

Multiple Applications of Sailing Simulation

Mr John MOONEY;

Virtual Sailing Pty Ltd

johnmooney@virtual.net.au

Prof. Norman R. SAUNDERS

University of Melbourne & Virtual Sailing Pty Ltd

n.saunders@unimelb.edu.au

Dr. Mark HABGOOD

University of Melbourne & Virtual Sailing Pty Ltd

mhabgood@unimelb.edu.au

Dr. Jonathan R. BINNS

Australian Maritime College, University of Tasmania

& Virtual Sailing Pty Ltd

j.binns@amc.edu.au

Abstract. The world's only ride-on sailing simulator has been produced by the Australian company Virtual Sailing (VS) for 10 years. Over this period significant research and development has occurred. On-going R&D is incorporated into new and retro-fitted to old simulators. During this time a number of users have owned and operated the VS-Laser, VSail-Trainer, VSail-Access and VSail-Researcher simulators showing the way for a variety of uses.

The initial intention of the VSail-Trainer was for fitness training and physiological evaluation of elite athletes. This has shown promise with four sailors at the recent Olympics using and praising the simulator as a useful tool for fitness training and tactics and strategy development. The VSail-Researcher has been integrated into the undergraduate engineering course at the AMC to demonstrate the basic principles of sailing and simulation. As a rehabilitation tool the VSail-Access simulator has been used to introduce disabled people to sailing and reintroduce sailors post accident (in Melbourne, Sydney, Miami and Auckland). A recent virtual regatta was organised by VS with participants from Australia and the USA.

The area showing the greatest numbers of participants is in learning to sail. Programs have been started within Australia for pre-teenagers through to university age students to learn to sail for the first time, adding simulation to the more traditional learning methodologies. The use of simulation in this area shows great promise for increasing participation and retention rates for the sailing industry as a whole.



Figure 1 The VSail-Researcher sailing simulation classroom

1. INTRODUCTION

Sailing simulation has been used for the analysis of tacking (Masuyama, Fukasawa, & Sasagawa, 1995), handicap assessment (Keuning, Vermeulen, & deRidder, 2005); design optimisation of engineering and human systems (Philpott & Mason, 2002; Scarponi,

Shenoi, Turnock, & Conti, 2006); and prediction of starting manoeuvres (Binns, Hochkirch, DeBord, & Burns, 2008). Simulation as a laboratory tool has been used in sailing for at least twenty years (Bursztyn, Coleman, Hale, & Harrison, 1988; Walls & Saunders, 1995) continuing to the present day (Cunningham & Hale, 2007) and more recently generalised sail training is making use of simulation (Binns, Bethwaite, & Saunders, 2002). Each of these applications requires varying degrees of accuracy in the predicted parameters. This paper describes the application of the simulation detailed in Binns, et al. (2002) to the areas of training, engineering education and novice learning exercises.

2. THE UNDERLYING SIMULATION

The physical simulation has been achieved through an explicit Euler time stepping procedure. From a numerical stability point of view this is a fairly clumsy method, as time steps of greater than 0.1 s result in serious instabilities. However, it does provide a consistent method across a wide variety of computing power and advances in computing power are immediately realised without the need for re-

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programming. This method also explicitly ties the simulation to real time.

To maintain a small time step the sailing simulation has been simplified. Details of the simplified characteristics of the three dinghy classes used in the simulation can be found in (Binns et al., 2002). Sailing a real dinghy safely and efficiently is related more to feel than it is to thinking about the complex system of forces and moments required to move the dinghy forward. Therefore the limiting factor in simplifying the physics of a sailing dinghy is that the feel of the simulation must remain sufficiently close to a real dinghy, otherwise the illusion of sailing is lost to the user, and the simulator is little more than a hiking bench. A quasi-dynamic measure of this feel can be made both on-water and on the simulator. Essentially, this method of analysis involves setting a wind angle relative to the dinghy's heading and sailing the dinghy as fast as possible at that heading. Reasons for some discrepancies between the model and full scale are discussed in Binns, et al. (2002); however, it should be noted that these discrepancies do not upset the feel of the simulator. A dynamic measure of the feel of a sailing dinghy has been made by considering the time to complete a tack. In the simplified simulation model the added mass and damping of the hull was essentially lumped into a few parameters. Realistic limits were placed on these lumped terms and users were allowed to vary the parameters within these realistic limits. Based on the variations suggested, these parameters were non-dimensionalised and hence applied to all dinghies permitted by the software.

