Çekme Tankı Deneyleri ve Hesaplamalı Akışkanlar Dinamiği Yöntemleri Kullanılarak Bir Sekiz Tek Yarış Teknesinin Trim Optimizasyonu

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Özet

Uluslararası ve Olimpik kürek yarışmalarında kullanılan yüksek performanslı yarış teknelerinin uzunluğu ve genişliği yıllar içerisinde biraz değişmiş olsa da gövde formları büyük ölçüde aynı kalmıştır. Bu konudaki çalışmaların çoğunluğu kürek tekniğinin biyomekaniğini ve küreklerin sudaki etkinliğini araştırmıştır. Bununla birlikte tekne formuna ve tekne hızına bağlı olarak ağırlık dağılımı açısından optimal araştırma eksikliği vardır. Birçok kürek yarışı bir saniyeden daha az farkla kazanılmaktadir. Bu sebepten dolayi, bu çalışmada deneysel ve Hesaplamalı Akışkanlar Dinamiği (HAD) yöntemlerini kullanarak bir sekiz tek yarış teknesinin 2000 m'lik yarışa en uygun trimini araştırmayı hedeflemiştir. Sayısal bir model üretilirek doğruluğunu değerlendirmek için model testlerle karşılaştırılmıştır. Model teknenin trim optimizasyonu ortalama bir yarış hızda gerçekleştirilmiş ve gerçek olan, kürek çekme hareketine bağlı değişen tekne hızları hariç tutulmuştur. Sonuçlar, referans ağırlık dağılımı ile (sıfır trim durumu) karşılaştırıldığında direncin azalmasını ortaya koymakla birlikte sporcuların aynı hızı korumak için yapması gereken çabadaki değişikliği de göstermektedir.

Anahtar kelimeler: Kurek yaris teknesi, trim optimizasyonu, çekme tankı, hesaplamalı akışkanlar dinamiği

A Trim Optimisation of an Eights Racing Shell using Towing Tank and Computational Fluid Dynamics Methods

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Abstract

High performance racing shells for international and Olympic rowing competitions over the years have varied slightly in length and breadth but have largely remained a very similar hull shape. Majority of studies have explored the biomechanics of rowing technique and the effectiveness of the oars through the water. There is still a lack of research into the optimal shell form and operation condition in terms of weight distribution. Given that many rowing races are won by less than a second. Therefore, the aim of this paper is to use experimental and Computational Fluid Dynamics (CFD) methods to investigate the optimal trim for an eights racing shell over a 2000m race. A computational model is produced and compared with model tests to assess its accuracy. Trim optimization of the model shell was performed at an average speed and the varying velocities of realistic rowing motion were excluded. Comparing the results with the reference result (zero trim condition) reveals the reduction in resistance obtained and hence demonstrate the difference in the effort the crew would have to make to maintain the same speed.

Keywords: Rowing shell, trim optimization, towing tank, computational fluid dynamics

1. Introduction

Rowing has been on the Olympic programme from the beginning in 1896. It is such a competitive sport even the difference between winners and runner-up can be split second. To improve the boat speed researchers have been focused on rowers' performance, biomechanics, displacement, weight distribution (sitting position), rigging, foot-stretcher set-up and shell form (Barrett and Manning, 2004, Buckeridge, Weinert-Aplin et al., 2016). The surrounding domain of the racing shell, such as water depth, is also important of factor effects the boat dynamics (Day et al., 2011).

Performance of rowers may be variable from race to race. However, studies showed that elite athletes, i.e. international and Olympic rowers, have quite a consistency and similar performance. This variability for the rowers is only ~1% in finish times (Smith and Hopkins, 2012).

An eights racing shell is a boat for eight rowers who propel the boat and a coxswain who steers. The boat is installed with outriggers and a small fin to improve course keeping. Eights racing shells for a competition have a long sleek shape with a length to beam ration of around 30 and U form midbody (Empacher 2018, Filippi 2018, Hudson 2018). To protect fairness and equality of opportunity Fédération Internationale des Sociétés d'Aviron's (FISA, 2015) imposed appropriate requirements which restricted the boat design (FISA, 2015).

Having similar athlete performance, limited design parameter of the racing boat shell and other equipment lead this study to investigate the effect of the trim on the boat speed. It is a simple variant to alter by changing the sitting order of rowers who have different weights (Hodge, 2016). The main objective of this paper is to optimize the trim to maximize speed. In order to identify optimal trim in still water with confidence experimental and numerical approach were used. The boat displacement is primarily depended on the crew weight category. Heaving light or heavyweight crew might differ the effect of trim on boat speed (Weitao et al., 2007). In the study, the Newcastle University's Rowing Club heavyweight crew was chosen. Finally, the relationship between trim and boat performance is presented.

2. Methodology

2.1. Problem definition and the geometry

The target crew was chosen as the Newcastle University eights racing team. Table 1 shows the weight distribution of the crew. The position 1 is the bow rower and 8 is stern rower. In an eights racing shell coxswain sits at the stern facing onto the rowers.

