while sailing. It failed and resulted into a short-cut that blew the fuse of the course computer, resulting in the loss of the autopilot and most electronics. The problem was solved by unplugging the multiplexer and changing the fuse. No measurements were recorded that evening, which was a pity because there was good winds and a good sea state. During the first night, all the electronics was carefully re-connected. It was ensured that there would not be anymore short-cut and that the system worked. However, it was realised that some of the data could not be read and that there was a problem of driver with the multiplexer. The firmware was not up-to-date. In Christiansø, the next stopover, the new driver was downloaded, thank to the local school teacher who gave access to his com-

puter and the internet. It was then installed on the computer and it was ensured that all the system worked. Next morning the crew took off to Utklippan. During this part of the journey, there was no wind whatsoever. An attempt was made at measuring performance, but it was impossible to get any speed as the sails were completely deflated. This was, however, a good opportunity to set the instrumentation accurately.

The next day, on the way to Kalmar, a last attempt was made. There was no wind in the late morning, but after lunch, a very light wind started to blow. It went stronger and stronger during the day to reach a good breeze strength by the evening. Five measurements were performed that day. The sea state was incredibly flat, thus the influence of waves can almost be neglected (waves of less than 10cm in amplitude). The autopilot was used for steering. It was the best way to ensure regularity in helm behaviour. It was also the easiest way to make sure that the unit would be going from upwind to downwind by angles of 10° . Data quality and accuracy was controlled by marking manually the different speeds reach for every angle.

The five measurements are listed below:

1. 20070609-10h35.txt
20070609, from 8h24'15" GMT to 8h37'23" GMT
2. 20070610-13h53.txt
20070610, from 10h34'04" GMT to 11h53'19" GMT
3. 20070610-14h40.txt
20070610, from 11h54'37" GMT to 12h40'47" GMT
4. 20070610-16h04.txt
20070610, from 12h41'21" GMT to 14h04'00" GMT
5. 20070610-17h03.txt
20070610, from 14h05'14" GMT to 15h03'04" GMT
6. 20070610-18h25.txt
20070610, from 15h23'10" GMT to 16h25'11" GMT

3.2.7 Problems encountered

With the experience gathered with “Le RM 1050”, most of the major problems that could have been encountered were prevented. Among the minor problems encountered we can mention the following:

- At first, the electric cables used to connect the multiplexer to the instruments had a too big section creating shorts and power loss in other cables of lesser diameter. On the journey, from Helsinborg to Copenhagen, the auto-pilot even exhibited an erratic behaviour on one occasion (steering full to port while in a narrow channel), thankfully without damages done. The problem was solved by using smaller electric cables (telephone cables).
- The set of instruments on board Vågvis could not be connected to the multiplexer at first. The NMEA output ports were not internally connected and therefore could not be retrieve directly. The other solution to retrieve the data would have been to connect every single screen through lengthy wires running in all the ship. This option was obviously out of question as it would have required to strip the unit partially to instal the cables. It was later realised that the SeaTalk© ports of the course computer could be plugged to the multiplexer. However the details of the connection procedure and decoding of the proprietary language were not solved before the end of the first campaign. When returning to university the electrical set-up and the way to decode SeaTalk© data was solved, allowing the second campaign to go almost as planed.
- The last problem that was discovered was the driver issue. Since the multiplexer was not plugged during the first journey, the problem appeared during the second one. Thankfully, the driver problem became obvious on a inhabited island with a great internet connection to shore. Once the driver was downloaded and installed, there was no more problems opposing the measurements but the weather.

3.3 Future recommendation

Over these two campaigns, small errors were made and later corrected. It turned out that, in practice, these measurements were not as simple as first thought, but also, not as complicated to performed as one can expect. From the experience gathered, a couple of recommendation can be made for future experimentation.

3.3.1 Availability and distance

For both “Le RM 1050” and “Vågvis”, it proved problematic to not having easy access to the boat on a daily basis while setting-up the measurement

campaign. Has was already explained, having the boat close to university and with a free access, means everything can be tested and sorted out before starting the campaign itself. The electrical problems could have been sorted after a couple of try-outs, etc. Being close to university or your project advisors is also a key to success. With Vågvis, a lot of small problems were solved by having Mr Bathfield on board during a try-out.

However, it is hard have a good sailing boat available at will over a long period of time. If such an occasion happens, one should not hesitate to take it, even though the boat is far away and there is only one campaign to be done. There are ways to be ready and face the unknown once on board:

- First of all, the student needs to get the precise set-up of the electronics on board.
- Then all the documentation from all the electronics manufacturer needs to be found, studied and understood in order to set-up a connection plan for the multiplexer.
- The multiplexer can be tested from “home” with a car battery and a couple of similar boat instruments. Old instruments can be bought online, or anything that send an electric signal in the same voltage/power range can do.
- Before getting onboard, the researcher needs to be up to date with his electronic and electrical skills and have all the necessary equipments with her/him (spare wires of different diameter, plier, welding tools that can work on 12V or 230V electrical network, spare fuses, etc).
- It is important to make sure that all the drivers, etc, are up to date.
- The student needs to set the simplest procedures possible for the installation, the try-out and the measurements. These procedures shall be thought-of to eliminate as many uncertainties as possible. These procedures also need to be flexible enough to incorporate changes due to unexpected events.
- At last, all the tools for the displacement measurement and the inclining test needs to be ready, and the student needs to be able to operate them confidently and adapt his plans to the reality of the boat.

With such preparation, the measurements should work. Nevertheless, if needed, a close-by internet access can always help to solve unexpected problems.

3.3.2 Reliability and Electronics

One of the problem encountered was that the electronics was too new on “Le RM 1050”. The set used proved highly unreliable. Using well proven electronics seems much more important than using the latest technology or newest brand.

In all cases, it is highly recommended to test the electronics and the electronic set-up before starting the campaign. If this is not possible, there is usually a lot of information on internet forums about all the different devices available on the market.

Depending on the budget dedicated for the thesis, it might also be possible to purchase more specific data recorders. In such a case, particular attention has to be put in choosing the most reliable device possible. At sea, the conditions are rough and the environment aggressive. The device will have to endure a lot and therefore, needs to be designed with such insight.

Due to the high potential of failure of most electronic devices when confronted to sea water or other major hazards at sea, it is important to back all the data up on different medium very regularly. If a too large sized file is not backed-up and the device gets lost, the data will be lost too.

3.3.3 Set-up and testing

If the possibility is given, it is highly recommended to proceed to several try-out before starting the measurements per se. As stated already, several set-up are sensitive to small parameters like electrical connections, etc. It is important to limit to the maximum the potential problems that can be encountered during the measurements. A series of try-out are perfect with that respect: problems can be identified clearly, solved quickly in the harbour, and validated by another try-out. That way, in a couple of hours or days, most of the set-up can be validated and corrected before the beginning of the measurement campaign.

3.3.4 Large Data Recording

One of the goal of the present work was to record large amount of data to study the accuracy of VPPs and DVPPs with reality. The idea was, therefore, to record data all around the clock over a year of sailing. That way, it was believed that sufficiently good recordings could lead to this assessment. However, two problems have appeared to take a lot of importance: the capacity of keeping a recording device working for long period; the capacity of storing and treating large amount of data.

On board “Le RM 1050” electrical power was a serious problem. The battery capacity was not big enough to supply power to an active computer 24/7. Though the diesel engine was producing enough power for such a use, the amount of fuel on board was not sufficient to run the engine around the clock during long journeys.

A typical recording of 5 hours was representing around 3,5Mb of data. Over the entire journey this would have represented around 3Gb of data (accounting for the fact that the boat sailed only 6 month over the full year). If this is an acceptable size of data for nowadays computers, it represents a significant size of data to treat back home. The data treatment of the 3,5Mb recording done with Vågvis took a week of computation (it is believed that the code was particularly inefficient. The computing time could easily have been reduced to a day, see section 4.3.3, page 85). Such large amount of data would require a very efficient database sorting code to be treated in a reasonable amount of time.

One set of data was not used in the present thesis: the logbook. All boats going over long distance have a logbook. On board “Le RM 1050” several data like estimated wind strength and direction, sea state, boat speed, etc, were recorded at every change of watch. This represents a large amount of data that can be more easily treated. However, such data are subject to errors as significant data are estimated by the seaman leaving watch and are not recorded by instruments. The logbook can be a good estimate but cannot be trusted. It is still a good help to check the accuracy of recorded data. It can also be a quick way to verify if simulations are on the right side. For example, on board “Le RM 1050”, it was logged that the boat reached 12 knots speed over ground in force 8 with strong sea, reaching. If a DVPP would give similar results for similar conditions, then the likeliness that the software is well predicting the performance of the boat could be assumed.

Chapter 4

Data Treatment

In this chapter, the tools developed to process and analyse the data are described. A Visual Basic Application (VBA) was developed in Excel© for this purpose. The code is presented in appendix B, from page 149 and onwards, and described in further details in appendix A, from page 127 and onwards.

4.1 Data Treatment: Finding the right tools

4.1.1 The Specificities of the NMEA 0183 language

The NMEA 0183 language is a data exchange protocol for marine electronic instruments. It is based on multiplexing principles¹. It has been developed by the “National Marine Electronics Association” of the United States of America. The standard 0183 is the most common in use in the yachting industry at the moment, but it will slowly be replaced by the 2000 standard in the coming years.

The NMEA 0183 protocol is independent from manufacturers. In the protocol, each instruments send “sentences” of data. Each sentence sent by the system starts by the type of instruments sending the data and the format of data following in that sentence. There are several sentences that are standard and others that are left to manufacturers freedom. On the NMEA ports, for all instruments complying with the NMEA 0183 standard, emission of certain sentences are compulsory. For example, a GPS will always output a sentence called GPGLL. The first two letters tells the system that it is a GPS that

¹Data from different instruments are collected by a station, sequenced and send through a single set of wires to another station where the data are then sorted out and transmitted to their final destination.

outputs the data. The last three letters indicate that this is a particular type of GPS data defining longitude, the latitude, and the time at which the coordinates were taken.

The problem of the NMEA language for the present use is the variable length of the sentences. From one instruction to the other, there are different number of characters into each different sentence. Data treatments becomes, then complicated because a lot of data treatment software needs a constant number of characters per line to perform calculations (this is the case of Matlab© for example).

4.1.2 Mathematical Software: First Trial

Several mathematical software were tried to process the data: Matlab©; Mathematica© and Excel©.

Matlab© could have been very promising as it is a good mathematical software that has good and easy programming facilities. However, it wasn't possible to import the data into the software because each line had a different number of characters. Matlab© is a matrix based software. It only works with matrices and vectors. Therefore, it needs data that can be properly stored into matrices to work. It is probably possible to create an input program for matlab©, but this was beyond our coding capabilities.

Mathematica© was used very briefly to try importing the data into the software. Similar problems were encountered as with Matlab©, therefore, it was abandoned.

Excel© was the software used in the end. A first trial revealed some difficulties to import the data. As will be seen later, these difficulties were probably due to a mis-use of the software. Nevertheless, it was impossible to import the data into Excel© at first, therefore, more sophisticated languages were investigated.

4.1.3 Programming With Better Languages

Several more robust languages were thought-of in this thesis:

- Applescript
- Perl
- C, C++
- Objective C

There were several reasons behind the choice of more sophisticated computing languages than those offered by mathematical software:

1. C, C++, Objective C, Perl, Applescript, etc, are not affected by the specificity of the NMEA 0183 language.
2. They are robust codes that can perform almost any actions.
3. A code based on any of these languages would execute much faster than any other solution using a software.
4. Programming was believed to be easy enough to produce a good solution quick enough to be used in this project
5. A code based on these languages could have been extended to produce a full application to be used by third parties.

The investigation about these languages have highlighted two languages in particular: Perl and Objective C.

Perl turned out to be a valid possibility thanks to its data treatment capabilities. On top of that, it is a language fully supported by the author's computer. The author also managed to find a code on internet by Peter Benet [5] that was intended to convert NMEA 0183 data into Excel© ready data. However, the author did not manage to understand that particular code, and attempts at modifying it to suite the special requirements of this project were not successful.

Objective C was the other valid possibility. This supplementary layer of C and C++ is supposed to be a very easy computing language as most of the objects one can need are already provided. This language is extensively used on Apple© computers. The second great interest of this language is its object oriented interface. Several modules can be designed to proceed to different data treatment depending on, for example, the need or not of a sequence, or the type of instrument and its brand. However, once again, coding with such a language requires a certain experience and expertise that was not available for this project.

For future developments, a language like Objective C should be considered. It is a very powerful language and its capabilities would be a great asset for such process as data treatment. This is specially the case if one is to do measurements over long period of time. The amount of data to treat becoming much bigger than that of this project, a good computer code in a better language would help.

4.1.4 Mathematical Software: Second Trial

When it became obvious that more serious computing languages were too complicated for the present work a way out was sought. From the above mentioned mathematical software only Excel© proved to be helpful. It appeared that the previous failed attempts at importing data into the software was due to a miss-understanding of its use.

Excel© is actually well fit to this project. It can import the data, and it is possible to develop a complicated computer code via the Visual Basic Application (VBA) language to process them. The main problems of Excel© are:

- it cannot contain more than 65000 lines per worksheet (at the time this work was carried out, Office 2007 was not released yet)
- it is rather slow if you do not de-activate the automatic screen refresh command
- Certain formulae are not available directly into VBA and it is therefore necessary to call the graphical interface of Excel© to solve the problem, which, in turn, makes the code slow.

On the other hands, its advantages are:

- The possibility to use the object oriented VBA language
- VBA is a very simple programming language
- Excel© and VBA in Excel© come with a very good help manual to ease their already easy use.
- It is possible to do almost anything with VBA

During the end of year 2006 and until end of summer 2007, a large VBA code was developed to convert and treat NMEA 0183 data. It is presented in appendix B, from page 149 and onwards, and explained in appendix A, from page 127 and onwards.

4.2 Data Treatment: Proceeding With Excel© and VBA©

4.2.1 Data Treatment Procedure

In order to proceed with the treatment of data, the data have to be filtered and sorted. They can, then, be processed to perform the required analysis.

4.2. DATA TREATMENT: PROCEEDING WITH EXCEL[®] AND VBA[®]77

The way data are filtered and sorted will affect the feasibility of further analysis. It took some time to find out a smart way to store data such that time dependency could be kept.

First, it was believed that time dependency was not important at all. The sorting of data was then, really simple: all different data would be stored in separate Excel[®] sheets. From there, the different figures of interest like maximum speed, etc, could be retrieved easily.

However, this way of proceeding neglected an important physical aspect of sailing: inertia. All sailing boat needs a certain time to respond to a change in driving force. This simple mechanical principle means that the wind speed recorded at a time “t” does not correspond to the boat speed at that same time. If accurate analysis is to be carried out, the time response of the boat has to be evaluated. The first step is to place time markers during the sorting of data to keep their time dependency.

This simple fact has turned the code into a much more complicated procedure than first thought. Figure 4.1, page 78 shows the procedure used to develop the code and its link with the rest of this thesis:

4.2.2 Reading of result produced

The sorting produces a database where every single useful information is stored in a separate spreadsheet. All the data are made time dependent. In practice, this means that every time a time marker is captured by the multiplexer, it is added to all spreadsheets as a new line. Therefore, data are regularly separated by a time marker. It was observed that a time marker was sent every second into the system. All the different input data were never sent more than three times per second and always in a chronological order. Using the time markers, we can therefore assume a quick good chronological definition and a good reading of events.

This time dependency capability that we kept into the database allows us to interpret the data in two ways:

1. The performance² of the yacht can be read linearly, i.e. the performance parameters, in the time domain, are taken as chronological events. Impact of inertia forces or external events on the performance are ignored.
2. The performance of the yacht is first post-processed and then read, taking into account inertia forces and external events in order to obtain

²The performance of a yacht will be defined here as the speed the yacht can reach for the wind present at that time. The performance is therefore defined for a wind angle and a wind speed.

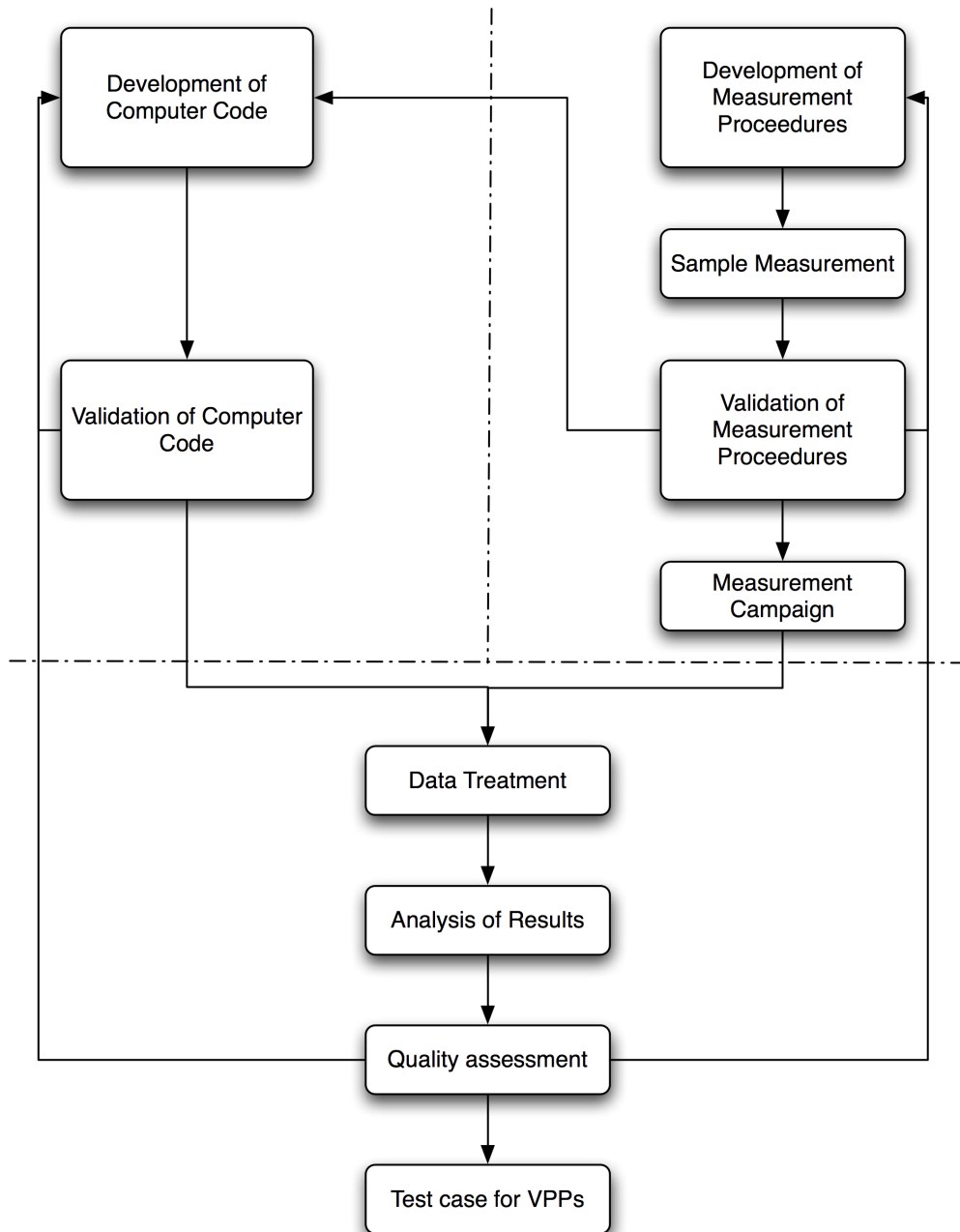


Figure 4.1: Test case generation work process

4.2. DATA TREATMENT: PROCEEDING WITH EXCEL© AND VBA©79

the absolute maximum capabilities of the yacht. We will call this second approach a “dynamical” reading of results.

These two approaches will be described now in a bit more detail.

Linear reading of results

In this approach, as already mentioned, we do not take into account the external events that affect in any kind of way the sequence of the events recorded. This means that the performance data are shown exactly in the same sequence as they were recorded. Examples of recording are shown in figures 4.3 and 4.4, pages 84 and 86. In these recordings, we can see that there is a delay in response between wind peak speeds and boat peak speeds. This are due to inertia or external events on the yacht’s motion. The implication is that if we look at a time t where the wind speed in maximum, the boat speed, is not yet maximum. If the data are sorted on this basis, then a bias is introduced into the performance reading as peak of performance are not linked to the conditions that made it possible but to the condition that existed at the time t when the event occurred.

During the present work, this approach was used to plot the data because of a lack of time to develop the second approach. The effect on reading of results is presented in section 6.1, page 103 and onwards. This endure incoherent plots where data that should be on different plots, gets plot together, thus inducing a difficult reading of the results.

Dynamical reading of results

This approach is a lot more interesting. Here we try to take into account the different events that affect the yacht’s performance to “correct” the recorded data into the time domain. From a practical point of view, this means that for every instantaneous event, we determine which data “triggered” it. By evaluating and computing speeds, accelerations and all kind of derivatives, we can link peak performance to peak wind speeds, etc. Various data can be processed that way, from helm angle, wind angle, yacht’s speed or heading, etc. The code can be developed to “comprehend” the behaviour of the boat. Plot of performance becomes more coherent since data resulting from a particular wind speed and angle are plot together. This type of reading of results also allow analysing what affects the performance through analysing the time lags and linking it to its cause. This part of the work is presented in further details into section 4.3.2, from page 81 and onwards. Due to lack of time this approach was not further developed.

4.2.3 The Importance of Details: Preparing Future Work

During the development of the code, it was quickly realised that the way data was handled from the beginning would be crucial to the success of the data treatment. A lot of time and effort was spent to find the best way to sort data.

It was decided to sort data in different matrices by their name. Then particular data that had to be computed would be computed. Finally, the useful data were sorted in another set of matrices by wind speed. This way, the data is accessible in different states:

1. raw state (not treated neither sorted)
2. sorted state (not treated but sorted by type of data)
3. treated state (processed useful data to produce a polar curve)

Details were found very important. For example, since two different brands of electronics were used, the data were not exactly the same from one manufacturer to another. The code, whose development started early in the project, had to be adapted to the new set of measurements finally used. It was therefore thought useful to introduce an error message into the code to tell the user when an unknown data was encountered. This would allow upgrading the code to new sentences introduced by different set of electronics.

Another question was found important from the beginning: the time dependency. A time flag was necessary to make the data time dependent. The need for time dependency comes from the will to correct the data for the ship time response to gusts and other variable events. Several instruments output time in there sequences. However, the format of the data made it difficult to treat. Inserting the time converted as one data (in seconds), has allowed making all the other data time dependent and has allowed studying the reaction of the boat time-wise compared to varying winds.

4.2.4 VBA code

The VBA code was developed specifically for the present project and is explained in detail in appendix A, page 127. The full code is presented in appendix B, page 149.

The details of the code are not presented here as they are not relevant per se with the present work. For explanations the readers can refer to the appendices mentioned above. It is recommended to read the appendix A, from page 127 and onwards for a better understanding of the discussion in section 4.3.

4.3 Resulting code: failures and achievements

The code that was developed using VBA is interesting in its ways of handling objects and the way a complicated data set could be turned into useful database. The code explained in appendix A, chapter A.1, page 127, will now be discussed.

4.3.1 Identified problems

Several problems have been identified that turn the code into an inefficient program:

- The Graphical User Interface (GUI) of Excel© was not turned off into the code. As a result, during each operation, the code was sending a data to display into the Excel© GUI. Displaying something is rather a heavy task for a computer (with regard to the amount of computer power necessary to perform such a task); displaying every single figure created or moved asked for a huge amount of power overall. What should have taken minutes or at worst, hours, took days.
- A lot of operations could have been coupled into the same loop. This was not done so because the development of this code was based on solving unforeseen problems, not on building an efficient code from well defined experiences. Also, due to the complexity of the data treatment, operations were performed one after the other to keep a clear picture of the process. If this code is to be used again one can therefore recombined all operation for a more efficient process.
- Using a data-base handling program would probably have made many problems simpler to solve. However, the author was not confident in using such programs. Many tasks that are performed by this code would have been done in a better and faster way by more specialised tools.

4.3.2 Ship Time Response

The evaluation of the ship response to gust was believed to be very important for the accuracy of the analysis. While this statement is true, the development of a tool to evaluate the time response have turned out to be more complicated than first thought.

One of the main problem when such an analysis has to be performed is that

the data have to be “interpreted” by the code in order to be processed accurately.

During the development of the code, to better spot bugs, two sample of around 30 seconds of measurements were processed. Early plots were used to get a better picture of the coding problems to be solved. This measurement is shown in figures 4.2 , 4.3 and 4.4, pages 83, 84 and 86, respectively. Figure 4.2, page 83, shows the difference between the wind angle as calculated with regard to the ground and as calculated with regard to the water. The difficulty of assessing the time response of the ship is clear: The speed has quick “irregular” variations.