3. OLYMPIC SAIL TRAINING

Through experience with the Victorian state youth squad, it has become apparent that a sailing simulator will be a valuable tool for studying and correcting hiking posture. A sailing dinghy creates forces to counteract hydrodynamic drag with a complicated force and moment balance. The essential parts of the heel moment balance are shown in the free body diagram of Figure 2. There is a large aerodynamic side force from the sail, which is balanced by a hydrodynamic side force from the centreboard and rudder. Since some distance offsets the aerodynamic and hydrodynamic forces, a moment is created. This moment is balanced by the centre of gravity of the sailor's mass being offset from the buoyancy force. The success of a competitive dinghy sailor is greatly influenced by the consistency and size of the balancing heel moment that they are able to produce; that is the further they are able to sit (hike) from the centreline of the boat and the longer they can hold this position. This means that a sailor's success is highly influenced by their ability to hold a strenuous position for long periods of time. As a consequence of the stresses involved, back pain appears to be quite common in competitive dinghy sailors, especially in Lasers.

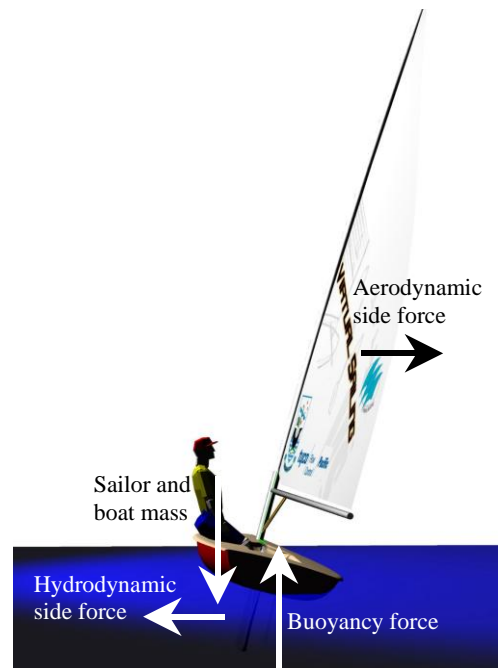


Figure 2 Simplified free body diagram of a dinghy sailing to windward, showing the main components of the heel moment balance.



Figure 3 The hiking posture. Laser dinghies are well known for producing back injuries in competitive sailors. Top image is pre-remedial posture; bottom is post-remedial following physiotherapy advice. The ability to take photos such as these for later analysis is unique to the sailing simulator (reproduced with permission of the Olympic sailor, Krystal Weir).

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It should be considered unacceptable for young people to injure themselves through sailing with inadequate hiking posture. The top female Australian Junior Laser Radial sailor was out of sailing for several months at the beginning of 2003, because of stress fractures in her vertebrae. Figure 3 shows this sailor's hiking posture before her back injury (top) and after re-education by her coach and physiotherapist (bottom). The ability to take pictures for analysis such as these is unique to the sailing simulator. To take these during on-water training sessions would be extremely expensive and time consuming. Such data collection would be impossible if reproducible conditions were required. It is now planned to carry out a study of hiking posture in the Victorian Youth squad, using a Virtual Sailing simulator.

The sailor mentioned in the previous paragraph has gone on to compete in the open classes of the Olympics, representing Australia in the Yngling class at the 2008 Olympics. Three additional athletes competed at these Olympics who have used the simulator, one Spanish competitor has purchased a unit for her sail training school.

4. ENGINEERING EDUCATION

4.1 Introduction

Sailing yacht design is taught at the Australian Maritime College (AMC) as an elective in the fourth year of the Bachelor of Engineering degree. The design of a sailing yacht is necessarily dominated by a number of engineering approximations due to the complexity of the force balance at the air/water interface (Claughton, 1998). Each of the approximations alluded to has definite physical meaning, which must be understood by an engineer engaged to design a sailing yacht. An example of such an approximation is the effective aspect ratio of the underwater appendages, which can be equated to the efficiency of the planform (Houghton & Brock, 1970).

The VSail-Researcher (see Figure 1) was used to demonstrate and actively involve the students in the effects of altering the underlying simulation parameters. In addition the process demonstrated to the students the difficulties of performing and analysing experiments on a sailing yacht.

4.2 Participants

Seven final year BE students were divided into 3 groups.

4.3 Protocol

Each group was requested to analyse the available simulation parameters and estimate changes to the parameters which would produce a simulation sailing quicker than the original set. Changes were only permitted on the boat side of the simulation, changes to environmental conditions were not permitted.

Each group was then required to nominate one member to be the sailor. The sailor was permitted to practice on the simulator for 5 minutes. This allowed the sailor to get accustomed to the simulator without overly tiring him/her.