Table 1. Rower's position and weights

Position	**Weight (kg)**
1 (Bow)	80
2	85
3	95
4	95
5	95
6	95
7	85
8 (Stroke)	90
Cox	55

Scaled model test in a towing tank and computational fluid dynamic methods were used to optimize the trim of the boat. A scale factor of 5.69 model eights racing shell was chosen as the target boat. Main properties of the model are given in Table 2. The 3D view of the model and the sections are given in Figure 1.

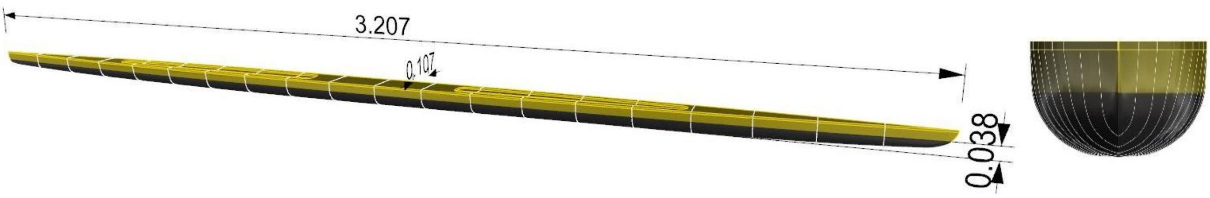

Fig. 1. The 3D view and the sections of the model.

Table 2. Main properties of model eights racing shell

Parameter	Model
Length m	3.207
Breadth m	0.107
Draught m	0.038
Displacement kg	6.183

The trim angle was varied between -0.5 and 2.0 º. Negative trim angles indicate the trim by bow and the positive angles indicate trim by stern. The change in trim is then calculated using Equation 1.

$$\Delta \mathrm{Trim} = \frac{\text{mass x 9.81 x distance moved}}{\mathrm{MCT}_{1\mathrm{cm}}} \tag{1}$$

2.1. Experimental setup

The model testing was carried out in the towing tank of School of Marine Sciences and Technology Newcastle University. 3.2 m model had a turbulence simulator at station 9.5. Figure 2 shows the model shell in the Newcastle University's towing tank. The tank is 37 m long, 3.75m wide with water depth 1.2m. The system can operate with a maximum speed of 3 m/s. A dynamometer is attached to the monorail. Gifford dynamometer consists of 4 strain gauges 2 of them for port and starboard resistance components; 2 of them for measuring fore and aft side of the forces. Pitch and heave motions are measured from potentiometers and connected to data acquisition system on the carriage. Data was recorded for 10 seconds at 100 Hz.

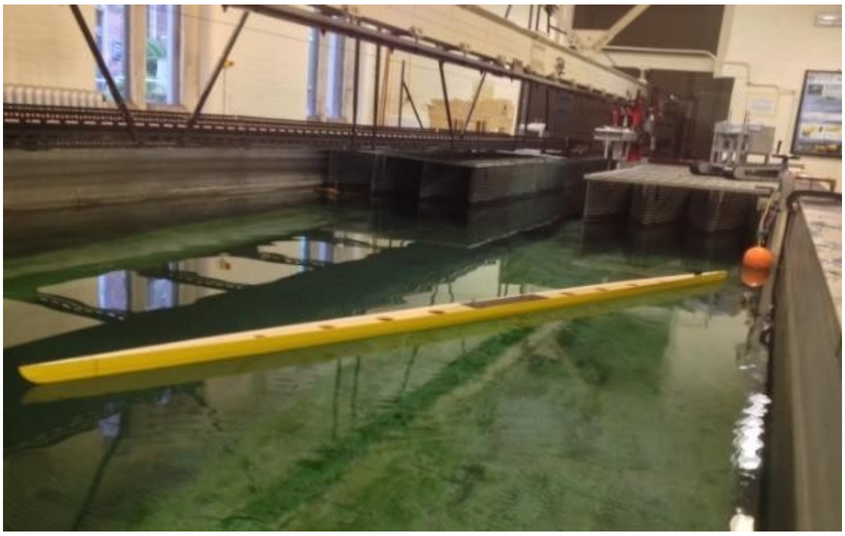

Fig. 2. The model in the Newcastle University Towing Tank.

The operation speeds are given in Table 3. The model was towed without simulating any motion (i.e. surge, pitch, and heave) which occurs due to the rowing action. Such a test rig would be realistic (Day et al., 2011). Having limited towing length and data collecting time would not allow capturing enough stroke. The average stroke for an eight in a race is around 41 (1/min). There was also a risk to bring uncertainty into the force measurements due to oscillation.

Table 3. The model and the full scale speeds

Model speed (m/s)	Full scale speed (m/s)
1.72	4.1
1.94	4.63
2.15	5.14
2.37	5.66
2.59	6.17
2.8	6.69

2.2. Numerical setup

The RANS solver was used to define the flow. κ-ω turbulence model is chosen for the effect of turbulence on the fluid. The number of the phases was chosen as multiphase flow (water and air). Trimmer mesh, prismatic boundary layers are created for two regions. The numerical mesh created for this study is given in Figure 3. In general, grid points are grouped around the hull and calm water plane to provide adequate resolution at the free surface interface. The total number of cells was approximately 2.2 million. The numerical model of the shell was simulated for fix trim and sinkage to reduce the converging time.