Figure 4.3, page 84, presents the problem of the importance of assessing the time response more comprehensively. The graph characteristics are as follow:

- time range: 32 seconds
- TWS-GPS: True Wind Speed computed with GPS figures
- SoG: Speed over Ground (given by GPS)
- SoW: Speed over Water (given by the Loch-meter)
- AWA: Apparent Wind Angle
- TWA-GPS: True Wind Angle computed with GPS figures

We can see that, when going upwind, the true wind speed and the true wind angle are not always correlated. There can be shifts in the wind angle at constant speed, or shifts in speed at the same angle. This reflect the true variations of the wind. The speed over ground and the speed over water of the unit have a perfect match in the present case (only very strong currents would actually provoke a shift at this timescale, which was not the case in the present set of measurements). The speed of the unit changes with the speed of wind with a varying time decay. There is a pattern in this change: a peak of wind speed will always induce a peak of boat speed. However that peak can happen with a varying time lag. The goal of the time response module is to identify it. This time lag is very important for the analysis of a VPP: These software are usually developed to give maximum speeds achieved by a unit in a perfect steady state condition. In reality a speed peak can be initiated by various elements like inertia forces, hydrodynamical loads, shifts in wind strength or direction, etc. A thoughtful analysis of this time lag depending on measured data like wind speed, angle, boat speed, heading, etc. could eventually let an empiric rule emerge. That rule could be defined in terms of headings, wind speed and wind angle to be incorporated in the

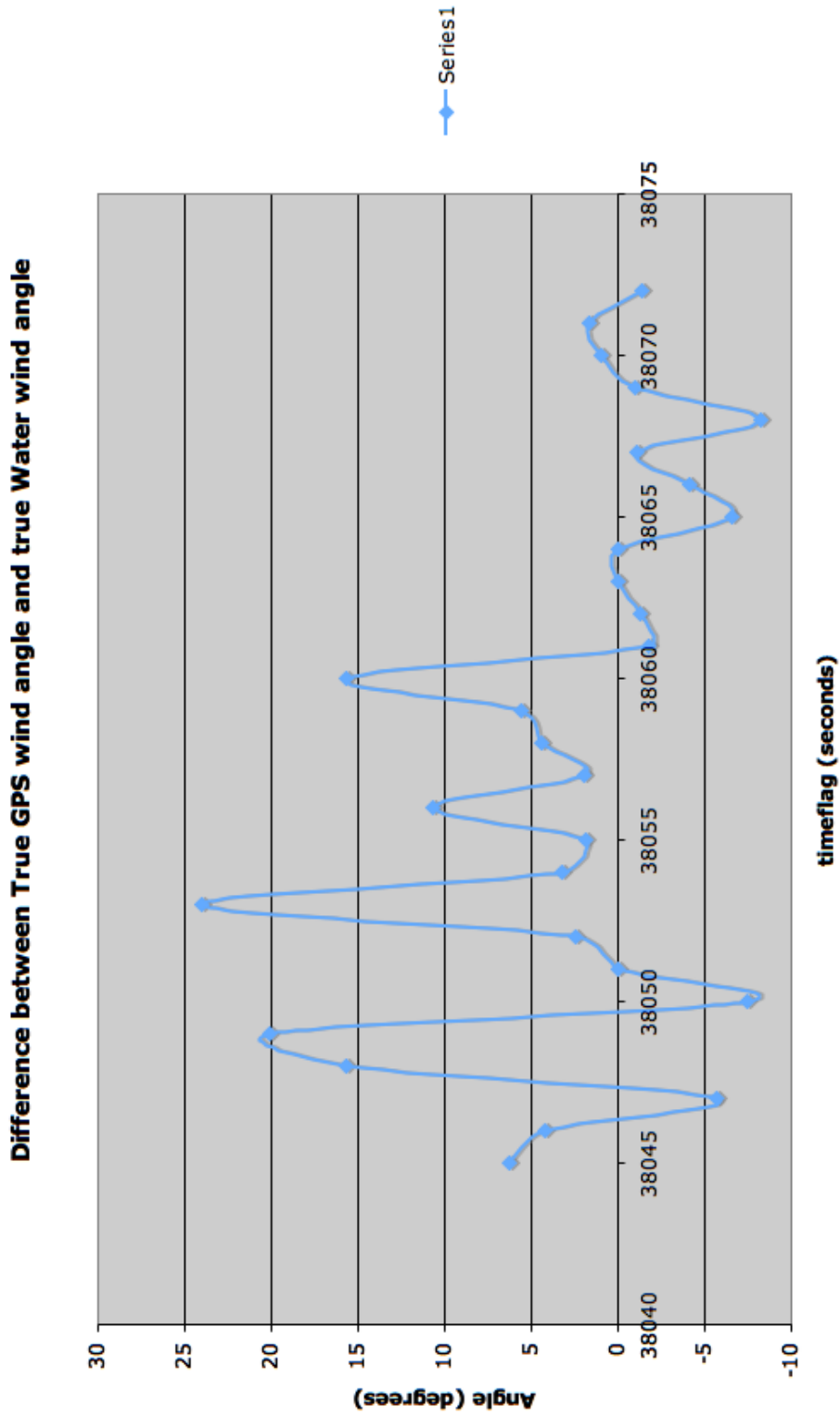


Figure 4.2: Wind shift between the true wind angle calculated from the GPS or calculated from the Loch-meter

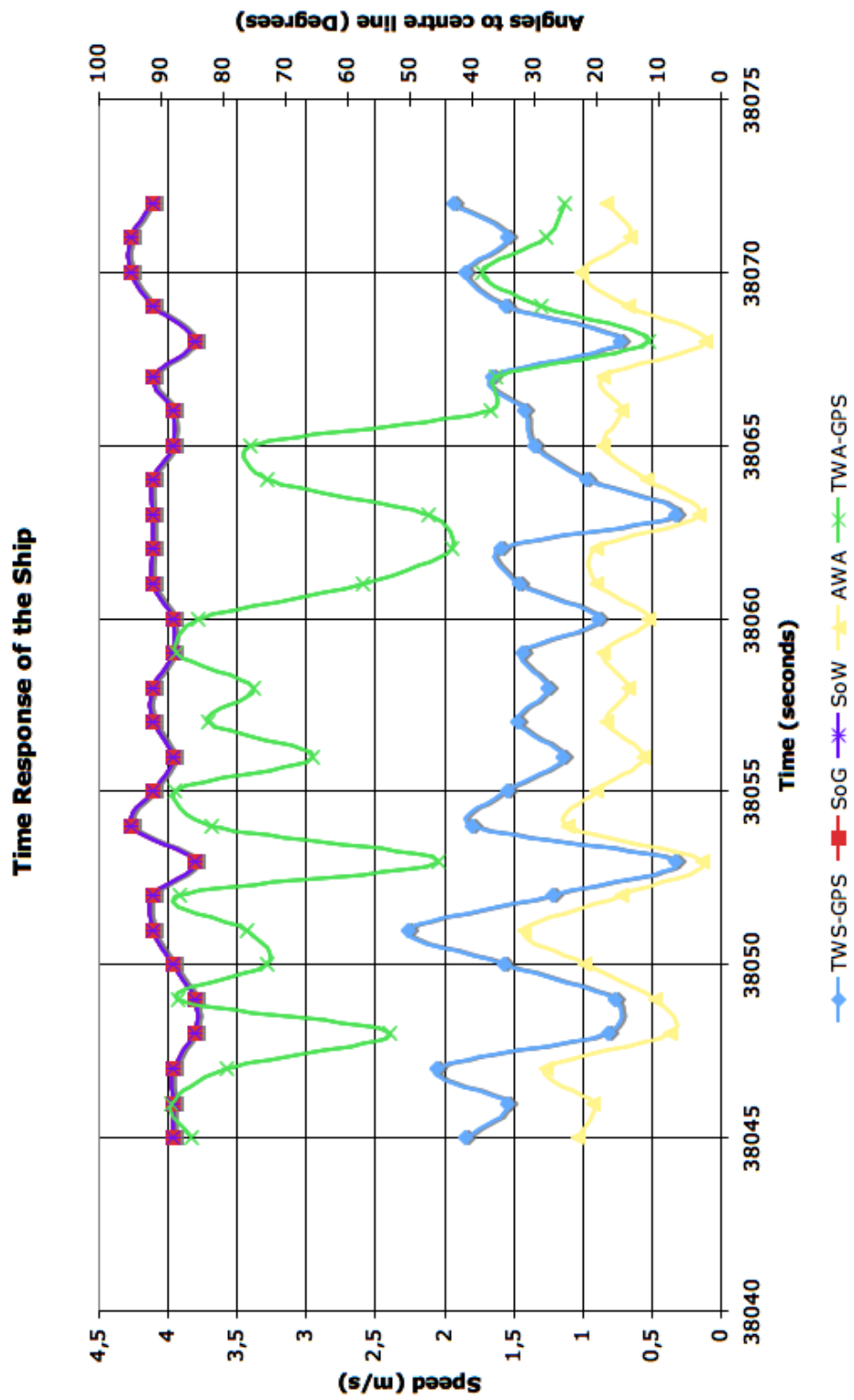


Figure 4.3: Time response of Vågvis going upwind

correction of the measured data. That way, peak speeds of the boat could eventually be related to, if necessary, the gust of wind that induced it.

The analysis of the time lag can be based on the analysis of the measured data. If we differentiate the boat's speed, we get its acceleration. Likewise, we can get the acceleration of the wind with regard to the boat and with regard to the ground. We can also get the rotational speed of the wind and the boat by differentiating the wind angle to the boat and the boat's heading. Differentiating again and we get the rotational accelerations. With all these information, the inertia effects on the boat can be estimated empirically. Using Newton's law, a mathematical model describing the time lag can be built.

If we compare figure 4.3, page 84 with figure 4.4, page 86, we can see that the time lag varies between upwind and downwind. Clearly, the mathematical model that shall be built has to "understand" this difference and adapt its model to the current condition of sailing. It is also suspected that depending on the wave height, frequency, and steepness, similar problems will occur. The question that then arises is: how to define precisely the time lag when many noticeable parameters influence it. If good measurements are provided, maybe the solution will appear straightforward and simple.

Due to time constrain on the present thesis, this module was not implemented and is left to future research.

4.3.3 Quality of the Resulting Code

The code that was created is too slow to achieve the original goal of this thesis (i.e. building a proper performance database for a sailing yacht in waves, see 1.3, page 11). If it takes a week to compute 5 hours of measurements in calm seas, the computing time would become overwhelming if one was to use this code to assess the performance of a boat in a real sea state and over a large amount of measurements.

However, as already mentioned, several bad coding practices can be corrected. It is believed that if the GUI is disabled during the process, then the computing time should be reduced by a factor of 5 to 10. On top of that, the processes put into place were not designed efficiently but comprehensively. An important task in the design of a code is to identify all the potential problems and solve them. Then, in a second loop, generally, the code is simplified and improved to be more efficient. That later stage was not performed due to lack of time. If this second loop can be performed, it is believe that the amount of computing time can be reduced drastically.

Overall, the quality of the code is good (if not accounting for computing time performance). The code is quite complex because a measurement set

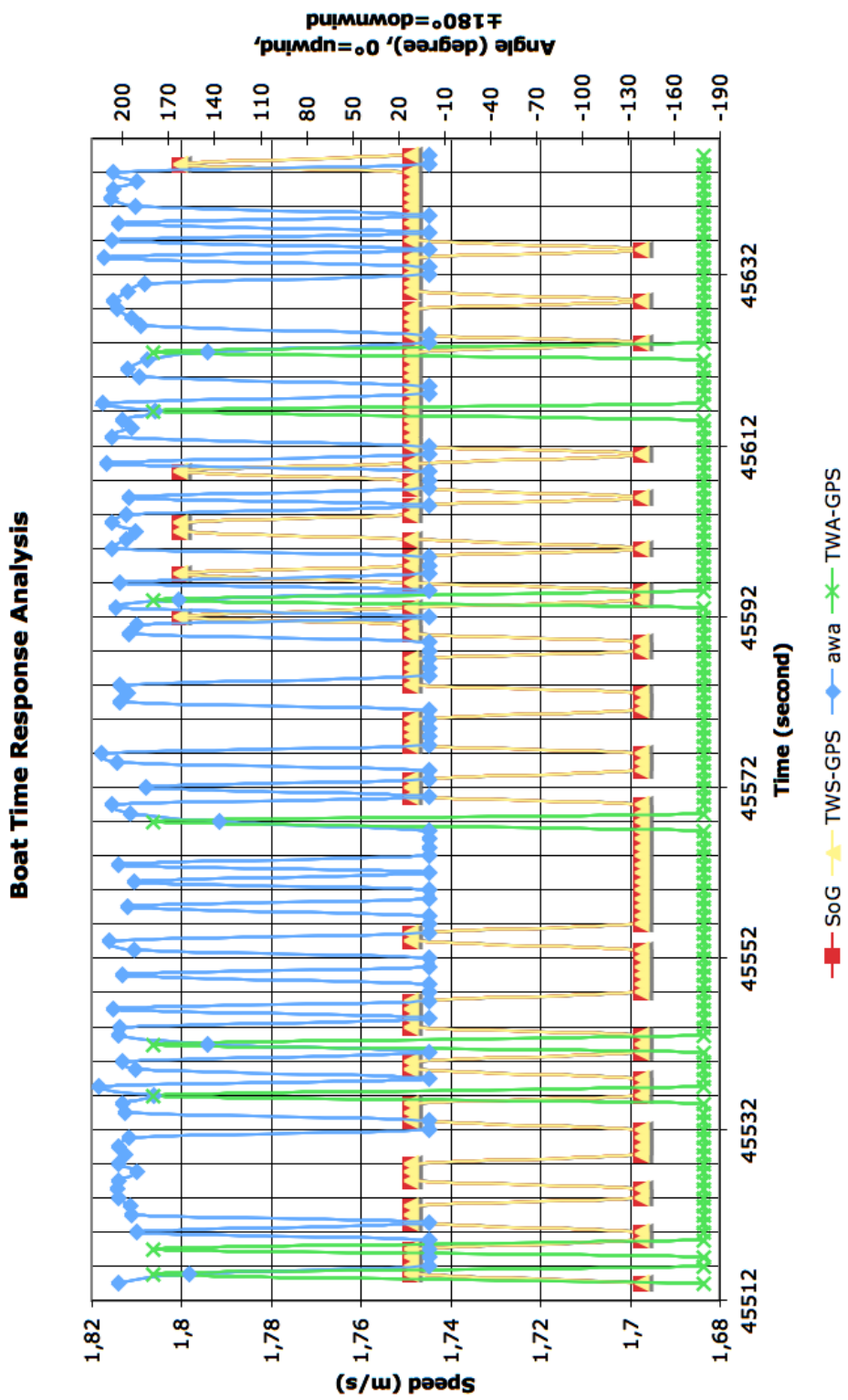


Figure 4.4: Time response of Vågvis going downwind

includes many small defects that need to be treated specifically. For example, if an instrument send erratic data, or when another one does not send an instruction for several burst like when there is a short in the system, the code filters the data accordingly, or lets the user know that something unexpected was encountered. This code takes care of many details which increase the accuracy of the results. However, for a new set of instruments and measurements, other problems might arise that will need to be assessed separately. As one can understand: the measurements will always depend on the instrumentations used.

4.3.4 Quality Analysis of the Treated Data

The quality of the processed data is relatively good. The fact that the ship time response (see 4.3.2, page 81) could not be evaluated has a significant impact on the results. For example, if we take the plot of the boat speed for winds between $3.5m.s^{-1}$ to $4.5m.s^{-1}$ presented in figure 4.5 page, 88, we can observe data points that are well outside the main stream of points. This data are most probably the result of other wind strength or wave effects and if a time response would have been taken into account, they would most probably not have appeared in this wind speed range but be shifted to another one instead.

The accuracy of the data, apart of being bounded to the inertia of the ship, is also linked to several choices that were made during the development of the code. For example, the data are here sorted by wind strength. The interval that was used is $1m.s^{-1}$. The purpose of this interval is to isolate more precisely the boat's performance induced by a particular wind strength. If this range is enlarge, the filtering becomes less efficient and we increase the likelihood of plotting data induced by another wind strength, like mentioned already. The filtering is therefore very important to assess the data.

As for the wind strength, the same problem occurs with true wind angles.

4.3.5 Plots for Analysis

To perform the analysis of the data measured and the validation of results given by VPP or DVPPs, the results were plotted in different manners using Excel© built-in capacities for charts.

If we plot in the performance data directly into a polar plot, it becomes unreadable as can be seen in figure 4.6 , page 90. Typically, once the data have been sorted by wind strength, angle, etc. they have to be sorted again in order to keep only one data per typical wind strength.

If more time would have been available, better polar plot could have been

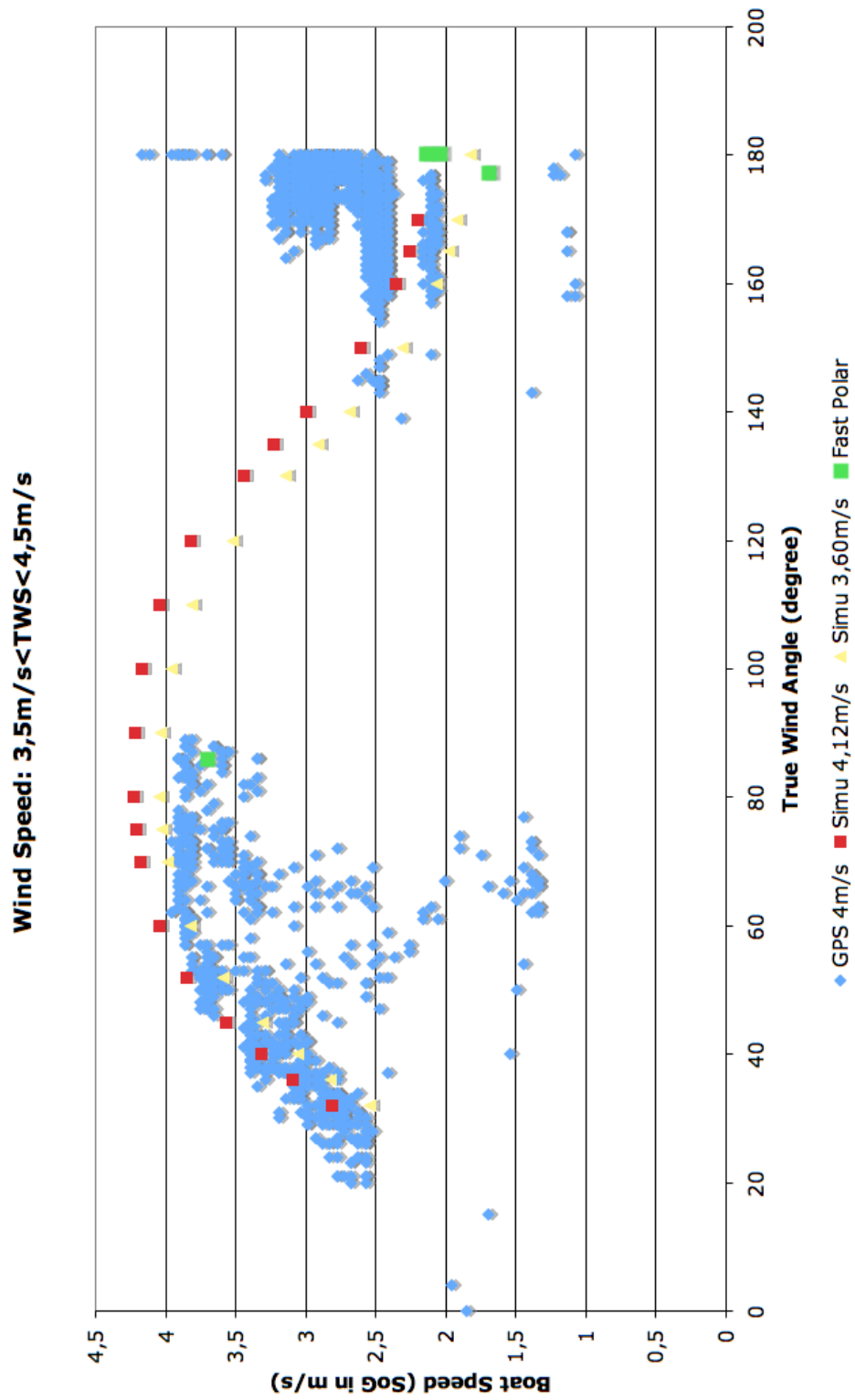


Figure 4.5: Vågvis speeds for a wind strength of $4\text{m}\cdot\text{s}^{-1}$ for different wind angles

produced. It would have required the use of statistical data analysis. The way the data were sorted allows this kind of analysis to take place.

For the general analysis and conclusion of this work, the type of plot presented in figure 4.5, page 88, was used instead as it give a much clearer picture for large scattered data.

4.4 Future Possible Development of the Code

The code was developed with future in mind. Most of the modules that were coded can be enlarged to account for new instruments or new instructions. Specially, the first module contains a tool to detect unknown figures.

4.4.1 Using a Better Language for a Faster Process or a Data-Base software

If the code is to be further developed, the procedures should be revised to make the process quicker. As already explained in section 4.3, from page 81 and onwards, the process could be made much more efficient.

Although it is not really the work of a naval architect, the code could be transposed to C, C++ or Objective C to make use of full computer power and of a real graphical interface. Once again, most of the process should be similar to the one developed during this thesis.

The interest of the program that was herein developed is that, if transposed into a better code, it could be used to process a very large amount of data that could be recorded over months of sailing, though, a data-base software like Access© or MySQL© would probably give good results too.

The code could also be used to process NMEA data in real time. This would mean that a useful data base could be created on board and used while at sea to evaluate the performance of the crew on board. It could also mean that a crew could use the data base when back in the harbour to analyse a run, etc. This gives a different perspective to the code. Of course, several commercial codes already perform this task well, but this could, nevertheless be a potential future development. From a research point of view, this could allow researchers to see in real time the impact of changing one parameter in there run. It could be quite useful to have a “in house” tool to do so, because all the parameters can be tuned and controlled accurately. It could be a nice tool to perform general research on performance at sea and better assess, for example, VPPs or DVPPs.

Database software, if they could be used, could be an efficient solution to

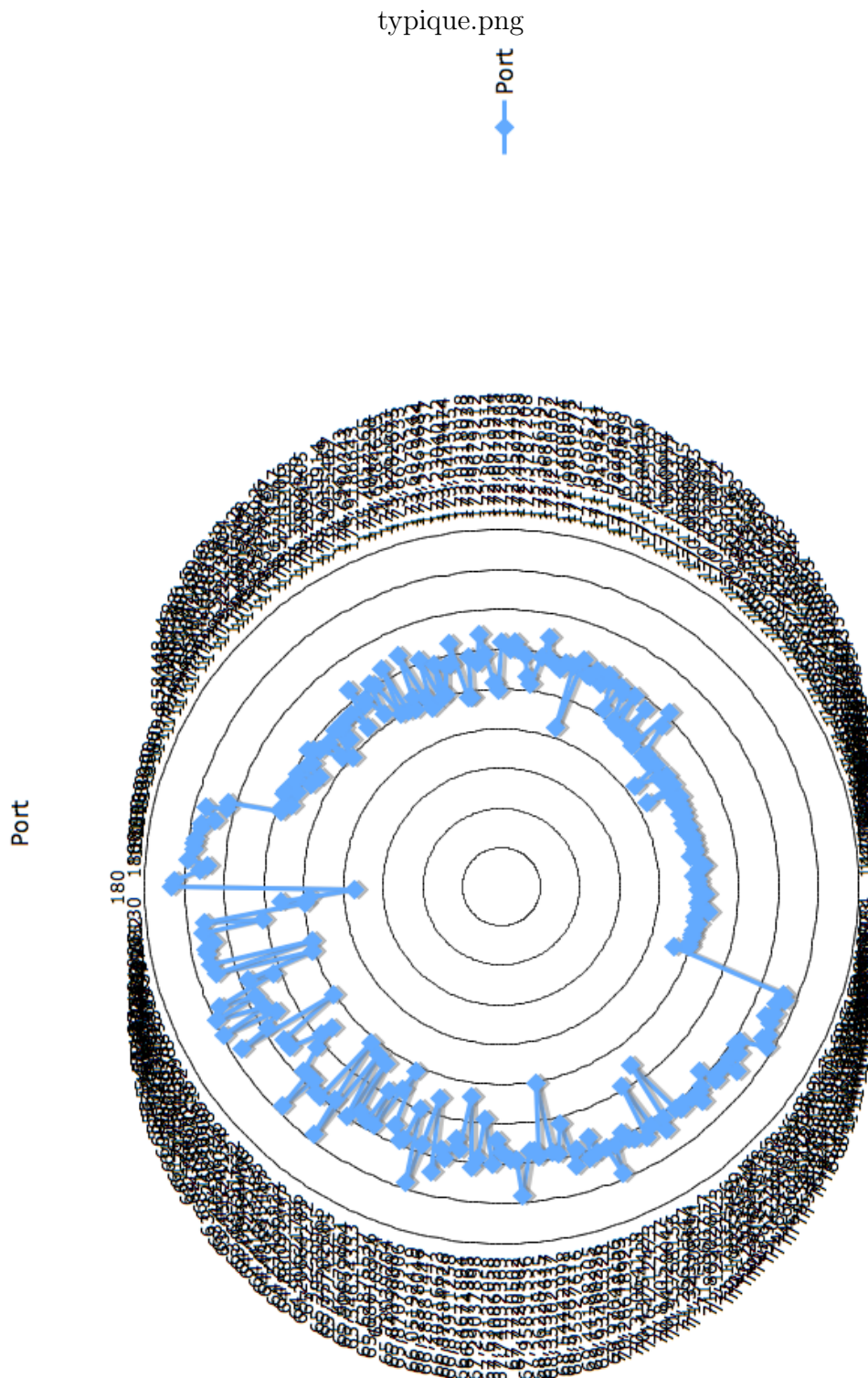


Figure 4.6: Vågvis typical polar plot of the measurements for one wind speed

process data. Investigating their viability should be a first step prior to any future development.

4.4.2 Incorporating External Data in The Process

While the original goal of the present thesis was to validate DVPPs, the incorporation of external data has yet to be added to the code. Presently, there is no tools that perform this task in the code.

By external data is meant:

- Wave height and direction
- Sails sheeting and luffing
- Weight distribution on board
- Mean heel angle under sails
- Results of the inclining test
- Displacement measurements
- etc.

Such data would give precious information that could be incorporated into the database in order to reach better accuracy and be able to validate the dynamical type of VPPs. If, for example, one manages to get several accelerometers onto the boat's electronic system (i.e. plugged to the multiplexer and connected, therefore to the recording computer), then a lot of information about wave impact, wave motion, wave height, etc, could be analysed and included into the research. This could give a fantastic opportunity to better understand sailing and find ways to predict performance of boats at sea.

However, there are a lot of technical challenges to such problems, though new technologies like smart phones could be used for input into a wireless-connected computer³ to solve most of them. Further development with these technologies could help create a very comprehensive ship motion and performance analysis tool for sailors and naval architects.

³Smart phones can be connected to a computer via bluetooth or wifi and run an application that runs as a manual input for data such as sails sheeting, etc. A second smart phone could be used as an accelerometer. Placed fixed on a known point, it could be used to measure accelerations, but also mean heel and trim, etc.

4.4.3 Ship Behaviour Module

If the data mentioned in section 4.4.2, page 91 could be included into the data base, the behaviour of boats could probably be assessed with high accuracy. The time response to external events like wind gust or waves impact could be taken into account and such phenomenon could be assessed to give better designing guidelines to naval architects.

Past the difficulty of collecting data, the difficulty remains into analysing data and determine the inertia behaviour of the boat. With one or two sets of accelerometers, noises generated in the data and time decays could be assessed with high accuracy. However, this would probably represent the work of several master thesis to reach a good result.

4.4.4 Plot Production and Plot Analysis Modules

Finally, the plots produced in Excel© were not satisfactory. From the difficulty to produce a clean polar curve to the difficulty to plot a large amount of data, a more dedicated tool like Matlab©, MathCad© or Mathematica© would be welcomed. These softwares have great abilities when it comes to complicated plotting.

Inside the code, a module could be developed to prepare the data to be plot and store them in the right format for a direct input in one of these software. With VBA, it is even possible, directly from Excel, to trigger a plot in Matlab©. This development should be investigated further as it would greatly improve the readability of the results.

Chapter 5

Computer Simulations

After the measurements, simulations were performed. The DVPP from SSPA AB, SailSim© was first investigated. Due to problems with the characteristics of “Le RM 1050” and later, lack of support, the software was dropped in favour of WinDesign© a VPP from the Wolfson unit, a department of the University of Southampton.

Both approaches will be detailed here.

5.1 SailSim© by SSPA AB

5.1.1 Characteristics and Capabilities

SailSim© is a DVPP based on SimNon©, a software developed by SSPA AB. SimNon© is used internally at SSPA AB to perform ship manoeuvring simulations in the time domain for the different ship motions. It solves Ordinary Differential Equations.

SailSim© can perform two kind of analysis:

1. “Static” velocity prediction
2. “Dynamic” velocity prediction

While the first one assumes the motion of a boat in equilibrium with a simulated wind on a virtual flat sea, the second one updates the heel, trim, yaw, surge, sway and leeway angles of the boat evolving into a “realistic” sea state with waves and current as defined by the user (i.e. the analysis includes motion analysis of the hull and the rig in a typical sea state).

The main advantage of a DVPP over a simpler VPP is the ability to evaluate the effect of real motions on the performances. The main problem induced is that a DVPP is necessarily more complicated to develop and to use than

a VPP. As a matter of fact, there is no commercial DVPP available on the market at the moment, and only a handful static VPPs. Even if decades of research are available, in this field, the complexity induced by coupling motion, resistance and propulsion with the characteristics of a boat, to produce an accurate simulation of its efficiency, have kept these tools unreliable for a long period of time.

SailSim© uses different geometrical input to simulate the motion of a boat. The hull is defined by a number of points per section. Once the coordinates are input, the software uses these point to discretise a hull shape and hence, calculate its motion. The appendages like the rudder and the keel, as well as the rig, are input as parameters. The efficiency of these appendages is then estimated based on similar appendages or rig which characteristics are held in a database. This database is based on the Delft series from the Technical University Delft, in the Netherlands. It also holds the resistance characteristics of a large number of hulls tested in towing tanks.

5.1.2 Preparation Work for “Le RM 1050”

To be able to simulate the performance of “Le RM 1050”, it was necessary to get all the details about the boat itself. Thus, the naval architect of the boat, **Marc Lombard** was contacted. He kindly let us use all his material including CAD drawings of the hull (lines plan), rig and appendages as well as 3D model of the hull (Rhinoceros 3D). His only condition was that none of the key data of the boat shall be shared and that the hull lines should not be published. If people want to have these data, they can contact him directly.