The sailor then performed a race using the original simulation parameters. The length of the race typically takes two to three minutes.

Finally a second race was performed by the sailor of each group during which the simulation parameters were altered to those selected by the group.

4.4 Results

The design parameter changes selected by the three groups are listed in Table 1. To understand these changes a summary of the force and moment balance of a sailing yacht follows.

A sailing yacht is able to progress through the water due to the lifting surface of the sail (aerodynamic forces) balancing with the lifting surfaces of the underwater appendages, or rudder and centerboard (hydrodynamic forces). As these surfaces are acting as wings, the forces can be easily increased by increasing the surface area. However, the aerodynamic and hydrodynamic forces are separated by some distance, creating an overturning moment. Therefore to keep the yacht sailing in a straight line, a significant righting moment is required. The speed of the yacht is therefore highly dependent on the size of the sails, rudder and centerboard and the available righting moment. The parameters selected by the students in Table 1 show an attempt by each group to increase the aerodynamic and hydrodynamic forces.

Table 1 Design parameter shifts selected by the three groups

Group	Parameter Change Summary
One	<ul style="list-style-type: none"> • Sail area increased by 99% • Centreboard area increased by 127% • Righting moment increased by 100%
Two	<ul style="list-style-type: none"> • Centreboard effective aspect ratio increased by 64%
Three	<ul style="list-style-type: none"> • Sail area increased by 14% • Sail effective aspect ratio increased by 6% • Centreboard area increased by 27% • Centreboard aspect ratio increased by 125%

The results of the test simulations were analysed by examining the recorded results of the first 36 seconds of sailing into the wind. During this time the performance of the simulation was assessed by calculating the distance travelled into the wind and dividing by the time taken (36 s). This provides an immediate assessment for a Velocity Made Good (VMG) into the direction of

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the wind. The results of this analysis are presented in Table 2, for which an increase in VMG shows an improvement in sailing performance.

Table 2 Velocity Made Good (VMG) for each design group

Group	VMG before change	VMG after change
One	62.6 m/min	N/A
Two	56.8 m/min	72.8 m/min
Three	77.7 m/min	88.4 m/min

4.5 Discussion

Within Table 2 the first result of note was that Group One was unable to record a result after the suggested design parameter modifications. This was because after the modifications were made the simulation was far too difficult to sail. The instabilities introduced in the heel rotation were much too difficult even for an author of this paper, with some 6 years of sailing simulation experience and over 20 years of competitive sailing experience to overcome. It is believed that this has occurred because the stiffness of the system in heel (the righting moment) has been substantially increased along with the excitation forces (aero and hydrodynamic lifting surface forces), however the damping has not been significantly increased. Therefore the damping ratio has been significantly decreased. In addition to this there was no attempt by Group One to increase the efficiency of the system, instead the total power available has been increased independent of efficiency. These two lessons were easily demonstrated in the sailing simulator classroom.

The results of Group Two and Three show a significant increase in VMG when the design parameter modifications were made. An increase in VMG can be directly correlated to improved sailing performance. These two groups achieved the improvement in performance by increasing the efficiency of the aero and hydrodynamic lifting surfaces. Which group succeeded the most is inconclusive based on these results, as a statistical measure would need to be estimated. This is the final lesson to be learnt by the students through simulation: even under the perfectly controlled environment of the sailing simulator, the human influence can cloud design assessment and require probabilistically based experimental procedures.

The lessons of dynamic stability; aero and hydrodynamic efficiency; and probabilistic requirements of experiments involving human interaction are all lucidly and repeatable demonstrable using simulation. If environmental factors were added, then these engineering elements could not be isolated, in addition to an explosion in cost of this teaching exercise.

5. DISABLED SAIL TRAINING

Virtual Sailing invited three rehabilitation centres, who use VSail-Access simulators in their rehabilitation programs to participate in a "Virtual Regatta" as a tribute to the Paralympics. The "Virtual Regatta" provided a means to bring the scattered VSail-Access simulators together.

A set of Sailing Instructions was drawn up and the challenge issued to: Royal Talbot Rehabilitation Hospital (Melbourne, Australia); Royal Rehabilitation Hospital (Sydney, Australia); and SALM (Miami, Florida, USA).

Although it is possible to run the regatta live by linking the VSail simulators together on-line, it was decided to allow a two week window for each institution to enter their best times. The regatta was sailed around a trapezoid course in Liberty Motor Sailor boats with 14 knots of wind. Each sailor was able to sail the course three times and register their best time. The best time overall won the trophy for their institution.