The data were then collected from the drawings. The manual of SailSim© [6] presents a list of all the data necessary to run the DVPP.

As agreed with the naval architect **Marc Lombard**, these data are not presented in this master thesis. The general data for “Le RM 1050” can be found in section 3.1, page 37.

5.1.3 Preparation Work for “Vågvis”

The work undertaken for “Le RM 1050” was also undertaken with “Vågvis”. The naval architect **Gabriel Heyman**, was kind enough to provide us with all the data he had produced over the years on his design of “Vågvis”. The data included all the CAD drawings, the hull lines, the 3D Rhinoceros model, as well as the weight estimates and inclining test data.

As the work went along with collecting data for “Vågvis”, it appeared that no further support could be provided by SSPA AB due to large work overload

on their side. The collection of data was therefore stopped and another VPP provider was sought to perform the simulations.

5.1.4 Reasons Why No Further Work Was Done With SailSim©

SailSim© is a very promising software. It's dynamic capabilities are quite unique in the world of VPPs. The original intension with this thesis was to assess its strength and weaknesses and hence, help its development.

However, it proved to be a software difficult to use due to large amount of precise data that had to be provided to make it run. The original hull that was intended to be used for the simulations wasn't suitable for the simulation abilities of the software. However, it was believed that SSPA AB could modify the source code to take into account the twin keels configuration of the boat. It turned out that SSPA AB just couldn't do the modifications because of lack of time. When a more conventional yacht was found, there was still questions to be answered: SailSim© was and is a software under development, and SSPA's help was crucial to solve the various problems encountered while trying to run the VPP and obtaining accurate results.

In agreement with Pr Larsson and Mr Bathfield, it was decided to look for a commercial VPP that would be available off-the-shelf and be use with support form the developers. Attention was fixed on WinDesign© from the Wolfson Unit at the University of Southampton because that VPP had been used by the yacht industry for sometime already.

5.2 WinDesign© by The Wolfson Unit

5.2.1 Characteristics and Capabilities

WinDesign© from the Wolfson Unit at the University of Southampton is a simpler velocity prediction program than SailSim©. It only considers a yacht in "static" virtual sea-states.

WinDesign© can process several different hulls at the same time, thus allowing the naval architect to compare several designs through the same conditions. This is performed via a simulated regatta where each yacht "races" in the same environmental conditions. For each particular characteristics, the fastest yacht of the leg can be identified and the winner overall highlighted. For a naval architect designing a new yacht with a particular race in mind, several options can be validated and compared together to assess the best opportunities and the best chances of success.

WinDesign is a fairly easy to use software. First hulls have to be entered into the system and are called “yacht”. They can be either entered with typical parameters (B/LoA, D/T, etc.), or with a set of points describing the hull. These offset points follow the rules of a lines plan: from front to aft, defined as sections along the girth, perpendicular to centreline and with a specified number of points on each section. The set of lines is used by the software to briefly calculate the basic hydrodynamic equilibrium of the hull under external forces. Alongside the hull data, each “yacht” is defined by several sets of sails. It can be any combinations of sails, either defined by parameters and based on the sails predefined inside the software, or sails created using the aerodynamical properties of a sail as measured in a wind tunnel or in similar manners. Then the user defines a set of wind directions and strengths to be used for the simulations and a race committee where the different courses are entered and performed for the different types of yacht and sail combinations defined. The output is polar curves and raw data that can then be used by the naval architect for his purposes.

WinDesign© has the great advantage of being fairly simple and quick to use. It requires little actual data to run, which means that an architect can quickly verify his ideas on a new design. However, like SailSim© it is based on tank testing data (and more specifically on the “Delft series”). Like for SailSim©, validation with full scale data is important to ensure accuracy. To do so, a set of simulations based on the real conditions encountered during the measurements is run and will later be compared with the measurements.

5.2.2 Preparation Work for “Vågvis”: LPP©

To input the characteristics of Vågvis into WinDesign©, we produce an offset file for the hull and general dimensions for the keel, rudder, and sails. These last three items are input parametrically into WinDesign©.

Using the displacement data as per measure 20070610 in table 3.3, page 63, we first set the 3D model of the hull to its right waterline in Rhinoceros 3D v5.0© (Rhino). A set of “contour” lines is produced from which we extract data points. These data points are, hence, located along the girth of the hull. These data points are exported into Excel© via a text file, where they are sorted into a specific order. This order matches the one of the OFE input protocol used by LPP©.

LPP© is a software dedicated to produce “yacht” files for WinDesign©. It consists in producing a parametrical model of a yacht useful for WinDesign© from general dimensions, or offset files. The validity of the input and the produced output can be checked in LPP©.

The offset file is read into LPP©. The keel and rudder dimensions are input

as measured on the CAD drawings provided by the naval architect, [Gabriel Heyman](#). We then apply a point load to the unit: a weight based on the displacement and inclining test measurement (table 3.3, page 63). We also define the water density and several other parameters like unit name, project description, etc. After inputting all data, a simple hydrostatic calculation is performed in LPP© in order to check that the properties of the yacht are correct. The file is finally exported in an appropriate format to WinDesign©.

5.2.3 Running WinDesign©

In WinDesign©, we import the unit as defined in LPP©. We then define the sails that are going to be used by the virtual yacht. The sail data are obtained by measurement on the CAD drawings provided by [Gabriel Heyman](#). Once the sails characteristics are entered, the unit is complete. The only thing that remains is the set-up of the simulations themselves.

We want to compare, here, the results of simulations with the experiment. Since during the journey there was no noticeable waves nor current, the simulations are performed for a no-wave-no-current condition. The wind range defined span the range of winds encountered during the measurements.

To set the simulations, we determine two cases: an upwind case and a downwind case. This is a necessary step, as, most boats, usually uses different types of sails for different wind angles. In our case, only two sails were used: the main and the genoa. For each case, we set a different type of wind angles, from 30° to 120° for the upwind case and from 80° to 180° for the downwind case.

During the simulations, WinDesign© maximises the boat speed by optimising the sails sheeting and angle. We obtain at the end of the simulation, the best possible speed the boat can reach for every wind angle. These data are presented in a final report as a polar curve and as tables containing for every wind angle and speed, the best speed reached. The polar curve is presented in figure 5.1, page 98. The results from WinDesign© are compared with the measurements and discussed further in chapter 6 from page 103 and onward. Limitations are discussed in the next section.

5.3 Limitations of the Simulations

The simulation have appeared to have some limitation even though they are powerful tools. Among the fact that the forces are estimated based on empirical data, the way the software is designed and developed is a limit on the use of a VPP.

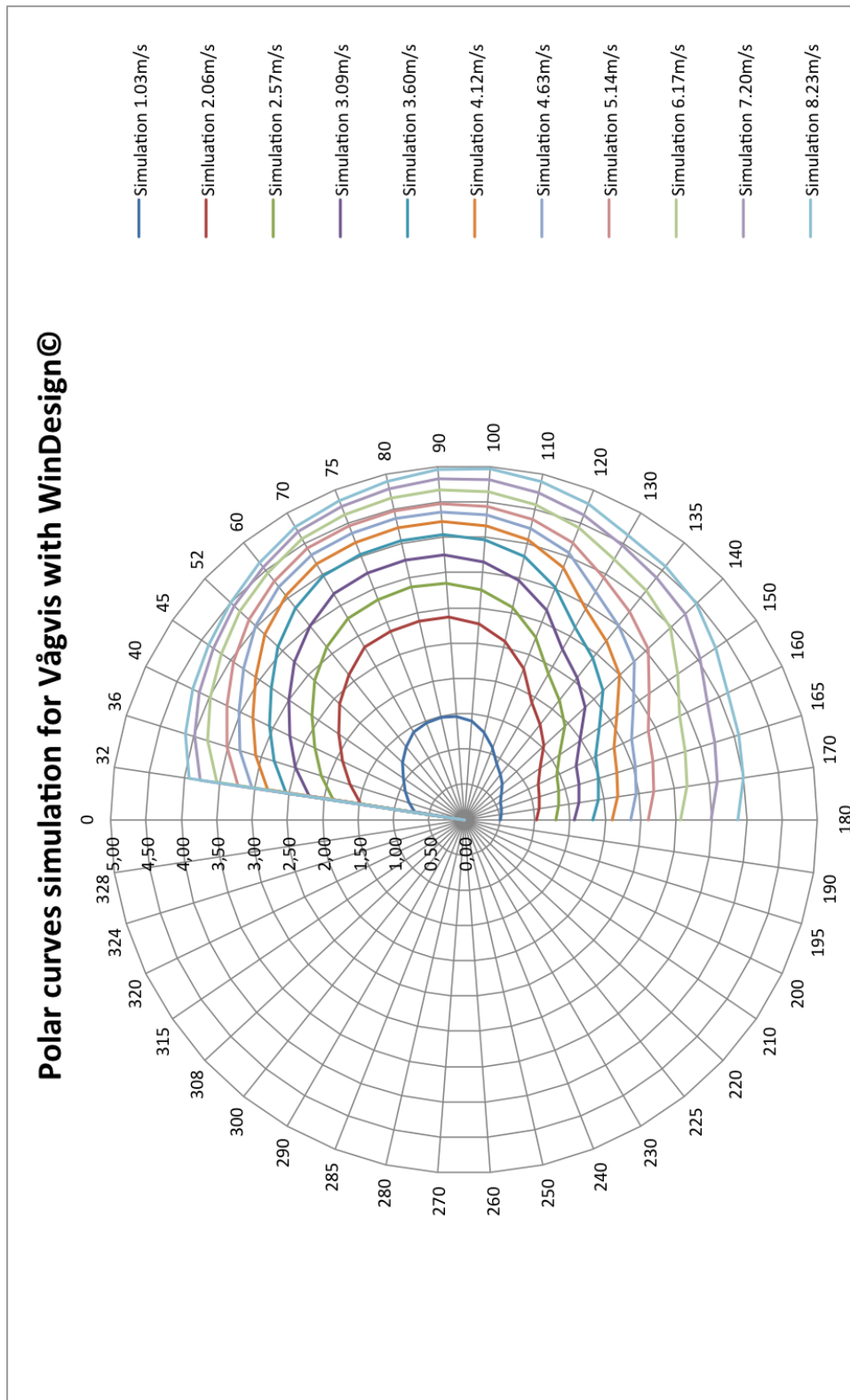


Figure 5.1: Simulation polar curve for “Vågvis”

5.3.1 SailSim©

Though SailSim© was the most interesting of the two software used in the present thesis, the interface and the lack of time to support this project at SSPA AB, made it a relatively difficult software to use. Starting new simulations requires tedious work. To be able to start the project in good conditions, it was necessary to produce a user manual to complete the one provided by SSPA AB. Once done, due to particularities of the yacht used (“Le RM1050” has a twin keel configuration that SailSim© could not take into account directly), too many simplification had to be done to get an accurate result. When measurements with a second yacht were available, the lack of time for support at SSPA AB ¹ made it impossible to finally validate the software.

The technical limitations with SailSim© mainly resides with the user interface as far as we are concerned. When it comes to validating the software itself and its capacity, such a work was not possible. It is therefore not possible to conclude with SailSim©. However, the fact that SailSim© assess dynamics of sailing in waves should, in theory, give very good agreements with measurements. This should be verified in further work.

5.3.2 WinDesign©

In literature, WinDesign© is presented as a well established VPP. Most researches on performances of sailing yachts either compare their results with WinDesign©, or use WinDesign© to validate their solutions (see [7], or [8] and [9]). However, and as Nijsten points out in [7]: “*It must be emphasized that any agreement with another VPP does not imply that the programs yields accurate absolute prediction of performance. No comparison has yet been made with actual boat data.*” We should therefore be careful with the results produced in WinDesign©, specially when comparing them with full scale data. It is difficult to say if the theory behind WinDesign© presents limitations to the present work as it was difficult to produce perfect results. However, we can present conclusions on more practical aspects of the limitations of WinDesign©: the usability for the present work.

For the present work, the hull was input as an offset of points instead of parameters. The parametric hull in WinDesign is based on the Delft Systematic Yacht Hull Series also known as the DSYHS (see [10], [11], [12], [13] and [14]). When inputing a hull offset, the hydrostatics and the stability are evaluated on the offset data instead. However, if the resistance, and popul-

¹due severe work overload at that time, SSPA AB was not able to dispatch any of its knowledgeable specialists to fix critical problems with SailSim©

sion data (lift and drag coefficients for the hull, appendages and sails) are not input manually, they are derived from the DSYHS based on parameters derived from the hull offsets. In the present project, the hull offset input was preferred because the hull exhibited properties differing from the DSYHS. Using the hull offsets, a true stability curve and hydrostatic properties could be used by WinDesign©. However, the performance criteria like drag, lift, etc. were based on the DSYHS and not on the true nature of the hull. CFD simulation or tank testing would have given better insight into the quality of the lift and drag models used in WinDesign©. But this was not the subject of this thesis. The reader should keep in mind this fact as it can very well be that hulls differing from the DSYHS could have better lift and drag properties than the models used in WinDesign©.

The last noticeable limitation was that results in WinDesign© are only output in knots. The software doesn't really allow to set the wind speed to decimal values. It is therefore impossible to compare the results directly with SI values. This drawback is very significant and has a large impact on the results presented here. Further work, to compensate this limitation, should ensure first, that both the data treatment system and the simulations are performed in the same units.

5.3.3 Dynamical Behaviour of Ships

Last limitation in the present work: the dynamic behaviour of boats inherently produces extra loss of energy compared to simulations. Complex oscillatory aero-hydro-mechanisms will induce motions that, as far as known, are not taken into account in simulations due to their complexity. If SailSim© does take into account motions of the boat in waves, WinDesign© does not (however, it possesses a module to estimate the extra drag induced by the motion in waves). It is generally known to sailors that oscillatory motions and vibrations induce extra drag. This is one of the reason why sailors do not run on a sailing yacht. Helmsmen also try to steer the boat with as little interaction with the helm as possible to reduce these effects. These effects are not, as far as known, taken into account into VPPs or DVPPs. This is because these effects depends on the way the boat is sailed, on the skills of the helmsman and the skills of the crew.

During the present measurements, the helmsman was the auto-pilot. The auto-pilot was chosen to steer the boat in order to have the most neutral "helmsman" as possible. It is also believed that course computers actually do steer sailing yachts in a very efficient way nowadays. But yet, it was observed that the auto-pilot would always had some kind of late response to steering the boat and thus, extra drag cannot be ruled out completely from

the measurements. It is therefore expected that in any cases, the measurements are at best of the same magnitude as the simulations but not more. If simulations under predict clearly the speed of the yacht, then it is a clear sign that the simulations are not correct.

In the next chapter, the results are going to be further discussed and the conclusions be drawn.

Chapter 6

Analysis and Discussion

First, the results from both the measurements and the simulation are analysed. Then the validation of WinDesign© from full scale measurement is discussed.

6.1 Analysis of the Results

6.1.1 Description of the results

Once the simulation is done, its results are imported into Excel© and compared to the measurements. Results from the simulations, do not give, by themselves an idea of their accuracy. If we compare them to reality, it is easier to determine that accuracy.

Due to the specificities of polar plots, it is simpler to compare the measures and the simulations in linear graphs with the true wind angle in X and the boat speed in Y. We plot the measurements data per range of true wind speed (i.e. $1m.s^{-1}$, $2m.s^{-1}$, $3m.s^{-1}$, $4m.s^{-1}$, ... $8m.s^{-1}$, $\pm 0.5m.s^{-1}$). The results of the simulations are plot together with the results of the measurements in figures 6.1 to 6.8 from pages 112 to 119.

Since the simulation were not performed in $[m.s^{-1}]$ but in $[knt]$, the simulation data for one particular wind speed do no correspond with the measurement range. Therefore, we plot, when available, on each measurement plot, the simulation data bounding the measurement data range. Thus the data corresponds more or less to each other. Additionally, the simulation plot is presented in a polar plot in figure 5.1, page 98. In this plot, the wind speed in $[knt]$ is converted into $[m.s^{-1}]$.

One may remember that the inertia effects on the boats were not analysed in the measurement sorting process. Therefore, there are data in each plot

that should be on other plots due to the time response of the boat. This is further explained in section 4.3.2, page 81. The results of the simulation for Vågvis with WinDesign© are presented in figure 5.1, page 98.

This simulations seems at first glance very good. However, it is possible that the speed is slightly over-predicted: some items like the propeller were not input into the system, for example, leading to a higher resistance on the real hull. Though Vågvis is equipped with a foldable propeller, the impact on speed, specially at lower wind speed, should be significant.

During the sailing, data were recorded by hand to have a quick estimate of the quality of the results. They are presented in the figures 6.2 to 6.8 under the name “Fast Polar”. These data were recorded as “observable” averages in that the measurer tried to ignore the speeds peaks. These data should therefore not be taken as “truth” but as good indications of the quality of both the measurements and the simulations.

6.1.2 Comments on the results

The results are plotted together for analysis. The plots are analysed in three sections: lower wind speeds (from 0.5 to 3.5 $m.s^{-1}$); medium wind speeds (from 3.5 to 5.5 $m.s^{-1}$) and higher wind speeds (from 5.5 to 8.5 $m.s^{-1}$). We also explain the reason for large erratic data on the plots.

Erratic points on plots

In figures 6.1 to 6.8, from pages 112 to 119 respectively, some areas are highlighted and numbered from A1 to A12. These areas highlight erratic data found in the records. They are sorted in four different groups:

- A1, A2, A5 and A8: going downwind in light wind
- A3 and A6: motoring
- A4 and A7: deceleration after switching off the motor
- A9, A10, A11 and A12: instrumentation or filtering error

Lets first discuss the first two most obvious errors: areas A3 (page 113) and A6 (page 114), and areas A4 (page 113) and A7 (page 114). At the very beginning of the measurements, the wind speed was very low. Actually, a couple of hours before the measurements, there was no wind at all around the boat. This was reflected by a perfect still water condition with no waves nor any disturbances of the water surface. The crew was motoring at that time in order to reach final destination before the night. When the wind became

strong enough, the instruments were set on, the sails put up and the engine cut-off. During a lapse of time of $2\text{min } 24\text{s}$, the instruments recorded a bit of motoring (areas A3 and A6) and the deceleration from motoring speed to sailing speed (areas A4 and A7) During that second phase, the wind angle went from between 0° to 20° to values around 35° to 40° as the boat went from straight into the wind while putting sails up, to sail upwind and then to the desired heading.

The second noticeable error, represented by areas A9, A10, A11 (page 115) and A12 (page 116), is due to filtering of data. If we look at area A9 for instance, we can see that the magnitude of the speed achieved and the pattern of the data is very similar to that found in page 114. The data in area A9 are likely to have been generated by a wind strength between 2.5 and $3.5\text{m}\cdot\text{s}^{-1}$. We already have discussed in section 4.3.2, page 81 the importance of the time lag between an event of wind speed accelerating the boat and the maximum speed associated with that event. The filtering of data should therefore take the time response of the ship into account to be accurate. If not, clouds of points such as areas A9, A10, A11 and A12 will be noticed on the plots.

The last erratic data found on the plots can be seen in areas A1 (page 112), A2 (page 113), A5 (page 114) and A8 (page 112). These erratic data are a bit more difficult to grasp. During the sailing journey, most of the time, the unit was going downwind. At first, the wind speed was very slow, but it increased in strength during the course of the day to reach about $15 - 16\text{knts}$ by the end of the day. There was, therefore, a lot of data measured at this sheet angle. Here, the same main reason behind the errors as for areas A9, A10, A11 and A12 can be expected. But because of the amount of data collected at these sailing angles, the density of the clouds of erratic data becomes more important. The second possible explanation resides in the fact that in light wind conditions, both the anemometer and the weathercock are more subject to the boat accelerations than in stronger winds. The aerodynamic forces and the motion-induced forces on these devices probably become of the same magnitude, introducing errors in the measurements. However, for this interpretation to be validated, the impact of the boat's response on the data should first be evaluated as was suggested in section 4.3.2, page 81.

For the present study, data from areas A1 to A12 can therefore be ignored. Further development of the present study could take care of improving the data treatment in order to reach better results.

Lower wind speed plots

For the lower speeds, conclusions are difficult to draw. We can see in figures 6.1, 6.2 and 6.3 pages 112, 113 and 114 that most data are actually

nowhere close to the simulation curves. Instead they are located into clouds of points mentioned above. At very low speeds, a sailing boat will have difficulty orient itself into the wind. Instrumentations like the weathercock are influenced by the natural oscillations of the boat, which generates forces that becomes governing when the aerodynamical forces are low. The data from the weathercock at low wind speed can therefore be influenced by wave motion, natural oscillation of the yacht, but also wind oscillations. We can therefore expect higher wind speed for every angles than simulations at the lowest wind speeds. As the wind speed increases the simulations and the measurements should, more and more, be in agreement, as the other disturbing parameters becomes less and less influential. If we also add to this fact, the “noise” from the data belonging to other plots, it is hard indeed to determine if the measurements and the simulations agree.

However, for figure 6.3 page 114, we can see that there are noticeable amounts of data along the two simulation curves. These data show relatively good agreements with the simulations. If we look at the “fast polar” data we can see that they are closer or below the lower bound curve for that particular speed. We can explain the difference between the “fast polar” curve and the measurements by the fact that the measurements are instantaneous data while the “fast polar” curve is based on averages observed by the sailors.

Medium wind speed plots

In figures 6.4 and 6.5, pages 115 and 116 we can see that the data are widespread across the pots. Most of the data should probably be sorted on other plots if the time response analysis was taken into account. However, among the clouds, we can see that some data are actually in good agreement with the simulations curves. From figure 6.4, we can clearly see a significant amount of data plot between the simulations points. Even if this is not enough to validate a VPP, it is still a strong indication that the validation, with better data filtering, is possible. In figure 6.5, however, only a minor part of the points are actually in the vicinity of the curves. It seems that, at that wind speed, either the data are not belonging to the plot (which call once again for a better filtering of data, see section 4.3.2 page 81) and that the data that do belong to it are on other plots, or that the speed is over-predicted by the simulation. A third option would be that the boat, at this wind speed was not sailed to its maximum potential speed, or that drag elements not taken into account in the simulations starts to have a significant effect.

Higher wind speed plots

For higher wind speed, only one simulation curve was plotted. It can be seen that the curve, for each plot, usually represents higher wind speed than that of the measurements (about $0.2m.s^{-1}$ higher for each plot). It is therefore normal that the data points are plotted below the curves.

This is one of the downsides of the present work: data were not produced in the same units. Some instruments output data in $[m.s^{-1}]$ and other did in knots. However the simulations could only be performed in knots, as far as the author is aware. This problem induced a problem of plot correspondence. It was decided early on to set the gage of measurement sorting to $1m.s^{-1}$, $\pm 0.5m.s^{-1}$. It was not until later that we discovered that this would cause problems for the interpretation of data.

Nevertheless, we can see that for figures 6.6, 6.7 and 6.8, there are also significant amount of data close to, or, plotted in the same general shape as the simulation, even if slightly below them. This should be brought to the attention of the reader as, once again, even if there are still a lot of data not well sorted, some of the data are actually presenting an interesting agreement with the simulation.

6.1.3 Quality assessment of the results

From the present results we can see that assessing the performance of a sailing yacht with full scale measurements should be possible with some extra effort. Good quality data are obtained that can be used for analysing the behaviour of a sailing yacht at sea.

It is possible to sort the data in order to plot the real performance of the yacht. This part of the process needs further development to improve the quality of the results. Because the behaviour of the yacht is not mathematically assessed in the present work, the full scale performance data suffer inadequacy when plotted. Data on plots belonging to other plots affect the readability of the results and can lead into mis-interpretations of the results. The quality of the full scale measurement as plotted for performance evaluation of the yacht is not good enough to establish a comparison between full scale data and a VPP. However, it is not the quality of the data itself that is incriminated here, but the fact that a proper smart correction of the raw data could not be performed. If given the opportunity, it is believed that the data can be proven to show good agreement with the simulation data, as some of them show in the plots.

6.2 Discussion

6.2.1 Interest of recording large amount of data

The original goal of this thesis was to create a procedure to measure performance of sailing yachts at sea. Quickly it was recognised that to capture the maximum potential of a full scale sailing yacht large amount of data had to be recorded. The main reason for this is that when we talk about performance, we have to distinguish between two types of performance:

1. The instantaneous performance
2. The maximum potential performance

Instantaneous performance

The first one, the instantaneous performance, is what we can call a regatta performance: given a particular wind and wave condition, we seek the best speed that one can achieve. In this type of performance, it's not the absolute speed reached per se that is important, but more the way the best speed is obtained. Reading of the behaviour of the boat under actions of the crew or of the helmsman are the most interesting in that the sailors can learn how to get the best out of their yacht. For a naval architect, the interest resides in learning how the boat behaves at sea and how to improve its dynamical behaviour.

The instantaneous performance depends mainly on external elements. Large amounts of recording are not necessary. People interested in this kind of data can record just the sequences of the sailing they want to improve or study. Through a smart analysis of the raw data, specially with the ship time response module presented in section 4.3.2, page 81, a very good understanding of the yacht behaviour can be obtained from a small amount of data (i.e. recordings of a couple of minutes). We can see a good example of the type of data we would get for such analysis from figures 4.3 and 4.4, pages 84 and 86, respectively for upwind and downwind sailing.

For this type for performance, the equipment presented in this report is more than enough. Data will never reach more than a couple of dozens of megabits. Processing with Excel© is enough, specially with newer versions of the software. The recordings stays cheap and the results very useful to the users. One can even think to extend the present code in order to “see” instantaneously on a screen the results of these investigations in order to better coach a crew.

Potential performance

For potential performance, the story is quite different. We are not interested here in instantaneous data per se, but in the best of the instantaneous data. If we are to study the potential of a sailing yacht for whatever reason, then, we need to make sure that the maximum speed that this yacht can achieve is recorded. This means that the yacht should be sailed in a lot of different conditions, configurations, and pushed to its limits. All these needs to be recorded in order to make sure that the best possible data are captured. This also means that these best data should be recorded a significant amount of time in order to have a statistical validation of these performance. All of a sudden, it is not a couple of megabits that needs recordings but gigabits of data!

Such a large amount of conditions, and data requires a tremendous amount of work. A yacht needs to be available for long periods of time together with its crew. The recordings needs to be meticulous and special attention should be brought to carefully logging sail changes, sheetings, actual sea state, etc. All these data needs to be processed. For a couple of gigabits, Excel might not be powerful enough anymore. The data treatment code should then be transposed into a more powerful language or used in a more powerful software.

In the end, the potential performance of the yacht requires more work to be obtained accurately. The interest for such data is also dubious for most people. However, there are specific applications that could use such data. One of them is the full scale validation of VPPs and DVPPs. If the amount of data is very large, with the help of a couple of naval architect and their designs and the help of owners and sailors, large amount of data could probably be recorded faster than expected. We can imagine providing a little recording software to sailors so that they can record all the data on their computer and then send it back to the researchers. This would also mean that the lines of the boats used for the studies are known: hence the need to implicate the naval architects of these boats. The sailors will also have to perform accurate displacement measurements and inclining tests. This might not be as bad as thought as these types of measurements are easy to perform. However, the potential for errors is also great. All in all, there are solutions to every problems, at least when there is a will to solve them.

Potential performance is interesting for a last reason: it allow verifying sailing theories. Many theories will predict the maximum potential of a boat: this means the maximum speed it can reach in a perfect steady state, given the conditions and the time. However, in nature this is clearly not possible as steady states involving wind, waves and current are never possible. To

compensate for this drawback we do need very large amount of data. Once this large amount of data is collected, we can be sure that the maximum potential of the yacht in real sailing condition is obtained. We can therefore validate theories based on these data and correct tank testing data with such recordings. After all, tank testing was invented and developed because at the time it was simply impossible to record and analyse all the external data influencing the performance and the behaviour of a yacht. With present technology, this becomes possible at a low cost. Why should we not benefit from it?

6.2.2 Ship Response and dynamics

One of the great surprise of the present thesis was the quality of the instantaneous data that were recorded. When figure 4.3, page 84 was first plotted, the author was amazed at the level of details that were obtained. This opened many opportunities for very interesting analysis about ship response to external events or about dynamical behaviour of sailing yachts at sea.

In the present thesis, these opportunities were left out because of lack of time. However, the capabilities of such studies were still investigated to some extent in order to produce a good database useful for validation of VPPs. Indeed, in order to produce such a database, it was necessary to identify data that were not reliable and those that were. It was also necessary to tidy all the data and make sure that time markers would be kept in order to preserve the instantaneousness of the data. After this work, the database was able to show properly the dynamical behaviour of the boat. That work opens the ability to understand how a yacht behaves in reality and how its performance can be affected by various events.

Of course, the present work is not enough for analysing the dynamics of sailing yacht. But not much is missing. With a couple of accelerometers, the recording of the rudder angle, or other parameters, one can capture the entire set of parameters necessary to reach that goal. And this is possible at little costs. For example, with smartphones, it is easy to get access to full 6 dimensions accelerometers (3 longitudinal and 3 rotational accelerations). From this accelerations, all of the boat motions can be derived and linked to the rest of the data recorded.

With the onboard instrumentations and the new instruments available nowadays, investigating full scale data becomes possible. As we have seen in the present work, with little effort, it is already possible to gather enough data to visualise what was only possible in expensive towing tank facilities. Understanding the full behaviour of a yacht has become feasible. Together with smart thinking, it becomes possible to a researcher to easily produce a set

of data for analysis. The quality of the data has become good enough to acquire a clear understanding of how a boat behaves at sea. Developing and validating a VPP in time domain like SailSim© becomes easier. If the equations increase in complexity, the data to validate them could easily become large enough to get a fine idea of the behaviour of the yacht and predict its performance in waves numerically.

6.2.3 Validation of a VPP: WinDesign©

For the validation of a VPP, more than one case should be investigated. The fact that one sailing yacht produces data in agreement with the result of a VPP does not mean that for every yacht, such an agreement will be obtained. Such a broad validation of a particular software should not, in fact be the work of universities, but the work of the company developing such software. However, science can help in building a test or a procedure to obtain the test case used for such a validation. This was one of the goals of the present work.

As a result, a method for validation was partly developed. We also proved that such a validation could be possible with further work. This is a great news as for a long time, such capabilities were not imaginable. We can now see the possibility in the future to verify that theories are indeed true and that simulations of performance are reliable enough in real life to rely on them. For instance, that could mean that computer aided sailing software could make use of polar plots from VPPs to guide sailors. It could also mean that bias in regatta could be removed with no criticism from contestants. That could also mean that we would be sure that advances in theories and exotic hull shapes, etc. could be evaluated before being enforced. That could also mean that we would be able to derive safer rules for construction of sailing yacht and for sailing.

Of course, if with this data, one can prove that, at least for one hull, the results of the VPPs or DVPPs studied are true (or not), it is far from meaning that it is true for all yachts. However, If one yacht which have characteristics within the capabilities of the software, and if the software's predictions are in agreement with both the tank measurement and the full scale measurement, then we can say that the theory to produce the data is likely to be valid and that the results from this software are also likely to be correct.

In the end, validation of a VPP will take time and a lot of recordings of sailing in different conditions with different yachts. But if this represents a lot of work, it would also help research and the industry in their permanent quest for better yacht design.

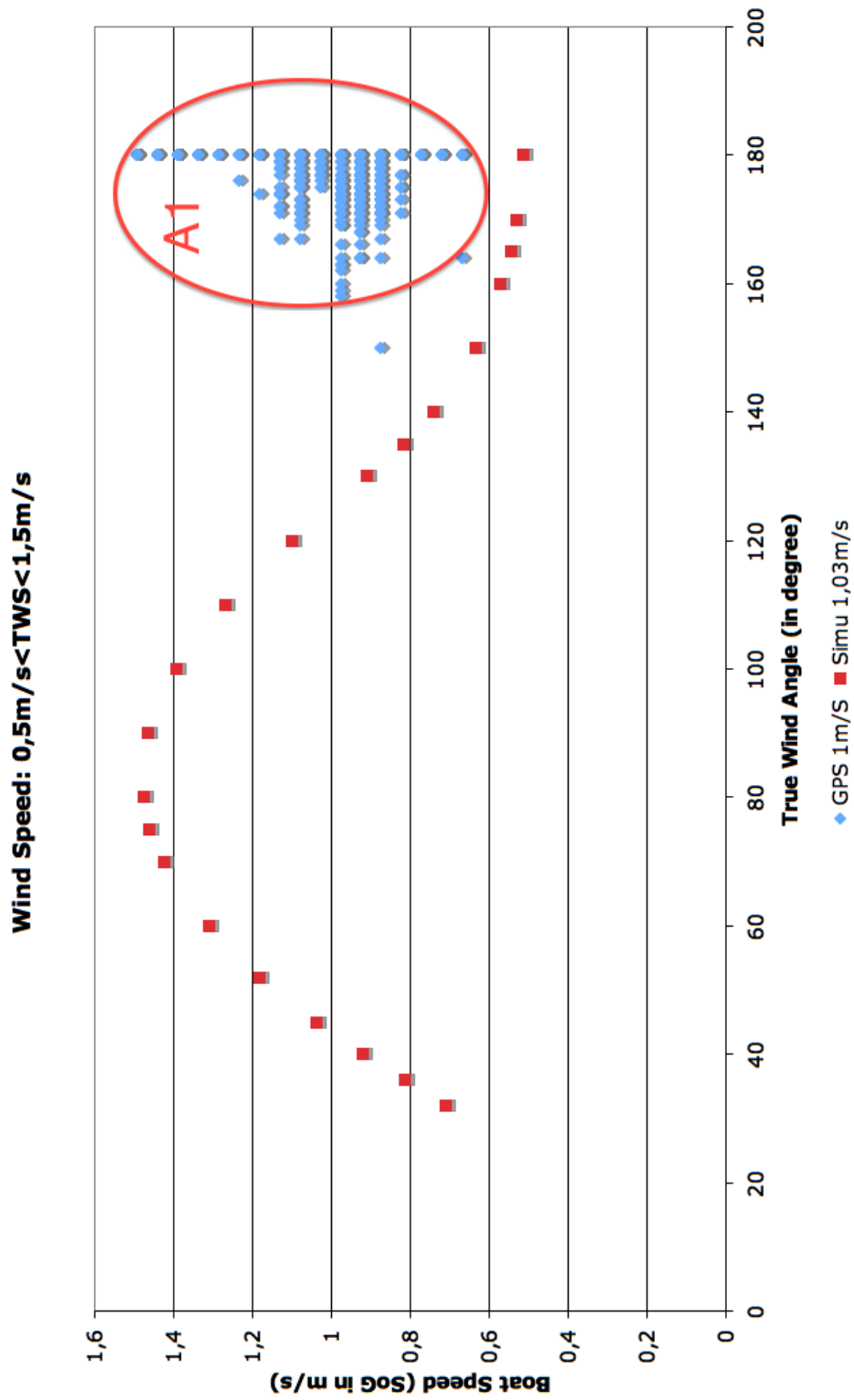


Figure 6.1: Performance plot of “Vägvis”: comparison between WinDesign© and the measures at $1m.s^{-1}$

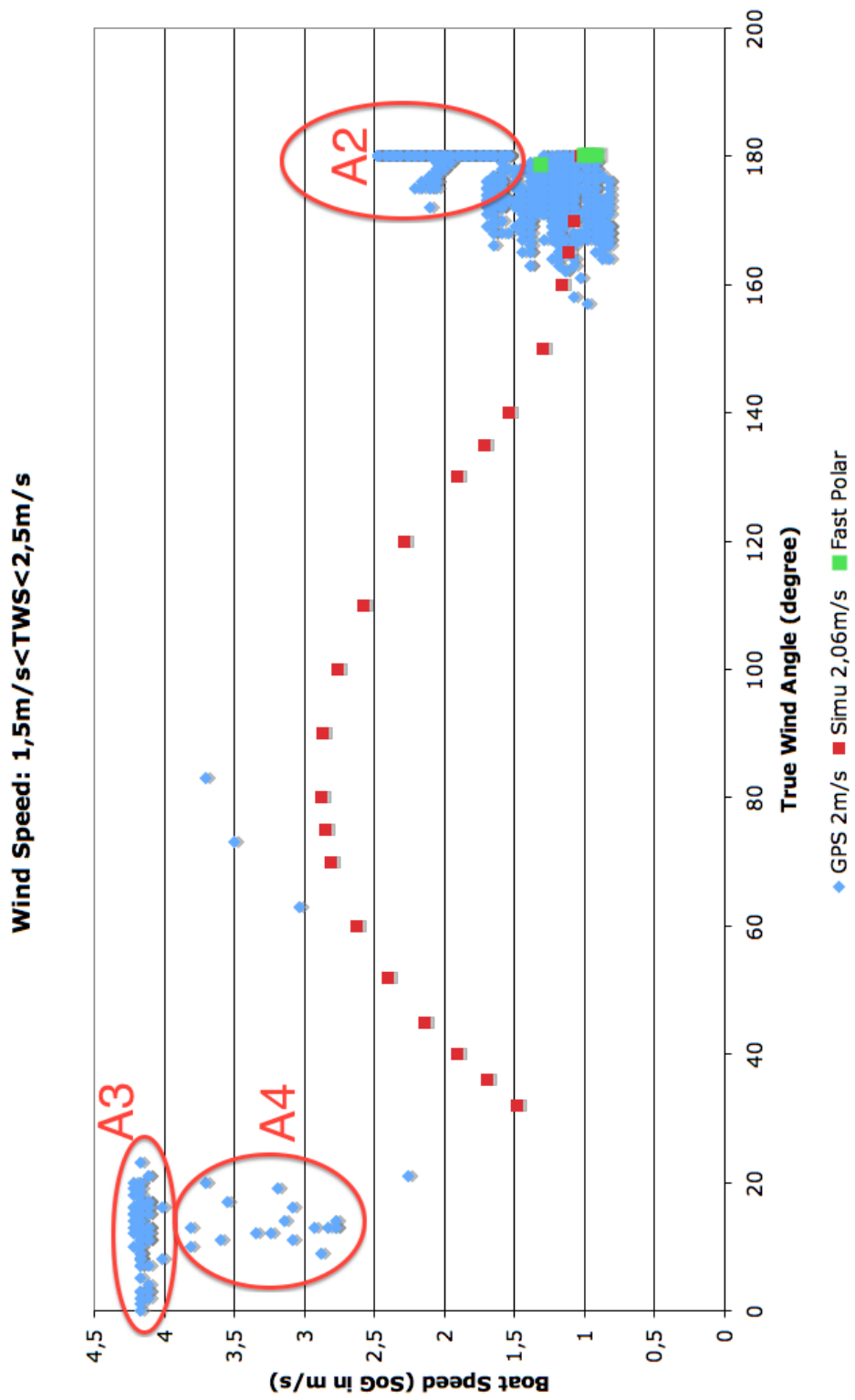


Figure 6.2: Performance plot of "Vågvis": comparison between WinDesign© and the measures at $2m \cdot s^{-1}$

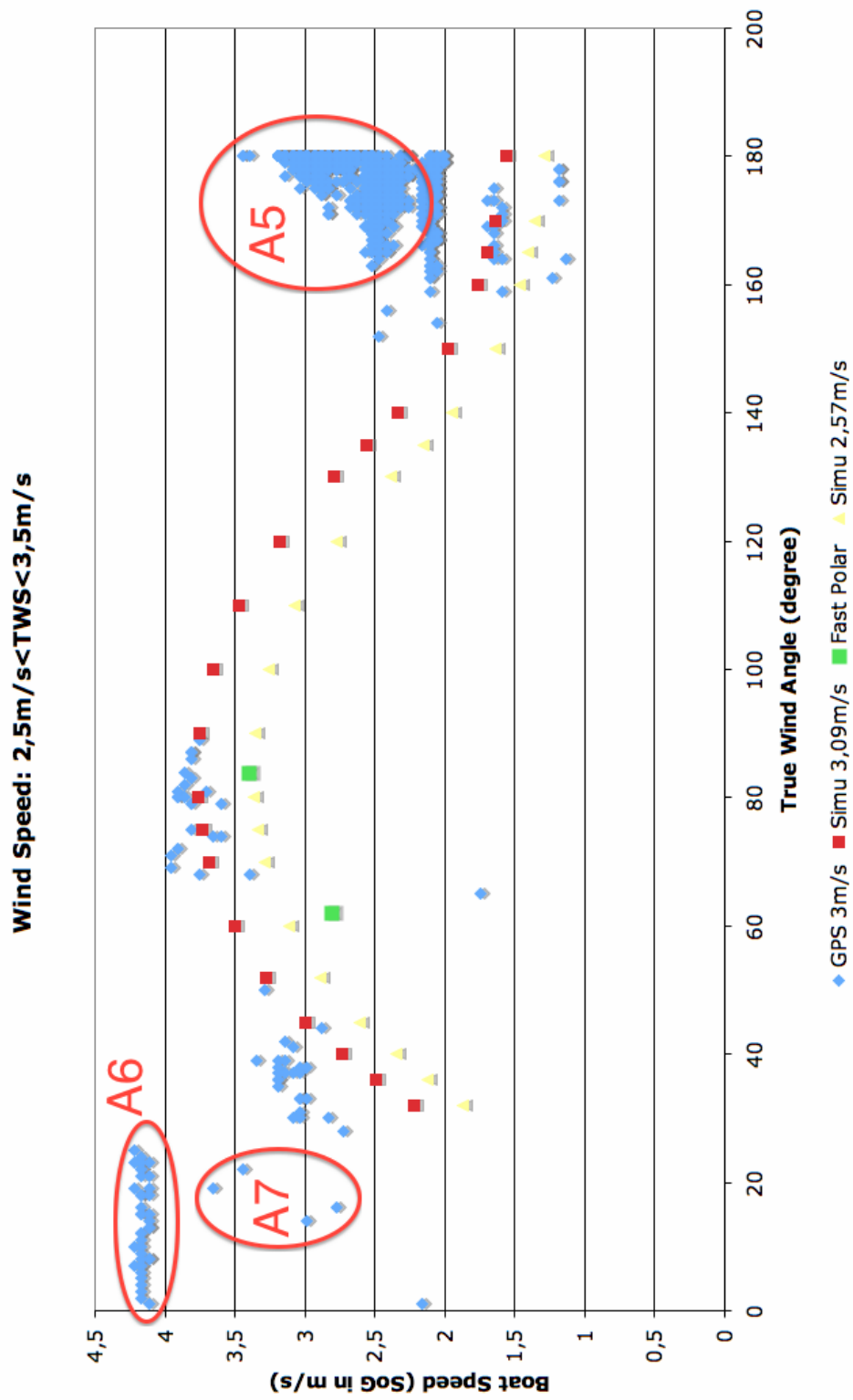


Figure 6.3: Performance plot of “Vågvis”: comparison between WinDesign© and the measures at $3m.s^{-1}$

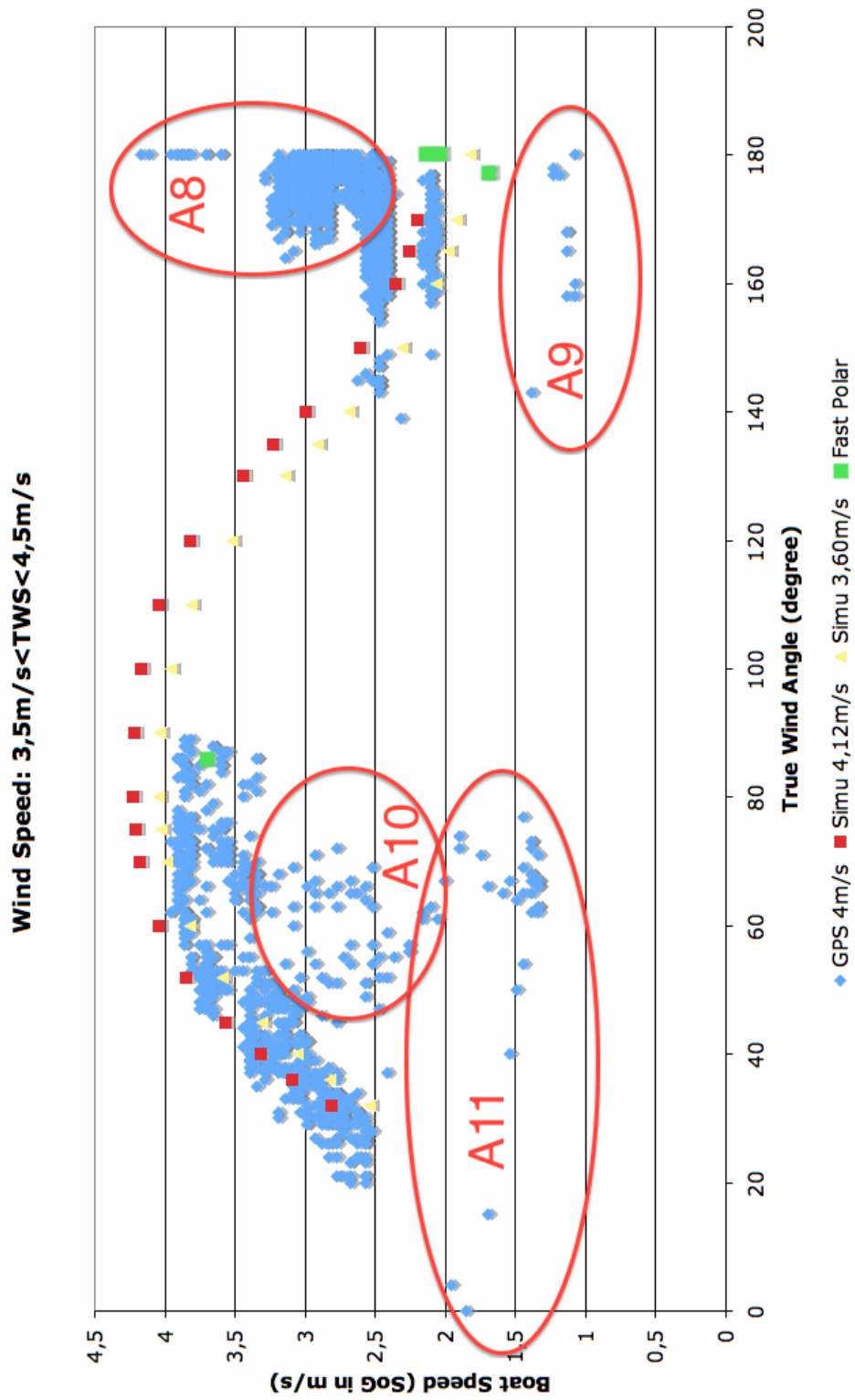


Figure 6.4: Performance plot of “Vågvis”: comparison between WinDesign© and the measures at $4m.s^{-1}$

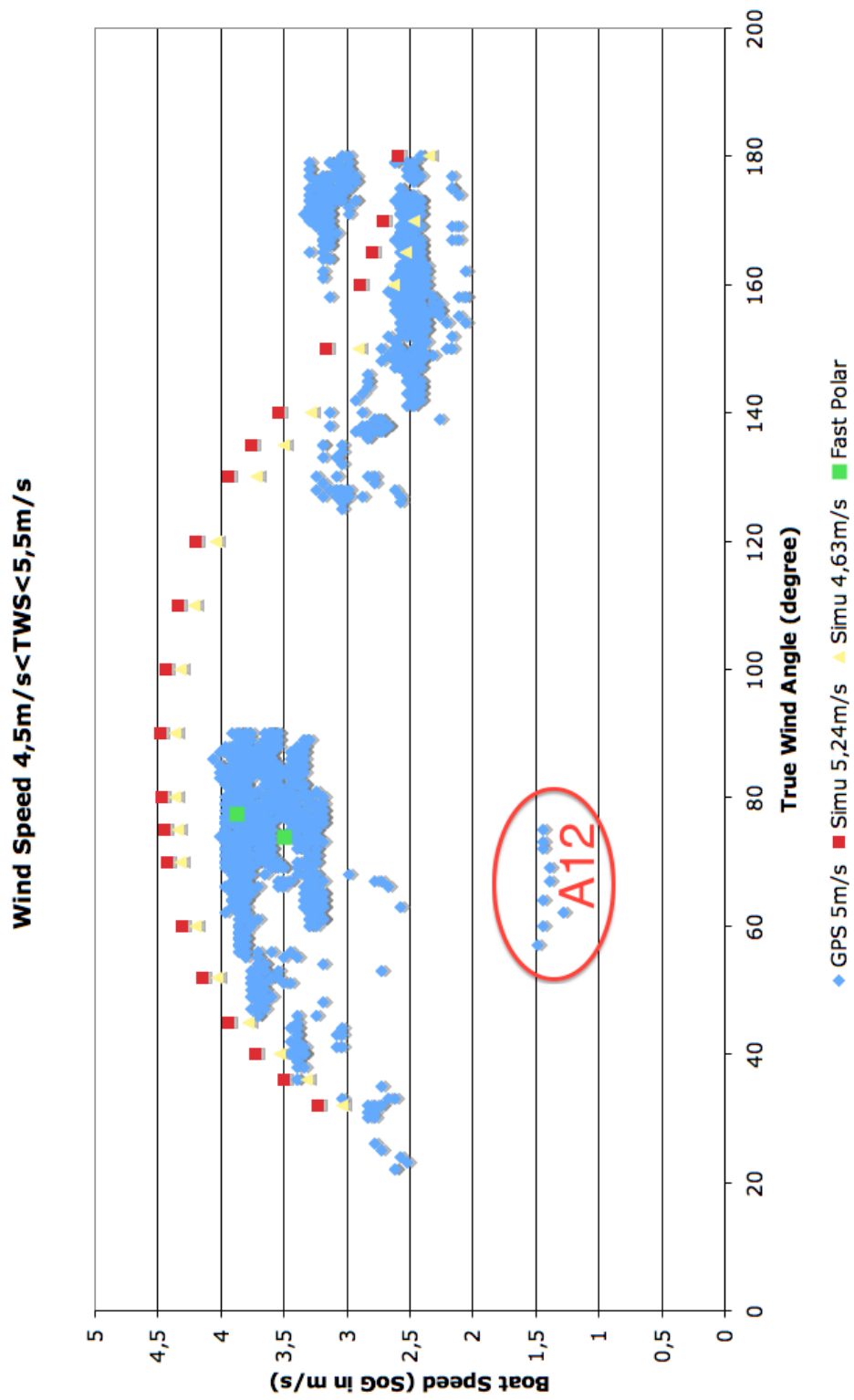


Figure 6.5: Performance plot of “Vägvis”: comparison between WinDesign© and the measures at $5m.s^{-1}$

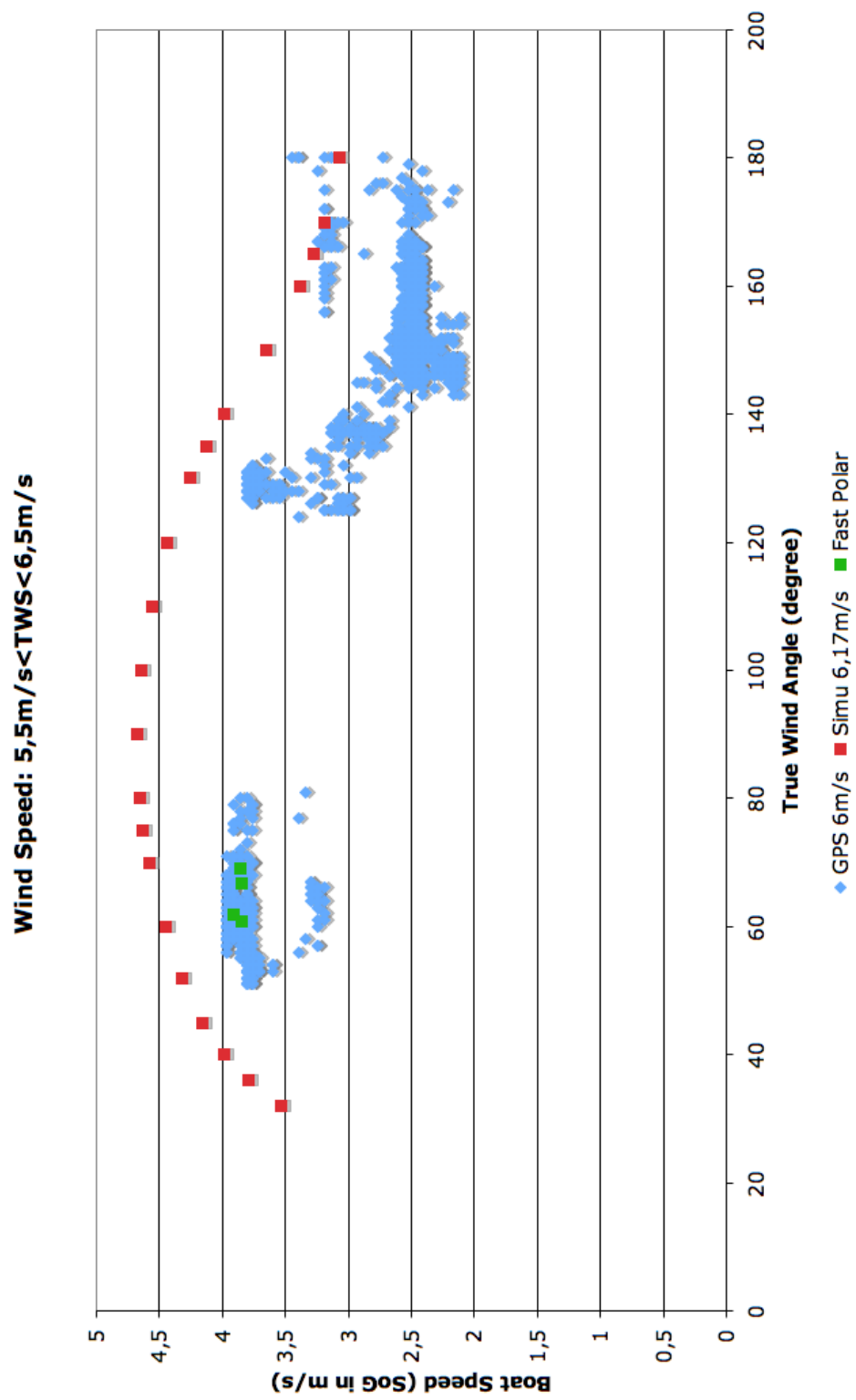


Figure 6.6: Performance plot of "Vågvis": comparison between WinDesign© and the measures at $6m \cdot s^{-1}$