Royal Rehabilitation (Sydney) were the first to submit their race times by their sailors Dale Williams a Sydney Sailability sailor and Phil Thompson a well known Sydney offshore sailor. The times were competitive but not good enough to stave off Royal Talbot represented by Frank Kleintz, who had previously sailed a Hobie 16 on the Gippsland Lakes before his accident 5 months ago. Frank had a faster time and he took the lead. At Virtual Sailing we nervously awaited the American entry from SALM. It did not go un-noticed that during the month of the regatta the 25th anniversary of the historic Australian victory in the America's Cup occurred. However, as with on water sailing, the weather played havoc with SALM and they battened down the hatches for a hurricane and were unable to submit a race result within the time limit. They have promised to mount an America's Cup style challenge for the next international challenge.



Figure 4 The VSail-Access simulator being used in the Virtual Regatta

6. ABLE-BODIED NOVICE SAIL LEARNING

A VS2 Laser (the predecessor to the VSail-Trainer pictured in **Figure 5**) simulator was used in a 2 day

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"Learn to sail" course for children at the Sandy Bay Sailing Club in Tasmania in December 2002. Twenty one of about 30 children (age range 8–14) had instruction on the simulator before going on the water in Optimist dinghies. The coaches reported that of the children who had been on the simulator, all of the girls and boys over 10 years old were more confident and learned on-water skill more rapidly than those who had not been on the simulator or boys 10 and under. The problems experienced with these younger boys both on-water and on the simulator appeared to relate to a short attention span.

In 2008, a school based instructional program was organized for 12 students (Year 8) from Laverton High School, Victoria using a VS-2 Laser simulator based at Altona Yacht Club, Victoria and a V-Sail Trainer at the new Yachting Victoria sail training centre at the Boatshed on Albert Park Lake, Melbourne. Lessons were organised by one of the authors assisted by two members of Altona YC. The students participated in half a dozen lessons in groups of 3-4, after which their simulator performance was assessed by Olympian Sarah Blanck (Figure 5) and they had the opportunity to sail on Albert Park Lake in a variety of sailing dinghies. Unpredicted side effects were that the students' self esteem and attitude to school work were reported by their teachers to have improved considerably and the previous high incidence of truancy fell to zero.

A trial was completed in the University of Melbourne in which 30 novice sailors were assigned randomly to two programs: (1) A standard instructional program involving an initial theoretical session followed by a simple introduction to on-water experience in Lasers or a Tasar under the supervision of coaches. (2) A simulator course in which groups of 5-6 students attended 6 evening classes involving instruction on a simulator. After this the simulator students were introduced to sailing on the water (in Lasers and a Tasar). A formal comparison of on-water performance by both groups was not completed due to time constraints; however some clear differences between the groups were apparent. In the simulator group 4 students were lost from one subgroup after the first evening class, in favour of other student pursuits. The other 11 completed the course and went sailing. They persisted with on-water sailing in spite of some difficult weather conditions, which involved several of the students capsizing. The coaches reported that all 11 students could beat, tack and sit out (hike) without difficulty. In contrast 8 of the on-water group gave up and the rest had considerably more difficulty than the simulator group in learning elementary boat handling skills. From this preliminary study a drop-out rate of 53% for the non-simulator group was strikingly different to 27% for the simulator group. Also, it has been reported that two of the simulator group were able to sail unaccompanied; at the same point in lessons none of the non-simulator group were able to do this.



Figure 5 The VSail-Trainer being used to introduce school children to sailing

7. CONCLUSIONS

The application of sailing simulation to solving problems has been growing through the work of a number of different groups worldwide. This paper has reported on four applications of a sailing simulator built in Australia.

Firstly the simulation has found application for elite sailing athletes. This application has been for physiological based research and remedial physiotherapy advice as well as for training.

A second area of application is to engineering education. For this application student educational experiences are greatly enhanced through simulation. Engineering education dictates that students are required to understand the principles of aerodynamics, hydrodynamics and dynamic systems as they apply their engineering skills to the design and construction of sailing vessels. As a repeatable and realisable representation of real world dynamics in the class room, simulation is unsurpassed. As the VS simulator engine is based on first principles engineering, students are able to gain immediate insight about design alterations such as foil shape changes and stability increases.

The third application described within this paper is to disabled sail training. For this purpose simulation offers a safe and comfortable introduction to sailing. The repeatable and recordable nature of simulation has been used to involve disparate institutions in the same competition.

Finally, the application of simulation to beginner sail training has been explored through programs involving pre-teenager children through to university aged students. For this last application evidence is emerging that simulation combined with actual on-water training can increase retention rates of new participants for sailing, as well as having some unexpected positive personal consequences in socially disadvantaged children.

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