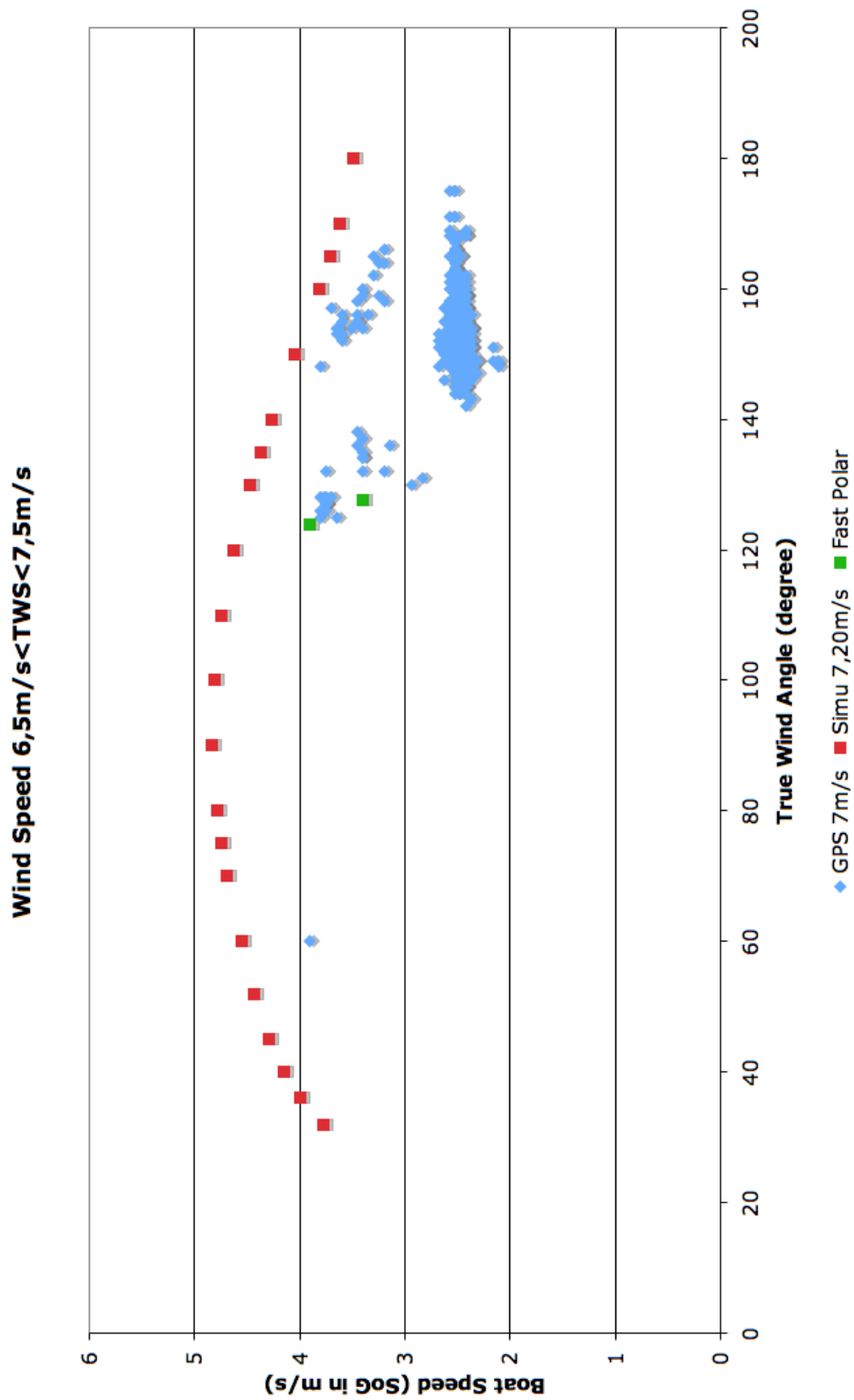


Figure 6.7: Performance plot of “Vågvis”: comparison between WinDesign© and the measures at $7m.s^{-1}$

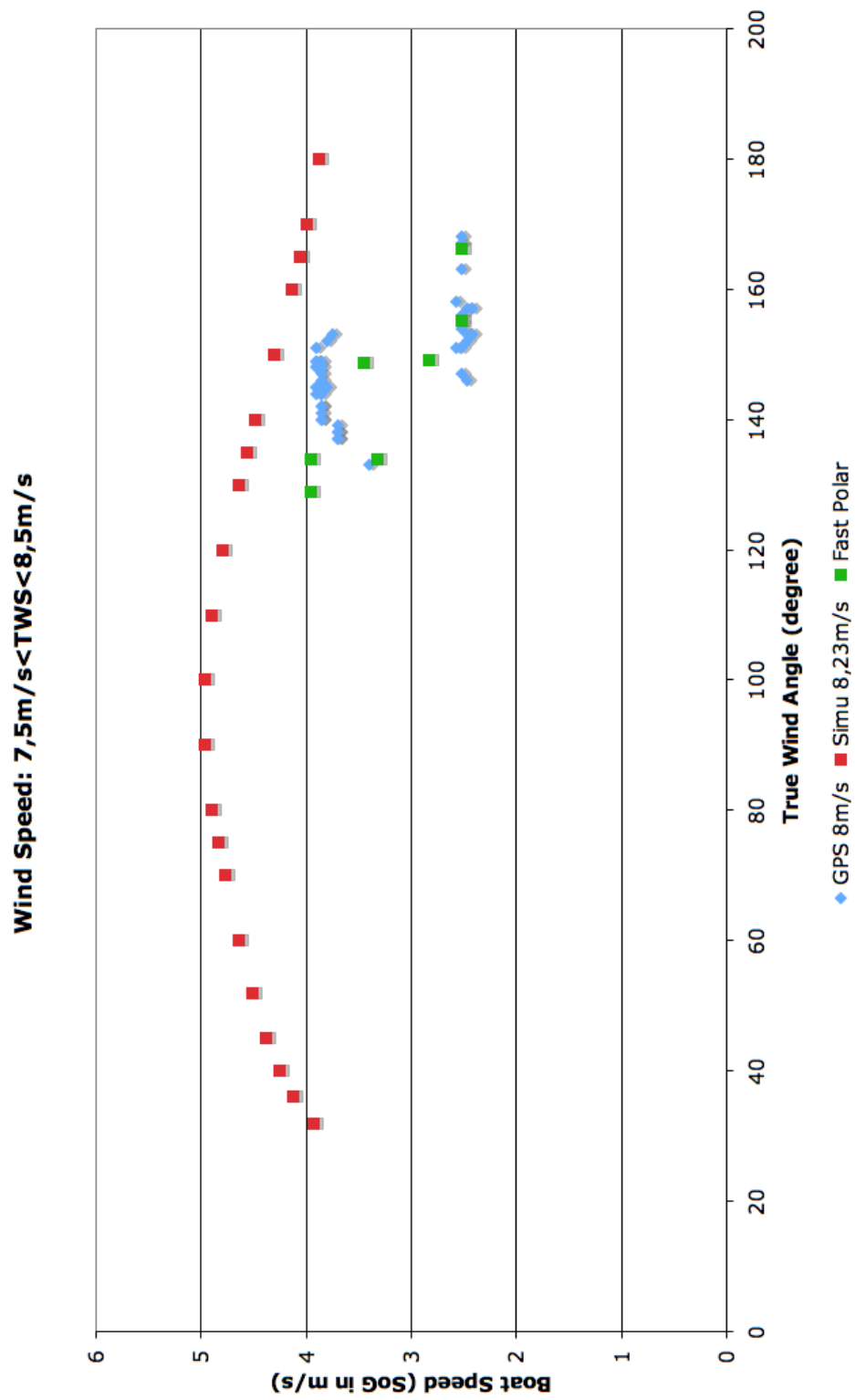


Figure 6.8: Performance plot of “Vågvis”: comparison between WinDesign© and the measures at $8\text{m}\cdot\text{s}^{-1}$

Chapter 7

Conclusions

7.1 Full Scale Measurements

During this research, we have proved that full scale measurement are now possible with inexpensive equipment and are therefore available to anyone for good quality research. The measurements were an exciting moment in this work. From finding the tools that would allow studying the performance of a yacht to finally do an accurate measurement, two years of experience were gathered.

The use of the boat's own instruments proved to be good enough to perform accurate performance measurements. Modern sets of electronics are highly integrated and their data are easy to record and read. The use of a simple NMEA 0183 compliant multiplexer as well as a standard laptop are enough to record most of the important data from the general instrumentation. Thus, for a cheap price, it is possible to perform the entire process of recording and analysing sailing data, provided access to a sailing yacht with such electronics on board.

The quality of the measurements, outside of the electronics set-up, is mainly governed by quality of the displacement measurements and the inclining test. If they both require a very calm weather condition, they only require inexpensive equipments to be performed accurately. A set of string, a weight and a scale are sufficient to make accurate measurements, provided that, for the inclining test, the pendulum is long enough. It is also to be noted that for the displacement measurements, access to the hull lines of the unit is essential in order to give a good estimate of the displacement of the unit. Without such data, other more complicated methods of measurement have to be used to determine the displacement.

Overall, in the present work, a simple reliable method to measure the perfor-

mance of a sailing yacht was set-up. This method can easily be transposed to any yacht which will be used for measurements. Following the procedure step by step, accurate data will be obtained. The main sources of errors inherited by this method, are the quality of the set-up of the on-board instrumentation, the quality of the measurement of the yacht displacement and the quality of the inclining test performed on board. The displacement measurement and the set-up of the instrumentation were well performed with Vågvis. However, the inclining test was performed with a too short pendulum inducing a too high potential error on the measured height of the VCG. A better inclining test would be necessary to ensure a good agreement between the theory and the measurements.

7.2 Data treatment

The data treatment was probably the hardest and most important part of this thesis. Several month of programming with Excel© and Visual Basic© were necessary in order to produce a good performance database and clean performance plots.

The code was developed to take into account the specificities of the NMEA 0183 language and its adaptation by different electronics manufacturer. The code was then built to reorganise data in a useful database. During this process, quality tools were developed to identify unknown data and filter-out unreasonable data recorded by the instrumentation. Finally, data useful for performance evaluation were computed and input into the database. The database was then sorted by ranges of true wind speeds and true wind angles in order to be compared with performance simulations from a VPP.

However, the code does not take into account response time lag of the boat due to inertia effects or external events. This part was not developed due to lack of time even though it was identified as very important for the quality of the plots produced. Such a development would ensure that the right performance data is linked to the right event (i.e. that a particular yacht's speed is linked to the wind speed and wind angle that induced it). That way, the noise described on the performance plots could be reduced drastically and accurate validation of a VPP be performed.

In the end, if the code developed to treat the recorded data is not perfect, it represents a great step forward for the treatment of performance data. Through its modular architecture in an easy to understand language, it becomes easy to extend, improve or transpose to a different language. It performs the basic task of identifying various data, transposing them into a clear and easy to use database. Through this data treatment, the behaviour

of sailing yachts and their performance can now be analysed scientifically.

7.3 Simulations

The simulations involved the use of two different promising software. Due to various constrains, simulations were performed with only one of the two. However, the capabilities of both software were investigated.

SailSim© from SSPA AB was first investigated. It is a dynamic velocity prediction program. It can assess the performance of a sailing boat both in static and dynamic conditions. Its capabilities were very promising, specially for the dynamical part. Originally, one of this thesis goal was to validate the dynamical part of this software with full scale measurements in waves. Simulations were prepared but not performed due to problems with the specificities of the yacht used. Large amount of work was done to clarify the use of the software. However, in the later months of the present work, SSPA AB run into a very heavy work load. It meant that there was no time on their side to support this project. It should be stressed that the support from SSPA AB was entirely unfunded and on a voluntary basis. As a result, the simulations with SailSim© had to be dropped.

SailSim© was then replaced by WinDesign© from the Wolfson Unit of the University of Southampton. This software does not have dynamic capabilities per se, but can only model extra drag induced by waves. It was preferred to SailSim© because it was obtained under a commercial conditions including a support contract. It is also a widespread used software in the industry. This software have proved relatively easy to use even though some shortcomings have been identified. With this software, a good simulation was performed matching the true conditions encountered during the full scale measurements. When compared, the results proved to have some interesting agreement even though the data treatment was not good enough to give clear validation data. All in all, simulation of sailing yacht performance have proved to be a mature subject that provide data accurate enough for most scientific use in sailing yacht research. However, these software, based on tank testing, have not yet been validated with full scale data. In the present work, we proved that full scale data can be used for validation of these softwares, given that extra work is performed into analysing these data. This opens large possibilities for VPPs and DVPPs software: if they can be validated by full scale data, they can also be further develop to agree with these data. Together with the development work done with tank testing, this will allow even better definition of sailing yacht's performance.

7.4 Limitations of the Project

The limitations of the present project were already partly discussed in section 3.3, section 4.3 and section 5.3, pages 68, 81 and 97.

The first limitation for the present research was distance: being distant from university or knowledgeable people will induce delays in the solving of problems; being distant from a well equipped harbour and from essential tools or professional help will also induce delays when facing technical problems. A close-by team or supervision also ensure that the work performed reaches the best quality.

For such project involving full scale measurement, distance also meant large time lag between post-processing data recorded, analysing errors and correcting the measurement procedure. During the one year of sailing initially done, because data were not post-processed instantly (since the post processing code was not yet developed), essential data were not recorded. This mistake meant that a year worth of work was lost and a new yacht had to be found to perform the recordings.

The third main limitation resided in the “ship time response” module of the data treatment code. This module is essential to ensure correction of data for the time lag between the ship response to an event and that event. Because of lack of time, that module was not developed. As a consequence, the performance data plot, represent an instantaneous picture of the performance of the yacht and not their true achieved performance. Because of this limitation, a validation per se of a VPP was not possible, though, its feasibility was highlighted.

The main limitation one the simulation resided in the support from SSPA AB for SailSim© and the inability for WinDesign© to handle dynamical cases. If the support problem for SailSim© can always be overcome in the future, there is no evidence that the Wolfson Unit will develop WinDesign© to take into account dynamical behaviour of sailing yachts in any other way than adding drag elements in the calculation of the performance. These limitations are, in the end, not really important as good results should still be obtained from these software. Further work is necessary to identify more important limitations from both software.

7.5 Suggested Future Work

During the present research several shortcomings were not assessed due to lack of time or means of solving. Further research is strongly advised in this promising field that is building a full scale test case for validation of sailing

yacht performance.

If the measurement procedure that was developed have overcome all the problems identified with the present work, it is possible that performing measurements in waves and strong weather will highlight further problems. Gathering data is essential if further work is to be performed. Indeed, the more data, the easier the development of the analysis of data. These data needs to be collected and for that, sailing yachts need to be available for the recordings. Incorporation of newer tools like smartphone's accelerometers should be investigated in order to provide the best picture of the performance possible. This should be an interesting subject for a motivated student.

However, the attention of further research should focus more on the data treatment code development. The first step should be to develop the ship time response module. This is probably going to be enough work for a dedicated master thesis but is essential to produce accurate data for performance evaluation. The second step should be to either transpose the code into a better computing language, or to improve the processes in the present code in order to make it faster and able to treat large databases.

If more data is available and if the development work on the code has been done, then a proper test case can be built. It will involve a fine statistical analysis of the results in order to produce the most accurate polar plot of performance possible. Such a polar plot can then be used to validate a VPP or a DVPP with full scale data.

The last development of this present research would be to develop a software based on all the above work, to analyse instantaneous sailing data and help sailors improve their skills at sea. This could be a long term development that could eventually lead towards a commercial software and a lot of opportunities.

Appendix A

VBA code: description

A.1 Explaining the code

A.1.1 Overall structure of the code and philosophy

The VBA code is composed of several modules (or objects). These modules have different distinctive goals into the process of sorting and treating the data recorded at sea. Using several objects to process the data was found useful in the present case because it makes the code simpler and relatively smaller than if everything had to be sequenced. Also, due to the structure of the data themselves, the flexibility that offers object oriented programming has helped keeping the code clear and dynamic enough to allow quick upgrades, specially when new type of instruments had to be integrated into the system.

The general process and the relationship between the main objects are described in figure [A.1](#), page [128](#). From the figure, one can see that the code uses a lot of loops. The code in itself is quite inefficient and a better programmer can probably significantly reduce the computer time by reorganising the processes. However, it is believed that the procedure used is still interesting and can probably be investigated to produce better results. Specially, the “Analysis1” object calls many loops. This particular object was designed in a later time. It can certainly be integrated to “Main” in order to increase the efficiency of the process.

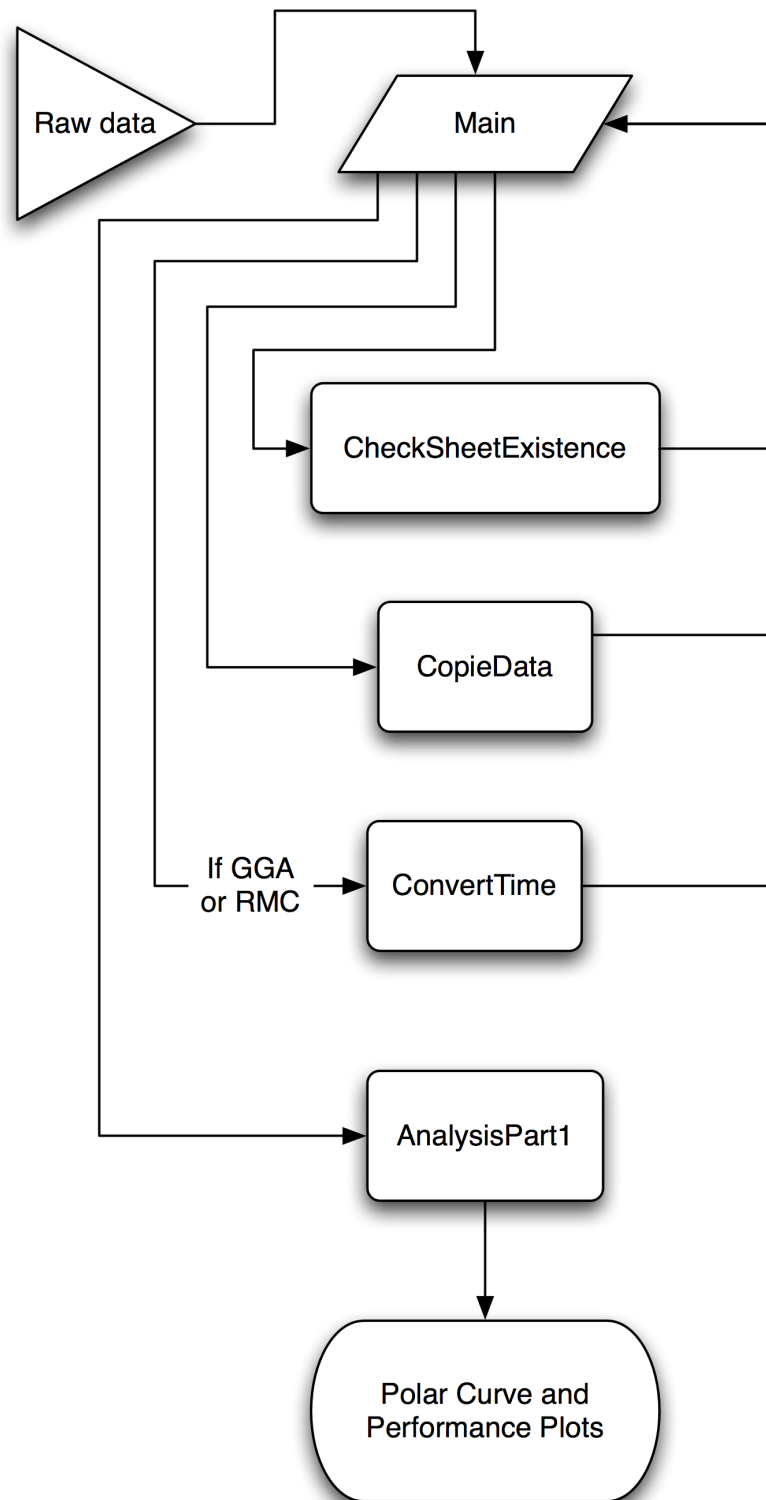


Figure A.1: Overall code structure

A.1.2 Importing the data to Excel©

Before proceeding with the code, the data had to be imported to Excel© . Since This software cannot work with more than 65000 lines a time¹, the data were cut in several pieces using a text editor (TexShop©) and then imported into Excel© . When the first data treatment trials were performed, it appeared that 65000 lines would take a lot of computer power and be very inefficient for the process, Excel© not being designed for such large data treatment. The number of lines was kept relatively low. The biggest file was containing just above 30000 lines. The used files are as follow:

- File 1-1, 20070610-13h53: 30065 lines
- File 1-2, 20070610-13h53: 15686 lines
- File 1-3, 20070610-13h53: 4257 lines
- File 2-1, 20070610-14h40: 30065 lines
- File 2-2, 20070610-14h40: 15686 lines
- File 2-3, 20070610-14h40: 2344 lines
- File 3-1, 20070610-16h04: 30065 lines
- File 3-2, 20070610-16h04: 30065 lines
- File 3-3, 20070610-16h04: 13245 lines
- File 3-4, 20070610-16h04: 13245 lines
- File 4-1, 20070610-17h03: 30115 lines
- File 4-2, 20070610-17h03: 30114 lines
- File 5-1, 20070610-18h25: 15953 lines
- File 5-2, 20070610-18h25: 15953 lines
- File 5-3, 20070610-18h25: 15953 lines
- File 5-4, 20070610-18h25: 15953 lines
- File 6-1, 20070610-21h00: 12762 lines

¹At the time the calculations were performed, Office 2007 or more recent were not available yet. This limitations are no longer an issue for small to medium recordings (lets say below several hours of recording)

- File 6-2, 20070610-21h00: 12762 lines
- File 6-3, 20070610-21h00: 12762 lines
- File 6-4, 20070610-21h00: 12762 lines
- File 6-5, 20070610-21h00: 12762 lines

The reason for the division of the files is based on the computers that were used to process the data. Three computer were used: a PowerMac G4 Quicksilver, a PowerBook G4 aluminium and MacBook Pro from Apple computers© . The PowerMac could be used 24h a day for computation, but not the PowerBook neither the MacBook Pro. Both computer were used for other work during day time. The files were therefore cut in such a way that, a computation would take a maximum of 24h on the PowerMac G4, 12h on the PowerBook G4 and 10h on the MacBook Pro.

Once the files had been cut, they were imported into Excel© keeping the same file names. The different figures into the data were kept separated by coma “,” and the data importing facility of the software was design to detect this feature into a large set of figures. Once in Excel© , it was necessary to change all the “.” (dots in the British system separates numbers and decimals) into “,” (the computers used for the data treatment were using the mainland European system, ie, coma to separate decimals). After performing these tasks, the VBA code was copied into all the Excel© files and the data processed by launching the VBA macro. The results were then copied into one last worksheet used to synthesised the treated data. The results were then presented into plots.

The next sections present the codes in more details.

A.1.3 Main

The goal of “Main” is to sort the data by their names, and depending on the type of figures to treat and/or to launch the right tidying procedure. The procedure of “Main” is better explained by the flow chart presented in figure [A.2](#), page [131](#).

At first the goal of “Main” was to be the central controlling module of the code. However, while the complexity of the program increased, it became easier to keep the sorting and the analysis parts separated.

“Main” reads the first column of the entry line. This column contains the name of the figure sent by the multiplexer. It is of the form: “\$M1GGA” for example. As already explained, the first three characters contains the name of the instrument sending the figure. The last three characters tells

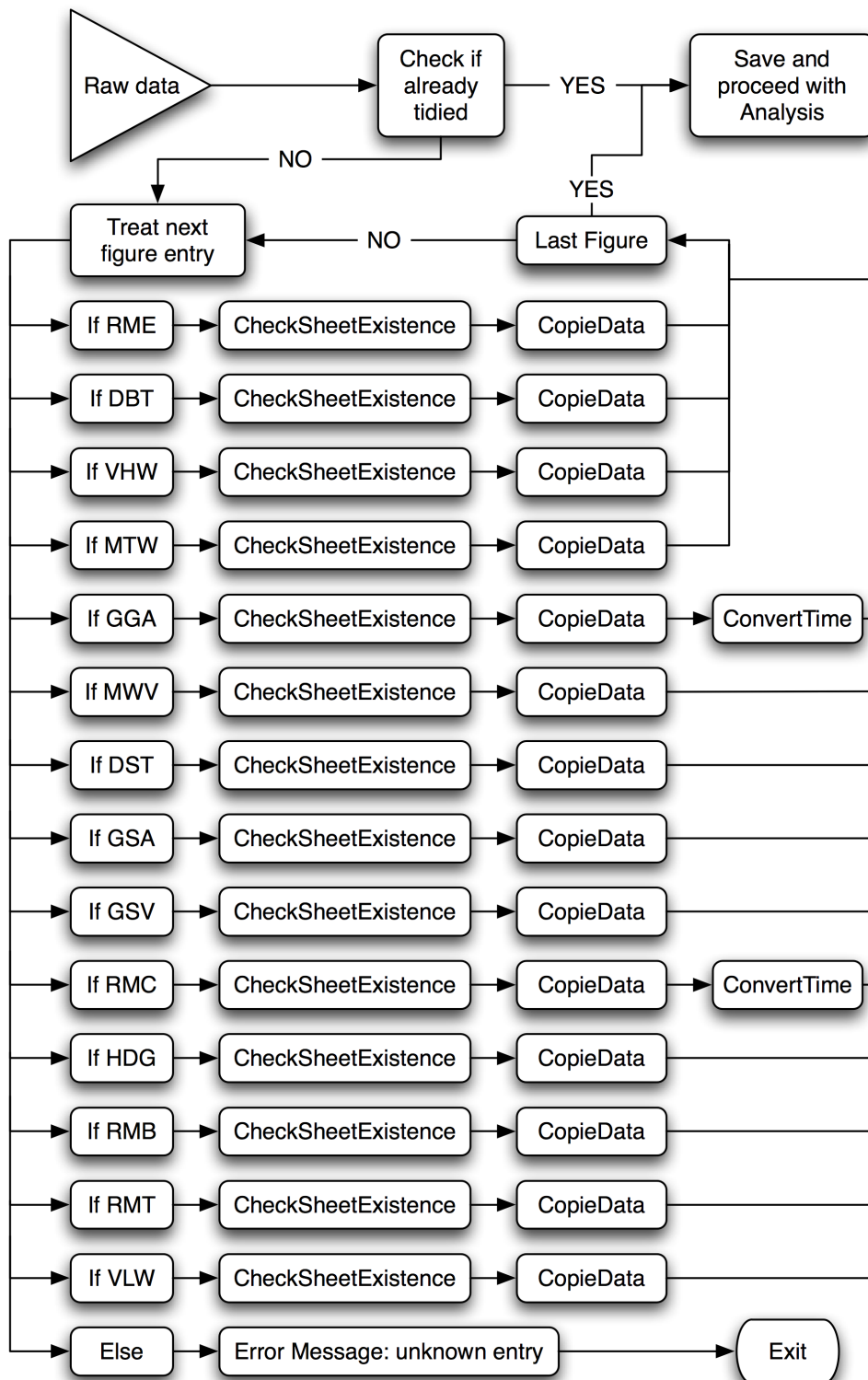


Figure A.2: "Main" flow chart

the system what kind of information follows on the same line.

“Main” works as one big loop that reads each entry line of the measurements. An “If” statement is used to sort the figures. If the figure is already known to the code, a specific treatment that includes “CheckSheetExistence”, “CopieData” and in some cases “ConvertTime” will be launched before treating next entry line. If the figure is unknown, “Main” prints an error message on screen. The error message gives the name of the unknown figure, and asks if the process should be continued or not. Usually, if the data is unknown, it is wiser to exit the process, go into the code and add the standard sorting procedure for that particular new figure. This should take 5 minutes not more. When the new figure treatment is added the error message will not appear anymore.

When the sorting is finished, a figure is stored in the specifically created sheet called “SheetNameStore”. This figure called “Tidy” is used to tell the code that the data into that worksheet have already been sorted. Since the sorting turned out to be very long (over 4 days of computation over 3 computers), this turned to be a very important feature to avoid processing again and again data.

At last, the workbook was saved before launching the analysis part of the code bundled into “AnalysisPart1”.

A.1.4 CheckSheetExistence

“CheckSheetExistence” is the first of the general modules used in this code. Its goal is to check into the workbook if there is a worksheet carrying the name transmitted to the module. If it doesn’t find a corresponding worksheet, it creates one, stores its name into a worksheet called “SheetNameStore” and returns to “Main”.

The sequence actually uses two sub-modules: one to check that the worksheet exist, and one to create it. The first sub-module is straight forward: via a loop, the module checks the name of all the worksheets and exit if one worksheet has the same name as the raw figure. The second module is called by the first one if there is no matching worksheets. It creates a worksheet placed at the end of the workbook with the name of the raw data. Then, if the name is different from “SheetNameStore”, it goes to the last line of that particular worksheet and write the name of the newly created worksheet into the first empty cell.

“SheetNameStore” is an important feature in this code. It keeps track of the names of all the worksheets and their sequence in the workbook. This worksheet is later on used by different modules to call worksheets or to perform some computations.

The flow chart of “CheckSheetExistence” is presented in figure A.3, page 133.

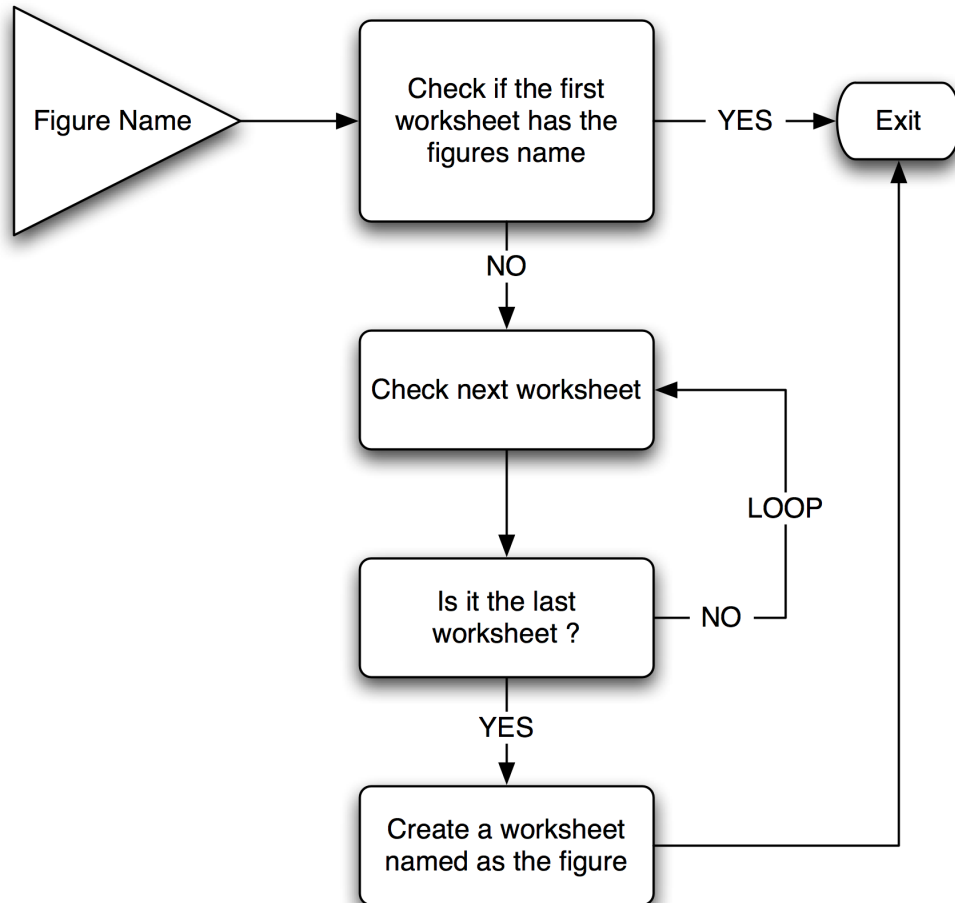


Figure A.3: “CheckSheetExistence” flow chart

A.1.5 CopieData

The goal of “CopieData” was to copie entirely the entry line into its corresponding worksheet. Before copying the figures, the module was designed to go to the first empty line and to fill it with the entry line.

This module is presented in figure A.4, page 134.

This is a general module that was design to be used by any other modules that needs to copie data onto a line.

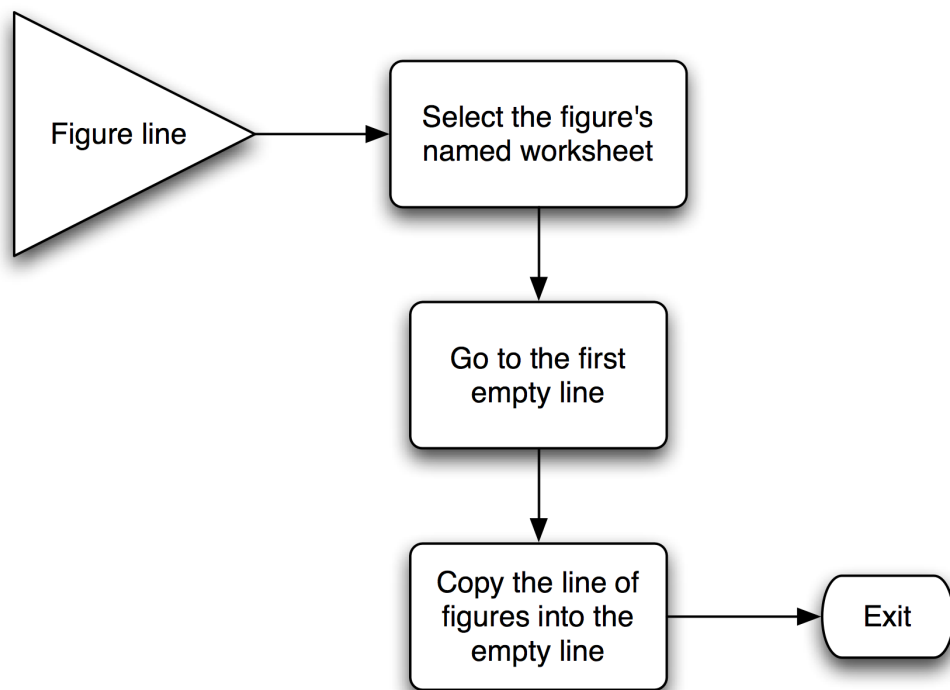


Figure A.4: "CopieData" flow chart

A.1.6 ConvertTime

The module “ConvertTime” became necessary when data had to be made time-dependent. The structure of the time and date figures into the NMEA 0183 standard are not useable as such. The time information is based on 6 numbers collated to one another making one complete number that could not be dissociated. The first two figures represent hours, based on a maximum of 24 hours (ie, 01, 02, 03, ... ,11, 12, ... , 22, 23, 00, 01, etc.). The two middle figures represent the minutes (based on a maximum of 60 minutes, ie, 00, 01, ... , 58, 59, 00, etc.). The last two figures of the number represent the seconds, based, like for the minutes, on 60 seconds.

It is the same for the date. The first two numbers are giving the day of the month (based on the right day per month structure, ie, taking into account the 29th of February, etc), the two middle ones, the month and the last two the year.

An example of the formats used are given below:

215813 corresponds to 21h 58min 13s

100607 corresponds to 10th of June 2007

As such, these formats are not useful to us. Both have to be converted to a more comprehensive and useful structure. This is the task of “ConvertTime”. As can be seen in the flow chart of the module presented in figure A.5, page 136, the module is divided into several distinctive modules that have their particular task. Since each of these modules is quite complex, they are explained separately in pages 135 (“ConvertTime” module), 137 (“Date-Computation” module), 137 (“TimeComputation” module), 138 (“TimeAnd-DateCheck” module), 138 (“TimeAndDateReport” module) and 140 (“CopyTimeFlag” module). Specially, “TimeFlag” is explained in more details.

ConvertTime

The sub-module “ConvertTime” is similar to “Main”. It defines the different treatments to perform depending on the type of figures that are passed on by “Main”. “ConvertTime”, unlike “Main”, does not hold an error message module if a figures is unknown. The only figures that are passed to “ConvertTime” are known in advance.

“ConvertTime” is only a controller designed to sort between the treatment of “M1RMC” and “\$M1GGA”, the two figures sent by the instrumentation that contains date and time information. The sorting is important here because only “\$M1RMC” contains date information. Processing date calls for a distinctive process explained in page 137.

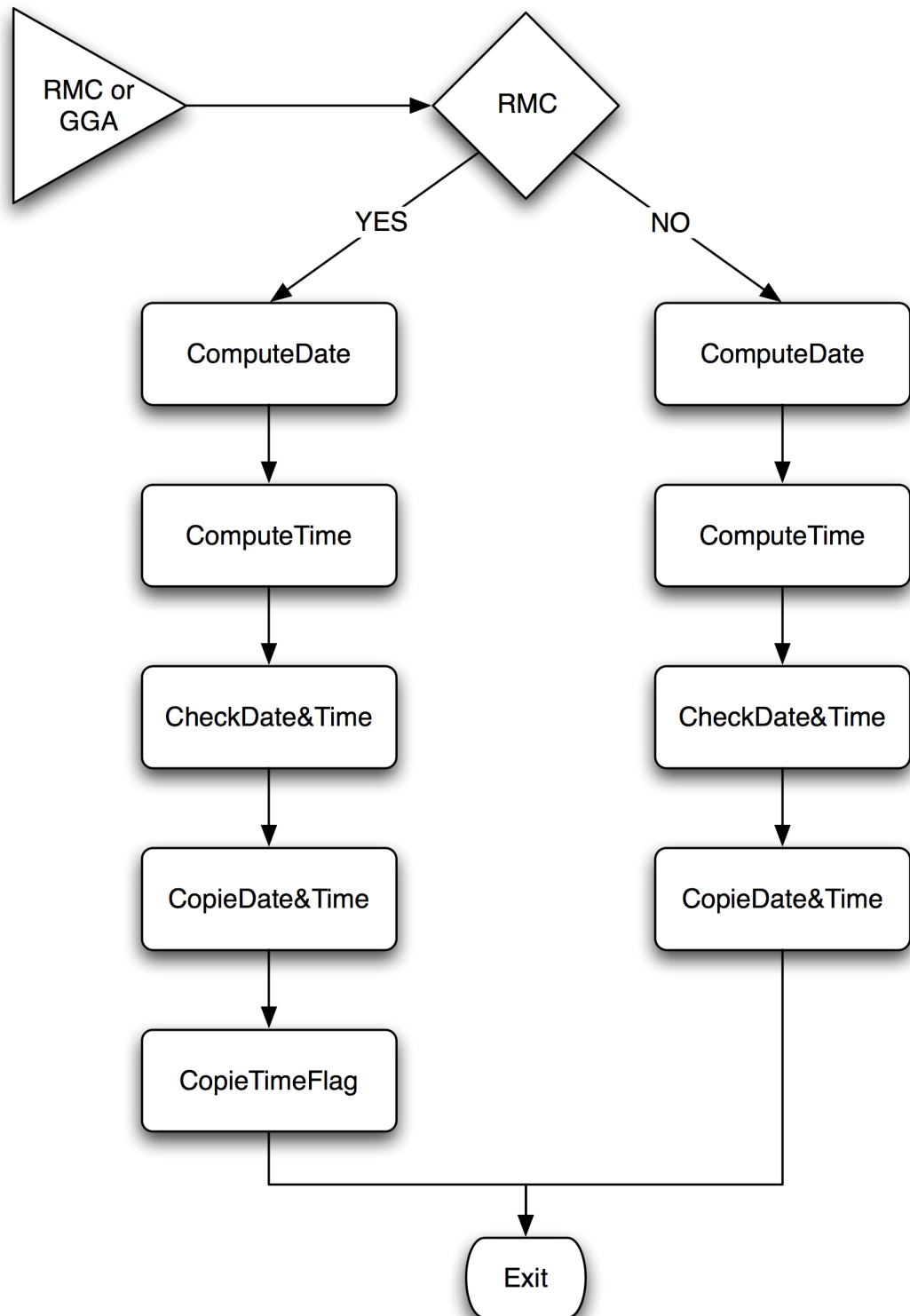


Figure A.5: ConvertTime flow chart

As can be seen in appendix B.4, page 155, sorting between “\$M1RMC” and “\$M1GGA” is done first by an “if” statement. Inside this “if” statement, different procedure explained below are launched in the following sequence:

1. “DateComputation” (only for \$M1RMC; module explained in page 137)
2. TimeComputation (module explained in page 137)
3. TimeAndDateCheck (module explained in page 138)
4. TimeAndDateReport (module explained in page 138)

DateComputation

In this sub-module, the date figure (as presented in section A.1.6, page 135) is divided into its different components (ie, day, month and year). To do so, the number is divided by 10000 to get the day. The day is found by using the “Fix” function from Excel©. This function keeps only the decimals of a number. In the present case, the decimals represent the day.

As a second operation, we subtract to the original date figure, the day number multiplied by 10,000 and divide the remaining by 100. We use, again, the “Fix” function to find the month.

The third operation is similar to the second one. We subtract to the original date figure the day number multiplied by 10,000 and the month number multiplied by 100. We use the “Fix” function to find the year.

A “DateFlag” is created. It is used as referenced and will be placed at every change of time (ie, going from a second to another) between the instructions of all the other modules. The “DateFlag” corresponds to the addition of 20,000,000, the year multiplied, by 10,000, the month multiplied by 100 and the day. It becomes of the standard European form: 20070610 for the 10th of June 2007. This procedure is not valid for dates before the 1st of January 2000, but is valid for all the years onward.

The code can be find in appendix B.4, from page 155 onward.

TimeComputation

The sub-module “TimeComputation” is similar to “DateComputation” presented in section A.1.6, page 137. The main difference reside in the computation of the value “TimeFlag”. This value is used in the same way and at the same time as “DateFlag”. It’s use is presented in section A.1.6, page 140. This value is the sum of the hours multiplied by 3,600, the minutes multiplied by 60 and the seconds, that were previously computed using the

same division procedure as for “ComputeDate”. The “TimeFlag” computed is the time in seconds over the day, zero being midnight.

The code for this module is attached in appendix B.4, page 155 and onwards.

TimeAndDateCheck

This sub-module’s task is to check that the time and the date that were just computed by the modules above is indeed, a new date or a new time. If it is a new time, it means either that the time has past to the next second, or that a new measurement on a new date or new time is processed.

As such, the module does not make the difference between a new second in one measurement or a new measurement at a different time. This could be an interesting and useful upgrade of the code if translated to, for example, C, C++, Perl or Objective C, (in Excel©, since it isn’t possible to process more than 65,000 lines at a time, this is not perceived as a necessary feature).

Through a series of “If” statements, the code check that the time and date figures that have just been computed are different from the ones that were computed during the last call of the module by the central controller, “ConvertTime”. Figure A.6, page 139, show the module’s process.

If either the time or the date is new, then the module stores either the figure “Copy” or “dontcopy”. This figure is then read by the next module in “ConvertTime”. If the answer “Copy” is stored, then the old time and old date figures are replaced by the new time and date.

The code for this module is presented in appendix B.4, page 155 and onwards.

TimeAndDateReport

The sub-module “TimeAndDateReport” uses the answer from “TimeAndDateCheck” described in A.1.6, page 138, to copy the time and date figures into a specific worksheet called “DateAndTime”. This worksheet is used to store all the time and date information. It allows to magnify disruption of the data flow if it happens (ie, if the instruments stop sending data at the same flow rate for whatever reason).

The previous sub-module out-put a string that can be either “Copy” or “dontcopy”. If “TimeAndDateReport” detects the string “Copy”, then it check, first of all, that the worksheet “DateAndTime” exist. It uses the module “CheckSheetExistence” described in section A.1.4, page 132. If the worksheet doesn’t exist, it is created by this module. After this operation, a loop goes to the first empty line of “DateAndTime” worksheet and copy the year, month, day, hour, minute, second figures as well as the dateflag and the timeflag onto the same line.

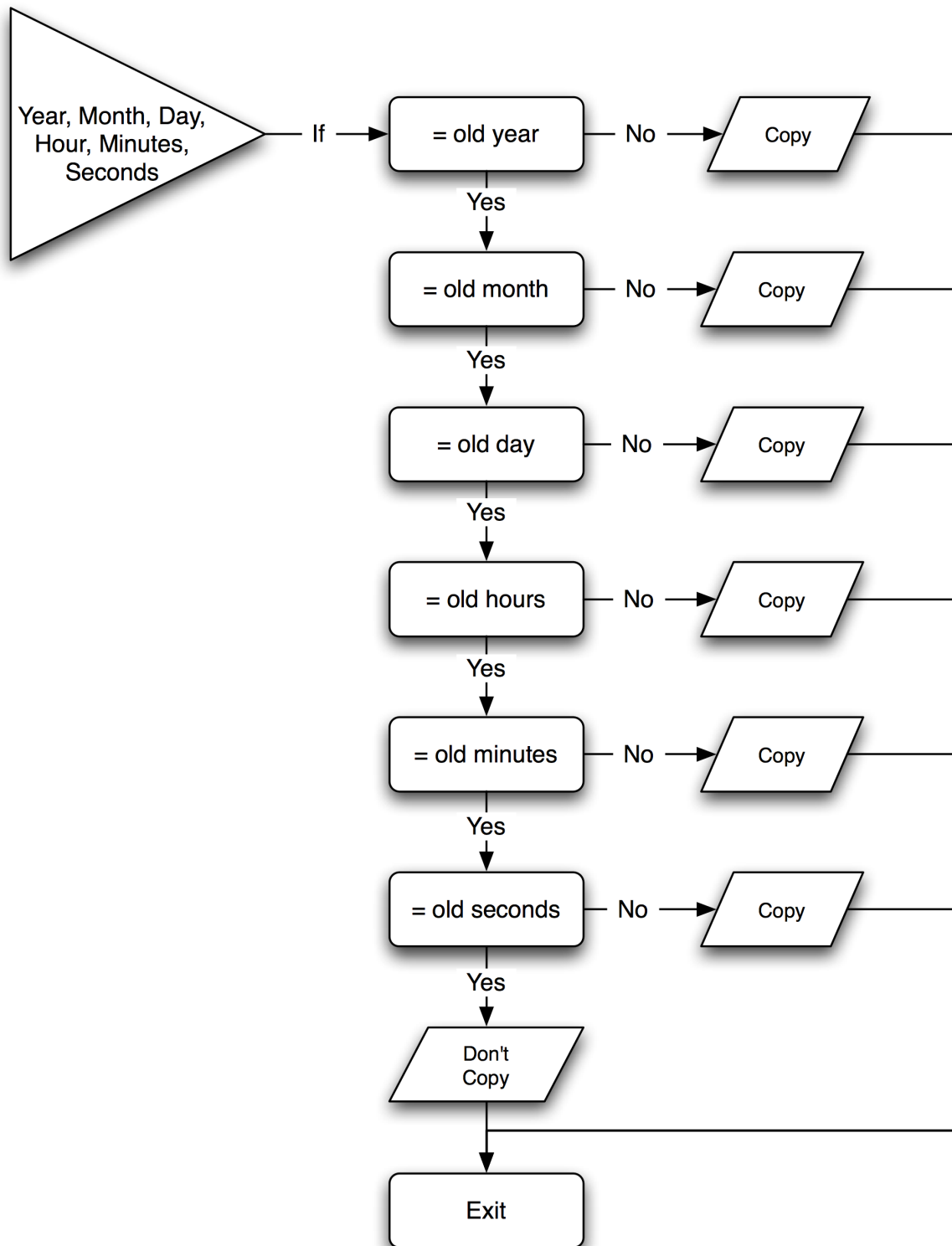


Figure A.6: CheckDateAndTime flow chart

The code for this module is presented in appendix B.4, page 155 and onwards.

CopieTimeFlag

“CopieTimeFlag” is a rather heavy computation sub-module. There are several loops in this module that were find necessary that takes a lot of resources. The goal of this module is to copy the Time and the Date Flags to all the existing worksheets of the workbook when a new time or a new date is encountered.

To do so, the module uses the reference worksheet “SheetNameStore” that was created previously by “CheckSheetExistence” (see section A.1.4, page 132). The module goes into “SheetNameStore” and for all the entry names of worksheet stored, it copies both the “DateFlag” and the “TimeFlag” at the first empty line of the corresponding worksheets. In other words, if the first cell of “SheetNameStore” contains “\$M1GGA”, for example, the code will “select” the worksheet named “\$M1GGA” and copy on the first empty line “DateFlag” in the first column and “TimeFlag” in the second column. It will then go down one line inside “SheetNameStore” and do the same process for the next worksheet name.

“TimeFlag” is a very important figure in this code. It makes the entire sorted measurement time-dependent. From this rather simple module, the five hours of measurements performed over the Swedish coast can be interpreted with a lot of details. A new “TimeFlag” is normally sent every second by the system. This should be a sufficient time interval to carry a lot of time-dependent studies on sailing boats with a certain minimum displacement. Boats that are too light might have important motion frequencies too high to be captured by that interval. But for a boat like Vågvis, this should be enough.

A.1.7 AnalysisPart1

“AnalysisPart1” is the most complicated module of the present code. It’s goal is to produce the polar plots or other output from the previously sorted data. It is divided into five modules that represent each, several pages of code. Each of these modules will be described in the following pages:

- AnalysisPart1, page 141
- ComputeTrueWindSpeed, page 141
- ShipTimeResponse, page 145
- ProducePolarPlot, page 147

- WindAngleSort, page 147

Each of the modules have a particular task. “AnalysisPart1” is, like “Main” a general controller module. It is used to check that the sorting was performed first, or if part of the analysis have already taken place or not. Since it turned out quickly that the computation were rather long, it was decided to divide the work into different steps. If at the end of a step, the process went fine, then a string would be placed into “SheetNameStore”. This way, “AnalysisPart1” can check if the sorting have been performed or not. The sorting is compulsory before starting the analysis. Then, it can check what part of the analysis was carried out and perform only the necessary part. This avoid redundant work and therefore saves time.

AnalysisPart1

This first module is divided into four section that are called “Checks”. The different “Checks” are series of “If” statements that are used to detect if all the necessary parts of either the sorting or the analysis have been carried out. If one part is missing, the procedure is to perform it and all the steps that are supposed to come afterward. The procedure is presented in “AnalysisPart1” flow chart, in figure A.7, page 142. If all the steps are already fulfilled, the sub-module is exited. If the last step only is missing, then it is performed before exiting. If the last two steps are not fulfilled, then they are performed before exiting, and so on. The only exception to this procedure is if the sorting did not take place. Then the sub-module is simply exited without performing any analysis. To be properly complete, this particular procedure should come with an error message to warn the user that the sorting did not take place. However, if the sorting was not perform at first, then “Main” will start it on launch anyway. It is a safety procedure (in case, for example, one manually remove the “tidy” figure from “SheetNameStore”).

ComputeTrueWindSpeed

The goal of “TrueWindSpeed” is to calculate the velocity and direction of the wind that originates the motion of the boat with regard to the ground. The anemometer can only indicate the velocity and direction of the wind with regard to the ship. These are better known as apparent wind speed and apparent wind angle.

To evaluate the performance of the boat, it is important to convert the apparent wind angle and velocity to true wind angle and velocity with regard to the course of the boat. This can be done relatively easily by using the velocity of the boat. Two velocity can be considered:

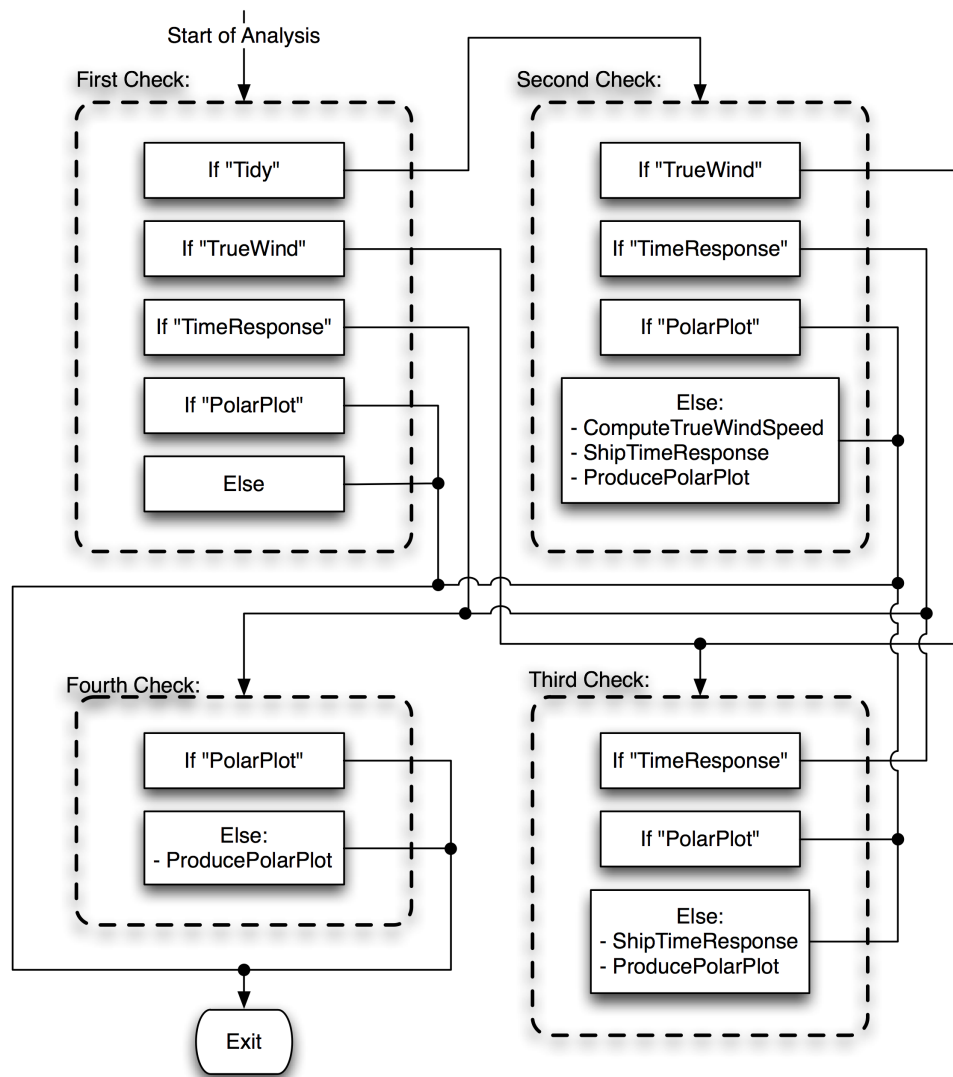


Figure A.7: AnalysisPart1 flow chart

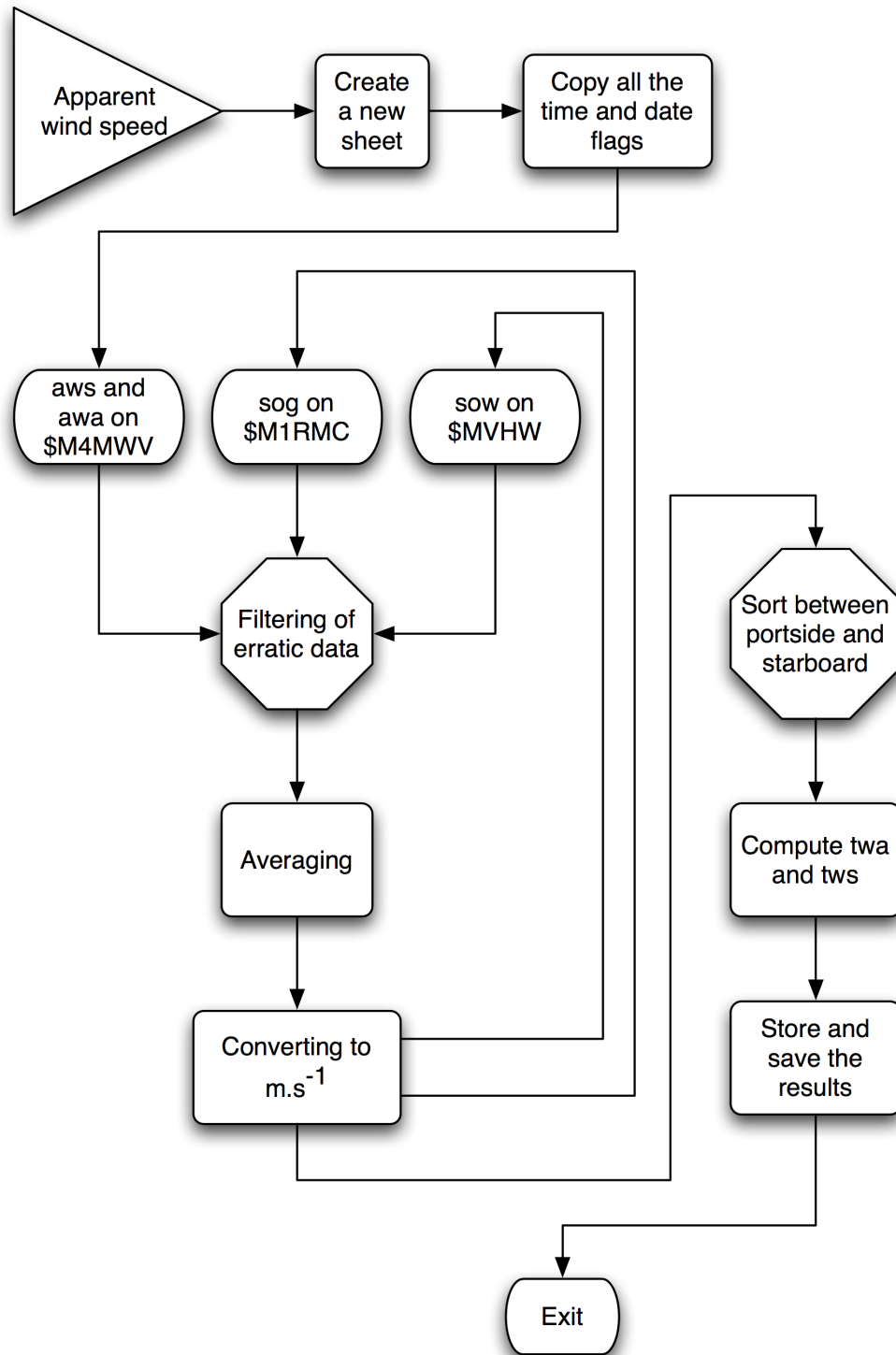


Figure A.8: ComputeTrueWindSpeed flow chart

- The velocity Over Water, VoW (ie, with regard to the water flow along the hull)
- The velocity Over Ground, VoG (ie, with regard to the seabed)

The VoW doesn't take current effects into account, while the VoG does. The computation of both data is relatively similar. Both velocities were calculated in the present work, but only the velocity over ground was analysed. It would have required more time and effort to analyse the velocity over water too.

To convert the data, the process is to, first, average figures if several are output between two "TimeFlag", then to compute the true wind speeds and angles. Since this computation uses trigonometric formulae, the code requires using Excel's graphical user interface (GUI). VBA does not permit trigonometric calculations. Values have to be copied and evaluated into Excel, before being further processed. This problem has made the code quite slow (specially since the possibility of freezing the GUI in excel wasn't brought to the attention of the developer).

The process of calculating includes filtering loops. During the first process, erratic data appeared in the series of figures. For example, boat speed of 44 knots were recorded every second burst by the loch-meter. These figures are not realistic and are probably due to internal instrumentation errors. Some other data were not sent to the burst. This sometimes happens and is probably due to electrical problems.

After filtering the data, the process averages and copies the data necessary for the wind speed and the wind angle calculations. The final stage is to copy the mathematical formulae used for the computation into a cell and perform the computation inside the Excel GUI. The input figures are copied in other cells and the result is output to another one. The result is then copied into the original worksheet where it is saved at the end of the sequence.

Figure A.8, page 143 shows the flow chart of the process. The wind speed is computed with the following formulae:

$$TWS = \sqrt{\left(aws \cdot \sin(awa) \cdot \frac{\pi}{180}\right)^2 + \left(-sog + aws \cdot \cos\left(awa \cdot \frac{\pi}{180}\right)\right)^2} \quad (\text{A.1})$$

$$\text{if } awa < 90^\circ \text{ then } TWA = \arcsin\left(\frac{aws}{TWS} \cdot \sin\left(\frac{awa\pi}{180}\right)\right) \cdot \frac{180}{\pi} \quad (\text{A.2})$$

$$\text{if } awa > 90^\circ \text{ then } TWA = 180 - \arcsin\left(\frac{aws}{TWS} \cdot \sin\left(\frac{awa\pi}{180}\right)\right) \cdot \frac{180}{\pi} \quad (\text{A.3})$$

The same formulae are used for both the computation of the wind speed and angle with regard to either SoW or SoG. Equation A.2 and A.3 are used to differentiate the data between the portside and starboard. Indeed, it is well known to sailors that a sailing boat never behave in the same way on each side. Therefore, for the accuracy of the present analysis, it is important that both sides are being sorted into the final processed data used for the analysis. The next piece of code calculates a gross estimate of the leeway angle. The leeway angle is calculated as the difference between the corrected magnetic heading (corrected for natural deviation of earth magnetic field) and the heading given by the GPS. The heading given by the GPS represent the motion of the boat over the ground, thus including the leeway, while the magnetic heading represent the motion of the boat without the leeway angle. The leeway angle is shown in figure A.9, page 146. The code differentiates, here, between East or West deviations and averages magnetic headings when more than one is sent between two timeflags.

The last part of code of this module is used to calculate the difference between the true wind angle calculated with GPS data and the true wind angle calculated with Loch-meter. Theoretically, the magnetic heading should give a wind angle that does not include effects due to leeway, while the one calculated using the GPS heading should. This parameter is therefore used as a way to check the accuracy of the data. It can also be used as a way to estimates the impact of the ship's time response to gust.

ShipTimeResponse

The original goal of this module was to calculate or estimate the time response of the ship to a wind gust. However, this task turned out to be too complicated to be assessed under the scope of the present thesis.

Instead, this module was used to sort the figures by true wind strength and then by true wind angle. As a result, the figures are sorted in different worksheets by wind strength in ranges of $1ms^{-1}$ with a $\pm 0,5ms^{-1}$ range. Another worksheet called "SimplePolarDataBaseGPS" was then used to find the maximum boat speed for each true wind range, and in wind angles of 10° with a $\pm 5^\circ$ range.

The databases that were created were the roots for the data analysis that will be explained later.

From a practical persepective, winds of the same speed range are placed in worksheets with that wind strength name. When all the figures are processed, then for each wind strength, the figures are sorted by wind angle into a new worksheet using the module "WindAngleSort" explained in section A.1.7, page 147.

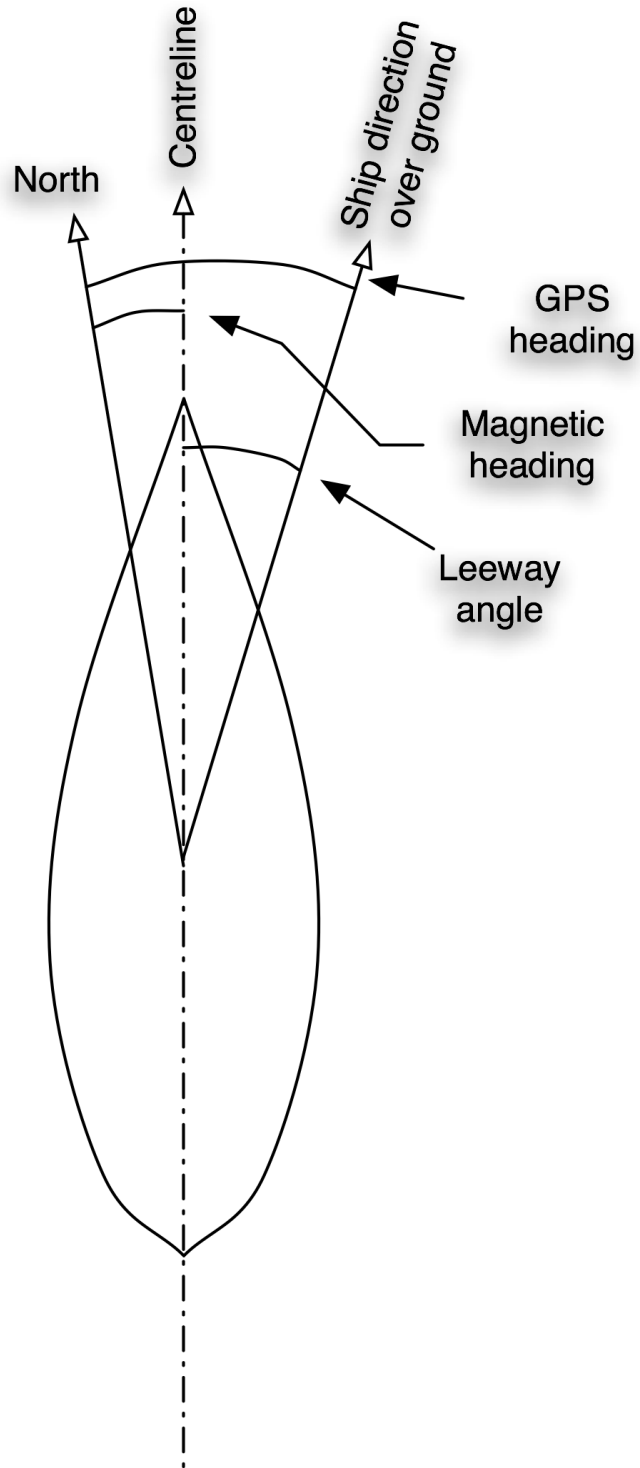


Figure A.9: Leeway angle and its relation with the Magnetic and GPS headings

ProducePolarPlot

“ProducePolarPlot” is the last module to intervene into the data treatment sequence. It comes from the first experiments in plotting the results. The first trials were not successful. It was therefore thought that by processing the result once more, a better data set for plotting could be obtained. The data were therefore converted into a set of Cartesian co-ordinates for both port-side and starboard.

However, the result obtained was not convincing and its usefulness was arguable.

WindAngleSort

“WindAngleSort” is a sub-module of “ShipTimeResponse” (see section [A.1.7](#), page [145](#)). It is used by that module to sort figures by port-side or starboard and finds the maximum speed in the given worksheet for a particular wind angle range. The maximum speeds for port-side and starboard are then stored into a worksheet called “SimplePolarDataBaseGPS”. This worksheet stores the boat speed achieved measured with the GPS for a range of true wind strength (calculated with the GPS speed to be consistent) and there corresponding range of true wind angle.

The result is a comprehensive database of best performance that can be used later to produce a polar curve describing the boat performance of the boat.

Appendix B

VBA code: Full code

The following appendix presents the exact code that was used in Excel. It is slitted in all different kind of modules.

B.1 VBA code: Main

```
Sub Main()
```

```
'The goal of the sub main is to check the data entry. For each  
new entry it creates a new worksheet with the entry name as a  
reference. The sub then passes onto sub copiedata that will  
perform the copie-past action.ŀ
```

```
Dim rownum, size, i, j, u, v As Integer    'used'  
Dim lngwkscount As Long  
Dim Cellname, cellnameCopie  
Dim Msg, Msg2, Msg3, Style, Style2, Title, Response, Response2,  
Response3,  
Mystring
```

```
'first, we need to add the necessary worksheets to the  
workbook. Those sheets correspond to the matrices we want to  
build. 1 worksheet per type of data would help to keep things  
clear...'
```

```
Sheets("Measures").Select
```

```
Cells.Replace What:= ".", Replacement:=",", LookAt:=xlPart,
```

```

SearchOrder _
    :=xlByRows, MatchCase:=False

rownum = 1
i = 1
j = 1
Do While Cells(i, 1) <> ""
    i = i + 1
    size = i
Loop

Cellname = "SheetNameStore"
CheckSheetExistence.CheckSheetExistence Cellname

u = 1
Do While Sheets(Cellname).Cells(u, 1) <> ""
    If Sheets(Cellname).Cells(u, 1) = "Tidy" Then
        GoTo analysis
    Else
        End If
    u = u + 1
Loop

cellnameCopie = "Measures"
Cellname = Sheets(cellnameCopie).Cells(rownum, 1)

GoTo Tidyingloop

'In the tidying loop, for each entry line, we launch a new
procedure until all the data have been analysed. We use goto
commands to start new procedure on a different part of the
code. When the new procedure is finished, another goto bring
back the cursor to its previous position in the loop.'

Incrementrownum:
Sheets("Measures").Select
rownum = rownum + 1
Cellname = Sheets("Measures").Cells(rownum, 1)

Tidyingloop:
Do While rownum < size

```

```

If Cellname = "$M1RME" Then
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData rownum, Cellname, cellnameCopie
    GoTo Incrementrownum
ElseIf Cellname = "$M4DBT" Then
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData rownum, Cellname, cellnameCopie
    GoTo Incrementrownum
ElseIf Cellname = "$M4VHW" Then
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData rownum, Cellname, cellnameCopie
    GoTo Incrementrownum
ElseIf Cellname = "$M4MTW" Then
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData rownum, Cellname, cellnameCopie
    GoTo Incrementrownum
    'GGA is a time flag. Its procedure include, converting
the time in seconds and copying it to all the other sheets.'
ElseIf Cellname = "$M1GGA" Then
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData rownum, Cellname, cellnameCopie
    ConvertTime.ConvertTime rownum, Cellname
    GoTo Incrementrownum
ElseIf Cellname = "$M4MWV" Then
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData rownum, Cellname, cellnameCopie
    GoTo Incrementrownum
ElseIf Cellname = "$M4MDST" Then
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData rownum, Cellname, cellnameCopie
    GoTo Incrementrownum
ElseIf Cellname = "$M1GSA" Then
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData rownum, Cellname, cellnameCopie
    GoTo Incrementrownum
ElseIf Cellname = "$M1GSV" Then
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData rownum, Cellname, cellnameCopie
    GoTo Incrementrownum
    'GGA is a time flag. Its procedure include, converting
the time in seconds and copying it to all the other sheets.'

```

```

ElseIf Cellname = "$M1RMC" Then
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData rownum, Cellname, cellnameCopie
    ConvertTime.ConvertTime rownum, Cellname
    GoTo Incrementrownum
ElseIf Cellname = "$M4HDG" Then
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData rownum, Cellname, cellnameCopie
    GoTo Incrementrownum
ElseIf Cellname = "$M1RMB" Then
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData rownum, Cellname, cellnameCopie
    GoTo Incrementrownum
ElseIf Cellname = "$M1RMT" Then
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData rownum, Cellname, cellnameCopie
    GoTo Incrementrownum
ElseIf Cellname = "$M4VLW" Then
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData rownum, Cellname, cellnameCopie
    GoTo Incrementrownum
Else
    Msg = "Unknown figure encountered. The program doesn't
know how to proceed. Show the unknown Figure and exit? (if no
is choosen, the script will show the unknown figure and
continue with no further notice)"
    Style = vbYesNoCancel + vbExclamation + vbDefaultButton1
    Style2 = vbOKOnly
    Title = "Unknown NMEA0183 entry"
    Response = ""
    Response = MsgBox(Msg, Style, Title)
    If Response = vbYes Then
        Msg2 = Cellname
        Response2 = MsgBox(Msg2, Style2, Title)
        Response2 = vbOK
        Exit Sub
    ElseIf Response = vbNo Then
        Msg2 = Cellname
        Response2 = MsgBox(Msg2, Style2, Title)
        Response2 = vbOK
        GoTo Incrementrownum

```



```
        Else
            Response = vbCancel
            Exit Sub
        End If
    End If
Loop
'Exit Sub

ThisWorkbook.Save

v = 1
Do While Sheets("SheetNameStore").Cells(v, 1) <> ""
    If Sheets("SheetNameStore").Cells(v, 1) = "Tidy" Then
        GoTo analysis
    Else
        End If
    v = v + 1
Loop
Sheets("SheetNameStore").Cells(v, 1) = "Tidy"

analysis:
AnalysisPart1.AnalysisPart1

End Sub
```

B.2 VBA code: CheckSheetExistence

```
Sub CheckSheetExistence(Cellname)

Dim lngwkscount

Sheets("Measures").Select
lngwkscount = ThisWorkbook.Sheets.Count
j = 1
Do While j < lngwkscount + 1
    If Sheets(j).Name = Cellname Then
        Exit Sub
    Else
        j = j + 1
    End If
End While
```

```
Loop
CreateWorkSheets Cellname

End Sub

Sub CreateWorkSheets(Cellname)

Dim r

Sheets.Add.Name = Cellname
Sheets(Cellname).Move after:=Sheets(Sheets.Count)

If Cellname <> "SheetNameStore" Then
    r = 1
    Do While Sheets("SheetNameStore").Cells(r, 1) <> ""
        r = r + 1
    Loop
    Sheets("SheetNameStore").Cells(r, 1) = Cellname
Else
End If

End Sub
```

B.3 VBA code: CopieData

```
Sub CopieData(rownum, Cellname, cellnameCopie)

Dim u, rowi, colli, collumnum As Integer

u = 30 'u is the greatest number of figure expected on any
line plus 1

rowi = 1
colli = 1
collumnum = 1

Do While Sheets(Cellname).Cells(rowi, 1) <> ""
    rowi = rowi + 1
Loop
```

```

Do While collumnum < u
  If Sheets(cellnameCopie).Cells(rownum, collumnum) <> "" Then
    Sheets(Cellname).Cells(rowi,colli)=Sheets(cellnameCopie).
Cells(rownum,collumnum)
    colli = colli + 1
    collumnum = collumnum + 1
  Else
    collumnum = collumnum + 1
  End If
Loop
Sheets(cellnameCopie).Select

End Sub

```

B.4 VBA code: ConvertTime

```

Sub ConvertTime(rownum, Cellname)

Dim Year, Month, Day, Hours, Minutes, Seconds, answer,
TimeFlag, DateFlag
Dim rowj, rowk
rowj = 1
rowk = 1
If Cellname = "$M1RMC" Then
  Do While Sheets(Cellname).Cells(rowj, 1) <> ""
    rowj = rowj + 1
  Loop
  rowk = rowj - 1
  DateComputation Cellname, rowk, Year, Month, Day, DateFlag
  TimeComputation Cellname, rowk, Hours, Minutes, Seconds,
TimeFlag
  TimeAndDateCheck Year, Month, Day, Hours, Minutes, Seconds
  TimeAndDateReport Cellname, Year, Month, Day, Hours,
Minutes, Seconds, TimeFlag, answer, DateFlag
ElseIf Cellname = "$M1GGA" Then
  TimeComputation Cellname, rowk, Hours, Minutes, Seconds,
TimeFlag
  TimeAndDateCheck Year, Month, Day, Hours, Minutes, Seconds
  TimeAndDateReport Cellname, Year, Month, Day, Hours,
Minutes, Seconds, TimeFlag, answer, DateFlag

```

```
Else  
End If
```

```
End Sub
```

```
Sub DateComputation(Cellname, rowk, Year, Month, Day, DateFlag)
```

```
Dim Dates, DateOld, DateYear, DateMonth, DateDay
```

```
Dates = Sheets(Cellname).Cells(rowk, 10)
```

```
If DateOld = Dates Then
```

```
    GoTo IncrementDate
```

```
Else
```

```
    DateDay = Dates / 10000
```

```
    Day = Fix(DateDay)
```

```
    DateMonth = (Dates - (Day * 10000)) / 100
```

```
    Month = Fix(DateMonth)
```

```
    DateYear = (Dates - (Day * 10000) - (Month * 100))
```

```
    Year = Fix(DateYear)
```

```
    DateFlag = 20000000 + Year * 10000 + Month * 100 + Day
```

```
End If
```

```
IncrementDate:
```

```
DateOld = Dates
```

```
End Sub
```

```
Sub TimeComputation(Cellname, rowk, Hours, Minutes, Seconds,  
TimeFlag)
```

```
Dim Time, Timeold, TimeHours, TimeMinutes, TimeSeconds
```

```
Time = Sheets(Cellname).Cells(rowk, 2)
```

```
If Timeold = Time Then
```

```
    GoTo IncrementTime
```

```
Else
```

```
    TimeHours = Time / 10000
```

```
    Hours = Fix(TimeHours)
```

```
    TimeMinutes = (Time - (Hours * 10000)) / 100
    Minutes = Fix(TimeMinutes)
    TimeSeconds = (Time - (Hours * 10000) - (Minutes * 100))
    Seconds = Fix(TimeSeconds)
    TimeFlag = Hours * 3600 + Minutes * 60 + Seconds
End If

IncrementTime:

Timeold = Time

End Sub

Sub TimeAndDateCheck(Year, Month, Day, Hours, Minutes, Seconds)

Dim OldYear, OldMonth, OldDay, OldHours, OldMinutes, OldSeconds
Dim answer

If Year = OldYear Then
    If Month = OldMonth Then
        If Day = OldDay Then
            If Hours = OldHours Then
                If Minutes = OldMinutes Then
                    If Seconds = OldSeconds Then
                        answer = dontcopy
                    Else
                        answer = Copy
                    End If
                Else
                    answer = Copy
                End If
            Else
                answer = Copy
            End If
        Else
            answer = Copy
        End If
    Else
        answer = Copy
    End If
Else
    answer = Copy
End If

Else
    answer = Copy
End If

Else
```

```
        answer = Copy
    End If

    If answer = Copy Then
        OldYear = Year
        OldMonth = Month
        OldDay = Day
        OldHours = Hours
        OldMinutes = Minutes
        OldSeconds = Seconds
    Else
    End If

End Sub

Sub TimeAndDateReport(Cellname, Year, Month, Day, Hours,
Minutes, Seconds, TimeFlag, answer, DateFlag)

Dim rowi, gotonextline, truecellname, tempcellname

tempcellname = "DateAndTime"
rowi = 1

If answer = Copy Then
    CheckSheetExistence.CheckSheetExistence tempcellname
    Do While Sheets(tempcellname).Cells(rowi, 1) <> ""
        rowi = rowi + 1
    Loop
    Sheets(tempcellname).Cells(rowi, 1) = Year
    Sheets(tempcellname).Cells(rowi, 2) = Month
    Sheets(tempcellname).Cells(rowi, 3) = Day
    Sheets(tempcellname).Cells(rowi, 4) = Hours
    Sheets(tempcellname).Cells(rowi, 5) = Minutes
    Sheets(tempcellname).Cells(rowi, 6) = Seconds
    Sheets(tempcellname).Cells(rowi, 7) = TimeFlag
    Sheets(tempcellname).Cells(rowi, 8) = DateFlag
    CopieTimeFlag TimeFlag, DateFlag
    gotonextline = 1
Else
    gotonextline = 0
End If
```

```

End Sub

Sub CopieTimeFlag(TimeFlag, DateFlag)

Dim rowsheetnamestore, cellnametemp, rowinc

rowsheetnamestore = 1
Do While Sheets("SheetNameStore").Cells(rowsheetnamestore, 1)
<> ""
    cellnametemp = Sheets("SheetNameStore").Cells(rowsheetnamestore, 1)
    rowinc = 1
    If cellnametemp <> "DateAndTime" Then
        Do While Sheets(cellnametemp).Cells(rowinc, 1) <> ""
            rowinc = rowinc + 1
        Loop
        Sheets(cellnametemp).Cells(rowinc, 1) = DateFlag
        Sheets(cellnametemp).Cells(rowinc, 2) = TimeFlag
    Else
    End If
    rowsheetnamestore = rowsheetnamestore + 1
Loop

rowsheetnamestore = 1

End Sub

```

B.5 VBA code: AnalysisPart1

```

Sub AnalysisPart1()

'the goal of the analysis tool is to find all the necessary
data to produce a polar curve (for different wind speed and
angle, find the right boat speed). It is therefore necessary to
find out the time response of the boat to a gust.'

Dim a

FirstCheck:
a = 1

```

```

Do While Sheets("SheetNameStore").Cells(a, 1) <> ""
  If Sheets("SheetNameStore").Cells(a, 1) = "Tidy" Then
    GoTo SecondCheck
  ElseIf Sheets("SheetNameStore").Cells(a, 1) = "TrueWind" Then
    GoTo ThirdCheck
  ElseIf Sheets("SheetNameStore").Cells(a, 1) = "TimeResponse" Then
    GoTo FourthCheck
  ElseIf Sheets("SheetNameStore").Cells(a, 1) = "PolarPlot" Then
    Exit Sub
  ElseIf Sheets("SheetNameStore").Cells(a + 1, 1) = "" Then
    Exit Sub
  Else
    a = a + 1
  End If
Loop

```

SecondCheck:

```

a = 1
Do While Sheets("SheetNameStore").Cells(a, 1) <> ""
  If Sheets("SheetNameStore").Cells(a, 1) = "TrueWind" Then
    GoTo ThirdCheck
  ElseIf Sheets("SheetNameStore").Cells(a, 1) = "TimeResponse" Then
    GoTo FourthCheck
  ElseIf Sheets("SheetNameStore").Cells(a, 1) = "PolarPlot" Then
    Exit Sub
  ElseIf Sheets("SheetNameStore").Cells(a + 1, 1) = "" Then
    ComputeTrueWindSpeed
    ShipTimeResponse
    ProducePolarPlot
    Exit Sub
  Else
    a = a + 1
  End If
Loop

```

ThirdCheck:

```

a = 1
Do While Sheets("SheetNameStore").Cells(a, 1) <> ""
  If Sheets("SheetNameStore").Cells(a, 1) = "TimeResponse" Then
    GoTo FourthCheck
  ElseIf Sheets("SheetNameStore").Cells(a, 1) = "PolarPlot" Then

```



```

    Exit Sub
  ElseIf Sheets("SheetNameStore").Cells(a + 1, 1) = "" Then
    ShipTimeResponse
    ProducePolarPlot
    Exit Sub
  Else
    a = a + 1
  End If
Loop

FourthCheck:
a = 1
Do While Sheets("SheetNameStore").Cells(a, 1) <> ""
  If Sheets("SheetNameStore").Cells(a, 1) = "PolarPlot" Then
    Exit Sub
  ElseIf Sheets("SheetNameStore").Cells(a + 1, 1) = "" Then
    ProducePolarPlot
    Exit Sub
  Else
    a = a + 1
  End If
Loop

End Sub

Sub ComputeTrueWindSpeed()

Dim Cellname, aws, awa, sog, sow, tempawa, tempaws, tempsog,
tempow, twsgps, twagps, twswater, twawater, DateFlag, TimeFlag,
gpsheading, tempgpsheading, magneticheading, tempmagneticheading,
leeway, counting, nbr, b, c, d, e

Cellname = "InstantaneousWindSpeed"
CheckSheetExistence.CheckSheetExistence Cellname

'first, we can copy all the timeflag, then read the different speed
And that correspond to these timeflag. If there is several speed
under one timeflag, then we can choose to either average, use the
minimum, or use the maximum. Then we can keep on going for the other
data until everything is either copied or processed.'
```

```

'Lets copy all timeflag first'
b = 1
Do While Sheets("DateAndTime").Cells(b, 1) <> ""
    TimeFlag = Sheets("DateAndTime").Cells(b, 7)
    DateFlag = Sheets("DateAndTime").Cells(b, 8)
    Sheets("InstantaneousWindSpeed").Cells(b,1)=Sheets("DateAndTime").
Cells(b,7)

'check and copy of aws and awa on $M4MWV'
Cellname = "$M4MWV"
c = 1
Do While Sheets(Cellname).Cells(c, 2) <> TimeFlag
    c = c + 1
    If Sheets(Cellname).Cells(c, 2) = "" Then
        Sheets("InstantaneousWindSpeed").Cells(b, 2) = "NA"
        Sheets("InstantaneousWindSpeed").Cells(b, 3) = "NA"
        aws = "NA"
        awa = "NA"
        GoTo continewithsog
    Else
        End If
Loop
d = c + 1
counting = 0
If Sheets(Cellname).Cells(c, 2) < Sheets(Cellname).Cells(c - 1,
2) Then
    If Sheets(Cellname).Cells(d, 2) = "" Then
        GoTo increment
    Else
        End If
Else
    If Sheets(Cellname).Cells(d, 2) = "" Then
        Exit Do
    Else
        End If
End If
Do While Sheets(Cellname).Cells(d, 2) <> TimeFlag + 1
    counting = counting + 1
    d = d + 1
Loop
nbr = counting

```

```

aws = 0
awa = 0
Do While counting <> 0
  If Sheets(Cellname).Cells(d - counting, 4) = 0 Then
    aws = 0
    awa = Sheets(Cellname).Cells(d - counting, 2)
  ElseIf nbr = 1 Then
    aws = Sheets(Cellname).Cells(d - counting, 4) * (1609 /
3600)
    awa = Sheets(Cellname).Cells(d - counting, 2)
  Else
    tempaws = Sheets(Cellname).Cells(d - counting, 4) * (1609 /
3600)
    tempawa = Sheets(Cellname).Cells(d - counting, 2)
    aws = (aws + tempaws) / 2
    awa = (awa + tempawa) / 2
  End If
  counting = counting - 1
Loop
  Sheets("InstantaneousWindSpeed").Cells(b, 2) = aws
  Sheets("InstantaneousWindSpeed").Cells(b, 3) = awa

'Check and copy of SoG on $M1RMC'
continuewithsog:
  Cellname = "$M1RMC"
  c = 1
  Do While Sheets(Cellname).Cells(c, 2) <> TimeFlag
    c = c + 1
    If Sheets(Cellname).Cells(c, 2) = "" Then
      Sheets("InstantaneousWindSpeed").Cells(b, 4) = "NA"
      Sheets("InstantaneouswindSpeed").Cells(b, 11) = "NA"
      GoTo continuewithsow
    Else
      End If
  Loop
  d = c + 1
  counting = 0
  If Sheets(Cellname).Cells(d, 2) = "" Then
    Exit Do
  Else
    End If

```

```

Do While Sheets(Cellname).Cells(d, 2) <> TimeFlag + 1
    counting = counting + 1
    d = d + 1
Loop
nbr = counting
Do While counting <> 0
    If nbr = 1 Then
        sog = Sheets(Cellname).Cells(d - counting, 8) * 1852 / 3600
        gpsheading = Sheets(Cellname).Cells(d - counting, 9)
    Else
        tempsog = Sheets(Cellname).Cells(d - counting, 8) * 1852 /
3600
        tempgpsheading = Sheets(Cellname).Cells(d - counting, 9)
        sog = (sog + tempsog) / 2
        gpsheading = (gpsheading + tempgpsheading) / 2
    End If
    counting = counting - 1
Loop
Sheets("InstantaneousWindSpeed").Cells(b, 4) = sog

'Check and copy of SoW on $M4VHW'
continewithsow:
Cellname = "$M4VHW"
c = 1
Do While Sheets(Cellname).Cells(c, 2) <> TimeFlag
    c = c + 1
    If Sheets(Cellname).Cells(c, 2) = "" Then
        Sheets("InstantaneousWindSpeed").Cells(b, 5) = "NA"
        GoTo continewithtws
    Else
        End If
Loop
d = c + 1
counting = 0
If Sheets(Cellname).Cells(d, 2) = "" Then
    Exit Do
Else
    End If
Do While Sheets(Cellname).Cells(d, 2) <> TimeFlag + 1
    counting = counting + 1
    d = d + 1

```

```

Loop
nbr = counting
sow = -5000
Do While counting <> 0
  If Sheets(Cellname).Cells(d - counting, 4) < 40 Then
    tempsow = Sheets(Cellname).Cells(d - counting, 4) * 1852 /
3600
  Else
    tempsow = -5000
  End If
  If tempsow >= 0 Then
    If tempsow > sow Then
      sow = tempsow
    Else
      End If
    Else
      End If
    counting = counting - 1
Loop
If sow < 0 Then
  Sheets("InstantaneousWindSpeed").Cells(b, 5) = "NA"
Else
  Sheets("InstantaneousWindSpeed").Cells(b, 5) = sow
End If

```

continuewithtws:

'compute and copy tws and twa for speed over ground and speed over water'

```

Sheets("SheetNameStore").Cells(1, 3) = aws
Sheets("SheetNameStore").Cells(1, 4) = awa
Sheets("SheetNameStore").Cells(1, 5) = sog
Sheets("SheetNameStore").Cells(1, 6) = sow
If aws = "NA" Then
  twsgps = "NA"
  twagps = "NA"
ElseIf awa = "NA" Then
  twsgps = "NA"
  twagps = "NA"
ElseIf sog = "NA" Then
  twsgps = "NA"
  twagps = "NA"

```

```

ElseIf sog = 0 Then
    If aws = 0 Then
        twagps = 0
        twsgps = Sqr(sog * sog)
    Else
        End If
ElseIf aws = 0 Then
    If sog = 0 Then
        twagps = 0
        twsgps = Sqr(sog * sog)
    Else
        twagps = 180
        twsgps = Sqr(sog * sog)
    End If
Else
    If awa > 180 Then
        Sheets("SheetNameStore").Cells(1, 4) = -(180 - (awa - 180))
        Sheets("SheetNameStore").Select
        Range("C2").Select
        ActiveCell.FormulaR1C1 = _
        "=SQRT(POWER(R[-1]C*SIN(R[-1]C[1]*PI()/180),2)+POWER(-R[-1]C[2]+
        R[-1]C*COS(R[-1]C[1]*PI()/180),2))"
        Range("D2").Select
        ActiveCell.FormulaR1C1 = _
        "=IF(R[-1]C<=-90,(180+ASIN(R[-1]C[-1]/RC[-1]*SIN(R[-1]C*PI()/180))*
        180/PI()),-(ASIN(R[-1]C[-1]/RC[-1]*SIN(R[-1]C*PI()/180))*180/PI())"
        twsgps = Sheets("SheetNameStore").Cells(2, 3)
        twagps = -Sheets("SheetNameStore").Cells(2, 4)
    Else
        Sheets("SheetNameStore").Select
        Range("C2").Select
        ActiveCell.FormulaR1C1 = _
        "=SQRT(POWER(R[-1]C*SIN(R[-1]C[1]*PI()/180),2)+POWER(-R[-1]C[2]+
        R[-1]C*COS(R[-1]C[1]*PI()/180),2))"
        Range("D2").Select
        ActiveCell.FormulaR1C1 = _
        "=IF(R[-1]C>=90,180-ASIN(R[-1]C[-1]/RC[-1]*SIN(R[-1]C*PI()/180))*
        180/PI(),ASIN(R[-1]C[-1]/RC[-1]*SIN(R[-1]C*PI()/180))*180/PI())"
        twsgps = Sheets("SheetNameStore").Cells(2, 3)
        twagps = Sheets("SheetNameStore").Cells(2, 4)
    End If

```

```

End If
Sheets("InstantaneousWindSpeed").Cells(b, 6) = twsgps
Sheets("InstantaneousWindSpeed").Cells(b, 7) = twagps
If aws = "NA" Then
    twswater = "NA"
    twawater = "NA"
ElseIf awa = "NA" Then
    twswater = "NA"
    twawater = "NA"
ElseIf sow = "NA" Then
    twswater = "NA"
    twawater = "NA"
ElseIf sow = 0 Then
    If aws = 0 Then
        twawater = 0
        twswater = Sqr(sow * sow)
    Else
        End If
    ElseIf aws = 0 Then
        If sow = 0 Then
            twawater = 0
            twswater = Sqr(sow * sow)
        Else
            twawater = 180
            twswater = Sqr(sow * sow)
        End If
    Else
        If awa > 180 Then
            Sheets("SheetNameStore").Cells(1, 4) = -(180 - (awa - 180))
            Sheets("SheetNameStore").Select
            Range("E2").Select
            ActiveCell.FormulaR1C1 = _
            "=SQRT(POWER(R[-1]C[-2]*SIN(R[-1]C[-1]*PI()/180),2)+POWER(-R[-1]C[1]+R[-1]C[-2]*COS(R[-1]C[-1]*PI()/180),2))"
            Range("F2").Select
            ActiveCell.FormulaR1C1 = _
            "=IF(R[-1]C[-2]<=-90,(180+ASIN(R[-1]C[-3]/RC[-1]*SIN(R[-1]C[-2]*PI()/180))*180/PI()),-(ASIN(R[-1]C[-3]/RC[-1]*SIN(R[-1]C[-2]*PI()/180))*180/PI()))"
            twswater = Sheets("SheetNameStore").Cells(2, 5)
            twawater = -Sheets("SheetNameStore").Cells(2, 6)
        End If
    End If
End If

```

```

Else
    Sheets("SheetNameStore").Select
    Range("E2").Select
    ActiveCell.FormulaR1C1 = _
"=SQRT(POWER(R[-1]C[-2]*SIN(R[-1]C[-1]*PI()/180),2)+POWER(-R[-1]
C[1]+R[-1]C[-2]*COS(R[-1]C[-1]*PI()/180),2))"
    Range("F2").Select
    ActiveCell.FormulaR1C1 = _
"=IF(R[-1]C[-2]>=90,180-ASIN(R[-1]C[-3]/RC[-1]*SIN(R[-1]C[-2]*PI()
/180))*180/PI(),ASIN(R[-1]C[-3]/RC[-1]*SIN(R[-1]C[-2]*PI()/180))*
180/PI())"
    twswater = Sheets("SheetNameStore").Cells(2, 5)
    twawater = Sheets("SheetNameStore").Cells(2, 6)
End If
End If
Sheets("InstantaneousWindSpeed").Cells(b, 8) = twswater
Sheets("InstantaneousWindSpeed").Cells(b, 9) = twawater

'lets calculate the leeway and the difference between the true wind
Angle from a gps point of view or from a speed on water. Õ
Cellname = "$M4HDG"
c = 1
Do While Sheets(Cellname).Cells(c, 2) <> TimeFlag
    c = c + 1
    If Sheets(Cellname).Cells(c, 2) = "" Then
        Sheets("InstantaneousWindSpeed").Cells(b, 11) = "NA"
        GoTo winddifference
    Else
    End If
Loop
d = c + 1
counting = 0
If Sheets(Cellname).Cells(d, 2) = "" Then
    Exit Do
Else
End If
Do While Sheets(Cellname).Cells(d, 2) <> TimeFlag + 1
    counting = counting + 1
    d = d + 1
Loop
nbr = counting

```



```

Do While counting <> 0
  If nbr = 1 Then
    If Sheets(Cellname).Cells(d - counting, 4) = "E" Then
      magneticheading = Sheets(Cellname).Cells(d - counting,
2) + Sheets(Cellname).Cells(d - counting, 3)
    Else
      magneticheading = Sheets(Cellname).Cells(d - counting,
2) - Sheets(Cellname).Cells(d - counting, 3)
    End If
  Else
    If Sheets(Cellname).Cells(d - counting, 4) = "E" Then
      tempmagneticheading=Sheets(Cellname).Cells(d-counting,2)
+Sheets(Cellname).Cells(d-counting,3)
    Else
      tempmagneticheading=Sheets(Cellname).Cells(d-counting,2)
-Sheets(Cellname).Cells(d-counting,3)
    End If
    magneticheading = (magneticheading + tempmagneticheading)/2
  End If
  counting = counting - 1
Loop
If Sheets("InstantaneousWindSpeed").Cells(b, 11) <> "NA" Then
  Sheets("InstantaneousWindSpeed").Cells(b,11)=gpsheading-
magneticheading
Else
  End If

winddifference:
  If twagps <> "NA" Then
    If twawater <> "NA" Then
      Sheets("InstantaneousWindSpeed").Cells(b, 10) = twagps -
twawater
    Else
      Sheets("InstantaneousWindSpeed").Cells(b, 10) = "NA"
    End If
  Else
    Sheets("InstantaneousWindSpeed").Cells(b, 10) = "NA"
  End If
increment:
  b = b + 1
Loop

```

```
ThisWorkbook.Save
```

```
e = 1
Do While Sheets("SheetNameStore").Cells(e, 1) <> ""
    e = e + 1
Loop
Sheets("SheetNameStore").Cells(e, 1) = "TrueWind"
```

'Copy aws and awa choosing the best first if several to their place
Close to timeflag units of speed are in m/s and units of angles are
in degree'

```
End Sub
```

```
Sub ShipTimeResponse()
```

```
Dim Cellname, cellnameCopie, angleIncrement, test, speed, maxspeed,  
a, b, c, d, e
```

'Correction of WindSpeed. The wind speed was thought to be in m/s
but is in Miles/hour. This needs to be converted back to m/s'

```
Cellname = "SimplePolarDataBaseGPS"  
CheckSheetExistence.CheckSheetExistence Cellname  
cellnameCopie = "InstantaneousWindSpeed"
```

```
a = 1
Do While Sheets("InstantaneousWindSpeed").Cells(a, 6) <> ""
    test = Sheets("InstantaneousWindSpeed").Cells(a, 6)
    If test = "NA" Then
        GoTo nextline
    ElseIf test <= (1 / 2) Then
        Cellname = "GPSWind0ms"
        CheckSheetExistence.CheckSheetExistence Cellname
        CopieData.CopieData a, Cellname, cellnameCopie
    ElseIf test <= (3 / 2) Then
        Cellname = "GPSWind1ms"
        CheckSheetExistence.CheckSheetExistence Cellname
        CopieData.CopieData a, Cellname, cellnameCopie
    ElseIf test <= (5 / 2) Then
```

```
    Cellname = "GPSWind2ms"
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData a, Cellname, cellnameCopie
ElseIf test <= (7 / 2) Then
    Cellname = "GPSWind3ms"
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData a, Cellname, cellnameCopie
ElseIf test < (9 / 2) Then
    Cellname = "GPSWind4ms"
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData a, Cellname, cellnameCopie
ElseIf test < (11 / 2) Then
    Cellname = "GPSWind5ms"
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData a, Cellname, cellnameCopie
ElseIf test < (13 / 2) Then
    Cellname = "GPSWind6ms"
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData a, Cellname, cellnameCopie
ElseIf test < (15 / 2) Then
    Cellname = "GPSWind7ms"
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData a, Cellname, cellnameCopie
ElseIf test < (17 / 2) Then
    Cellname = "GPSWind8ms"
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData a, Cellname, cellnameCopie
ElseIf test < (19 / 2) Then
    Cellname = "GPSWind9ms"
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData a, Cellname, cellnameCopie
ElseIf test < (21 / 2) Then
    Cellname = "GPSWind10ms"
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData a, Cellname, cellnameCopie
ElseIf test < (23 / 2) Then
    Cellname = "GPSWind11ms"
    CheckSheetExistence.CheckSheetExistence Cellname
    CopieData.CopieData a, Cellname, cellnameCopie
ElseIf test < (25 / 2) Then
    Cellname = "GPSWind12ms"
```

```
        CheckSheetExistence.CheckSheetExistence Cellname
        CopieData.CopieData a, Cellname, cellnameCopie
    ElseIf test < (27 / 2) Then
        Cellname = "GPSWind13ms"
        CheckSheetExistence.CheckSheetExistence Cellname
        CopieData.CopieData a, Cellname, cellnameCopie
    ElseIf test < (29 / 2) Then
        Cellname = "GPSWind14ms"
        CheckSheetExistence.CheckSheetExistence Cellname
        CopieData.CopieData a, Cellname, cellnameCopie
    ElseIf test < (31 / 2) Then
        Cellname = "GPSWind15ms"
        CheckSheetExistence.CheckSheetExistence Cellname
        CopieData.CopieData a, Cellname, cellnameCopie
    ElseIf test < (33 / 2) Then
        Cellname = "GPSWind16ms"
        CheckSheetExistence.CheckSheetExistence Cellname
        CopieData.CopieData a, Cellname, cellnameCopie
    ElseIf test < (35 / 2) Then
        Cellname = "GPSWind17ms"
        CheckSheetExistence.CheckSheetExistence Cellname
        CopieData.CopieData a, Cellname, cellnameCopie
    ElseIf test < (37 / 2) Then
        Cellname = "GPSWind18ms"
        CheckSheetExistence.CheckSheetExistence Cellname
        CopieData.CopieData a, Cellname, cellnameCopie
    ElseIf test < (39 / 2) Then
        Cellname = "GPSWind19ms"
        CheckSheetExistence.CheckSheetExistence Cellname
        CopieData.CopieData a, Cellname, cellnameCopie
    ElseIf test < (41 / 2) Then
        Cellname = "GPSWind20ms"
        CheckSheetExistence.CheckSheetExistence Cellname
        CopieData.CopieData a, Cellname, cellnameCopie
    Else
        Cellname = "GPSWindExtremeSpeedms"
        CheckSheetExistence.CheckSheetExistence Cellname
        CopieData.CopieData a, Cellname, cellnameCopie
    End If
nextline:
a = a + 1
```

```

Loop

b = 1
angleIncrement = 10

'First, we write into the first collumn, the true angle to the wind
from 0; to 180;

c = 3
e = 0
Sheets("SimplePolarDataBaseGPS").Cells(1, 1) = "\"
Sheets("SimplePolarDataBaseGPS").Cells(2, 1) = "P-S"
Do While e < 181
    Sheets("SimplePolarDataBaseGPS").Cells(c, 1) = e
    c = c + 1
    e = e + angleIncrement / 2
Loop
a = 2
b = 0
Do While a <= 43
    Sheets("SimplePolarDataBaseGPS").Cells(1, a) = b
    Sheets("SimplePolarDataBaseGPS").Cells(1, a + 1) = b
    Sheets("SimplePolarDataBaseGPS").Cells(2, a) = "P"
    Sheets("SimplePolarDataBaseGPS").Cells(2, a + 1) = "S"
    b = b + 1
a = a + 2
Loop
Sheets("SimplePolarDataBaseGPS").Cells(1, 44) = "Ext"
Sheets("SimplePolarDataBaseGPS").Cells(1, 45) = "Ext"
Sheets("SimplePolarDataBaseGPS").Cells(2, 44) = "P"
Sheets("SimplePolarDataBaseGPS").Cells(2, 45) = "S"

'Then we need to produce a set of polar data for each wind strength
For both port and starboard

cellnameCopie = "SimplePolarDataBaseGPS"
a = 1
Do While Sheets("SheetNameStore").Cells(a, 1) <> ""
    Cellname = Sheets("SheetNameStore").Cells(a, 1)
    If Cellname = "GPSWind-0-ms" Then
        WindAngleSort Cellname, cellnameCopie, 2, 3

```

```
ElseIf Cellname = "GPSWind1ms" Then
    WindAngleSort Cellname, cellnameCopie, 4, 5
ElseIf Cellname = "GPSWind2ms" Then
    WindAngleSort Cellname, cellnameCopie, 6, 7
ElseIf Cellname = "GPSWind3ms" Then
    WindAngleSort Cellname, cellnameCopie, 8, 9
ElseIf Cellname = "GPSWind4ms" Then
    WindAngleSort Cellname, cellnameCopie, 10, 11
ElseIf Cellname = "GPSWind5ms" Then
    WindAngleSort Cellname, cellnameCopie, 12, 13
ElseIf Cellname = "GPSWind6ms" Then
    WindAngleSort Cellname, cellnameCopie, 14, 15
ElseIf Cellname = "GPSWind7ms" Then
    WindAngleSort Cellname, cellnameCopie, 16, 17
ElseIf Cellname = "GPSWind8ms" Then
    WindAngleSort Cellname, cellnameCopie, 18, 19
ElseIf Cellname = "GPSWind9ms" Then
    WindAngleSort Cellname, cellnameCopie, 20, 21
ElseIf Cellname = "GPSWind10ms" Then
    WindAngleSort Cellname, cellnameCopie, 22, 23
ElseIf Cellname = "GPSWind11ms" Then
    WindAngleSort Cellname, cellnameCopie, 24, 25
ElseIf Cellname = "GPSWind12ms" Then
    WindAngleSort Cellname, cellnameCopie, 26, 27
ElseIf Cellname = "GPSWind13ms" Then
    WindAngleSort Cellname, cellnameCopie, 28, 29
ElseIf Cellname = "GPSWind14ms" Then
    WindAngleSort Cellname, cellnameCopie, 30, 31
ElseIf Cellname = "GPSWind15ms" Then
    WindAngleSort Cellname, cellnameCopie, 32, 33
ElseIf Cellname = "GPSWind16ms" Then
    WindAngleSort Cellname, cellnameCopie, 34, 35
ElseIf Cellname = "GPSWind17ms" Then
    WindAngleSort Cellname, cellnameCopie, 36, 37
ElseIf Cellname = "GPSWind18ms" Then
    WindAngleSort Cellname, cellnameCopie, 38, 39
ElseIf Cellname = "GPSWind19ms" Then
    WindAngleSort Cellname, cellnameCopie, 40, 41
ElseIf Cellname = "GPSWind20ms" Then
    WindAngleSort Cellname, cellnameCopie, 42, 43
ElseIf Cellname = "GPSWindExtremeSpeedms" Then
```

```

        WindAngleSort Cellname, cellnameCopie, 44, 45
    Else
    End If
a = a + 1
Loop

ThisWorkbook.Save

e = 1
Do While Sheets("SheetNameStore").Cells(e, 1) <> ""
    e = e + 1
Loop
Sheets("SheetNameStore").Cells(e, 1) = "TimeResponse"

End Sub

Sub ProducePolarPlot()

'write in a new sheet the figures in terms of Xs and Ys instead of
Speed and angle.

Dim a, b, c, d, e, f, inc, Cellname, CopieCellname, x, y, angle

CopieCellname = "PolarPlot"
Cellname = "SimplePolarDataBaseGPS"
CheckSheetExistence.CheckSheetExistence CopieCellname

a = 2
Do While Sheets(Cellname).Cells(1, a) <> ""
    If Sheets(Cellname).Cells(1, a) = "Ext" Then
        inc = Sheets(Cellname).Cells(1, a - 2)
        inc = inc + 1
    Else
        inc = Sheets(Cellname).Cells(1, a)
    End If
    b = 1
    Do While b < 5
        Sheets(CopieCellname).Cells(1,inc*4+b)=Sheets(Cellname).Cells(1,a)
        b = b + 1
    Loop
    a = a + 2

```

Loop

```

a = 1
Do While Sheets(CopieCellname).Cells(1, a) <> ""
  If a = 1 Then
    Sheets(CopieCellname).Cells(2, a) = "Px"
    a = a + 1
    Sheets(CopieCellname).Cells(2, a) = "Py"
    a = a + 1
    Sheets(CopieCellname).Cells(2, a) = "Sx"
    a = a + 1
    Sheets(CopieCellname).Cells(2, a) = "Sy"
  ElseIf Sheets(CopieCellname).Cells(1,a+1)=Sheets(CopieCellname).
Cells(1,a) Then
    a = a + 1
  Else
    a = a + 1
    Sheets(CopieCellname).Cells(2, a) = "Px"
    a = a + 1
    Sheets(CopieCellname).Cells(2, a) = "Py"
    a = a + 1
    Sheets(CopieCellname).Cells(2, a) = "Sx"
    a = a + 1
    Sheets(CopieCellname).Cells(2, a) = "Sy"
  End If
Loop

```

```

a = 3
Do While Sheets(Cellname).Cells(a, 1) <> ""
  b = 2
  Do While Sheets(Cellname).Cells(1, b) <> ""
    If Sheets(Cellname).Cells(1, b + 1) = Sheets(Cellname).
Cells(1, b) Then
      c = 1
      Do While Sheets(CopieCellname).Cells(1,c)<>Sheets(Cellname)
.Cells(1,b)
        c = c + 1
        If Sheets(CopieCellname).Cells(1, c) = "" Then
          Exit Do
        Else
          End If
    End If
  End If

```



```

        Loop
        Sheets("SheetNameStore").Cells(4,3)=90-Sheets(Cellname).
Cells(a,1)
        Sheets("SheetNameStore").Cells(4,4)=Sheets(Cellname).
Cells(a,b)
        Sheets("SheetNameStore").Cells(4,5)=Sheets(Cellname).
Cells(a,b+1)
        Sheets("SheetNameStore").Select
        Range("C5").Select
        ActiveCell.FormulaR1C1 = _
            "=R[-1]C[1]*COS(R[-1]C*PI()/180)"
        Range("D5").Select
        ActiveCell.FormulaR1C1 = _
            "=R[-1]C*SIN(R[-1]C[-1]*PI()/180)"
        Range("E5").Select
        ActiveCell.FormulaR1C1 = _
            "=R[-1]C*COS(R[-1]C[-2]*PI()/180)"
        Range("F5").Select
        ActiveCell.FormulaR1C1 = _
            "=R[-1]C[-1]*SIN(R[-1]C[-3]*PI()/180)"
        Sheets(CopieCellname).Cells(a,c)=Sheets("SheetNameStore").
Cells(5,3)
        Sheets(CopieCellname).Cells(a,c+1)=Sheets("SheetNameStore")
.Cells(5,4)
        Sheets(CopieCellname).Cells(a,c+2)=Sheets("SheetNameStore")
.Cells(5,5)
        Sheets(CopieCellname).Cells(a,c+3)=Sheets("SheetNameStore")
.Cells(5,6)
        Else
            b = b - 1
        End If
        b = b + 2
    Loop
a = a + 1
Loop

ThisWorkbook.Save

e = 1
Do While Sheets("SheetNameStore").Cells(e, 1) <> ""
    e = e + 1

```

```

Loop
Sheets("SheetNameStore").Cells(e, 1) = "PolarPlot"

End Sub

Sub WindAngleSort(Cellname, CopieCellname, collumnport,
collumnstarboard)

Dim a, b, c, d, angle, speed, maxspeed

a = 1
Do While Sheets(Cellname).Cells(a, 7) <> ""
  If Sheets(Cellname).Cells(a, 7) < 0 Then
    angle = -5 / 2
    b = 0
    Do While Sheets(Cellname).Cells(a, 7) < angle + b
      c = Abs(b)
      If angle + b < -185 Then
        Exit Do
      Else
        b = b - 5
      End If
    Loop
    d = 3
    Do While Sheets(CopieCellname).Cells(d, 1) <> c
      d = d + 1
      If Sheets(CopieCellname).Cells(d, 1) = "" Then
        Exit Do
      Else
        End If
    Loop
    If Sheets(CopieCellname).Cells(d, collumnport) = "" Then
      maxspeed = 0
    Else
      maxspeed = Sheets(CopieCellname).Cells(d, collumnport)
    End If
    speed = Sheets(Cellname).Cells(a, 4)
    If speed > maxspeed Then
      Sheets(CopieCellname).Cells(d, collumnport) = speed
    Else
      End If
  End If

```

```
Else
    angle = 5 / 2
    b = 0
    Do While Sheets(Cellname).Cells(a, 7) < angle + b
        c = Abs(b)
        If angle + b > 185 Then
            Exit Do
        Else
            b = b + 5
        End If
    Loop
    d = 3
    Do While Sheets(CopieCellname).Cells(d, 1) <> c
        d = d + 1
        If Sheets(CopieCellname).Cells(d, 1) = "" Then
            Exit Do
        Else
            End If
    Loop
    If Sheets(CopieCellname).Cells(d, collumnstarboard) = "" Then
        maxspeed = 0
    Else
        maxspeed = Sheets(CopieCellname).Cells(d, collumnstarboard)
    End If
    speed = Sheets(Cellname).Cells(a, 4)
    If speed > maxspeed Then
        Sheets(CopieCellname).Cells(d, collumnstarboard) = speed
    Else
        End If
    End If
a = a + 1
Loop
End Sub
```


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