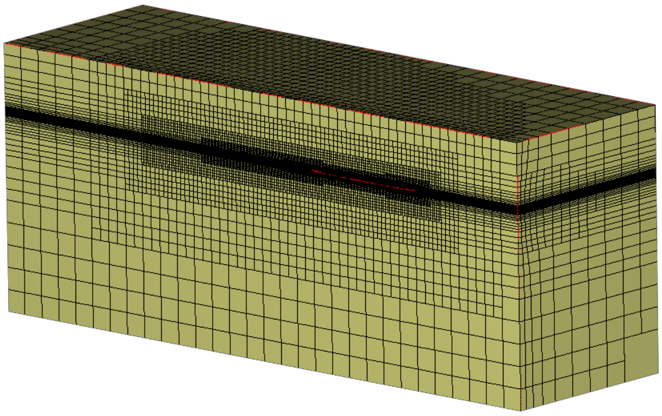

Fig. 3. The general view of the domain and the mesh structure.

3. Results and discussion

Figure 4 shows the towing resistance at the zero-trim condition which is accepted as a reference point to be able to compare with the other trim conditions (Hodge, 2016).

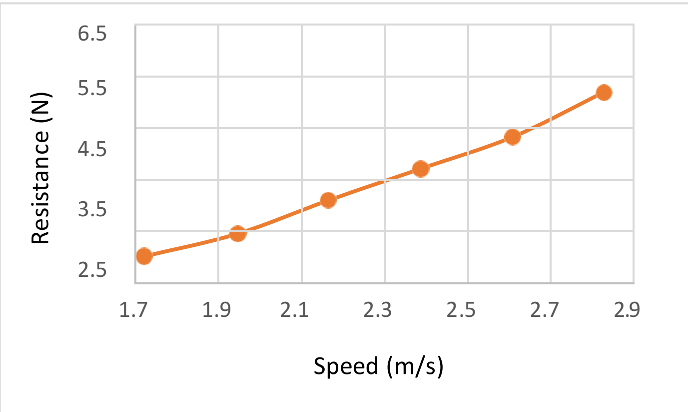

Fig. 4. Model speed vs. resistance.

Figure 5 shows the towing resistance of the model at different trim and speed. In full scale, 5.65 m/s is likely the average speed most of the crew reaches along the 2000m race course. Thus, the model was towed for extra trim to look at the detailed results. The resistance is decreasing at 0.5 º trim for the speeds from 2.15 to 2.8 m/s. Curves are a fitted second-degree polynomial for 2.37, 2.59 and 2.8 m/s.

The hydrodynamic performance of the boat starting to show a different trend at 2.15 m/s. The resistance could be better described by a linear curve at those low speeds 1.72 and 1.94.

The cylinder thin form of the shell generated very low drag. Therefore, a bias was caused by low drag due to towing a boat at the low end of the dynamometer’s range. An electrical background noise on the data acquisition system contributed to around 10% of the overall resistance (Adam, 2016).

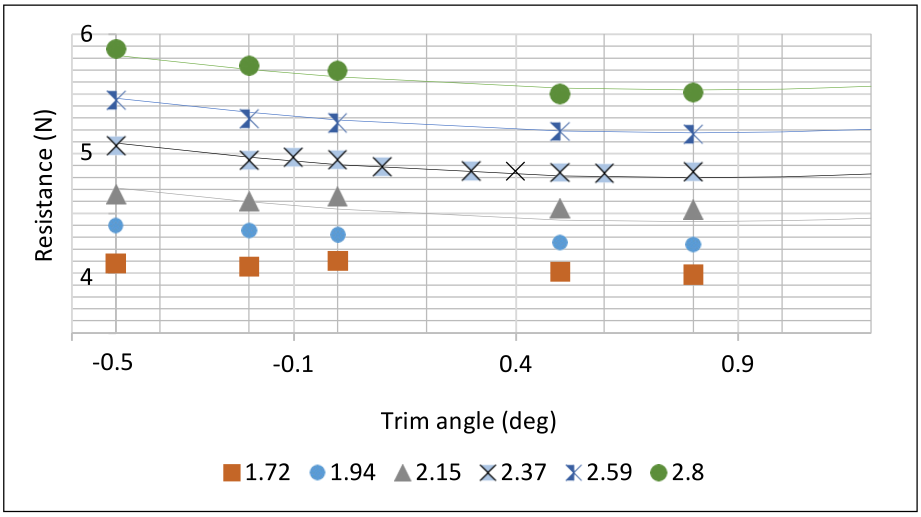

Fig. 5. Results from the towing tank: Resistance of the rowing eight's shell at various speed and trim.

The CFD results are plotted in Figure 6. As it can be seen from the figure, the resistance from the CFD simulation is lower the towing tank results. Nevertheless, there is a resistance reduction around zero trim.

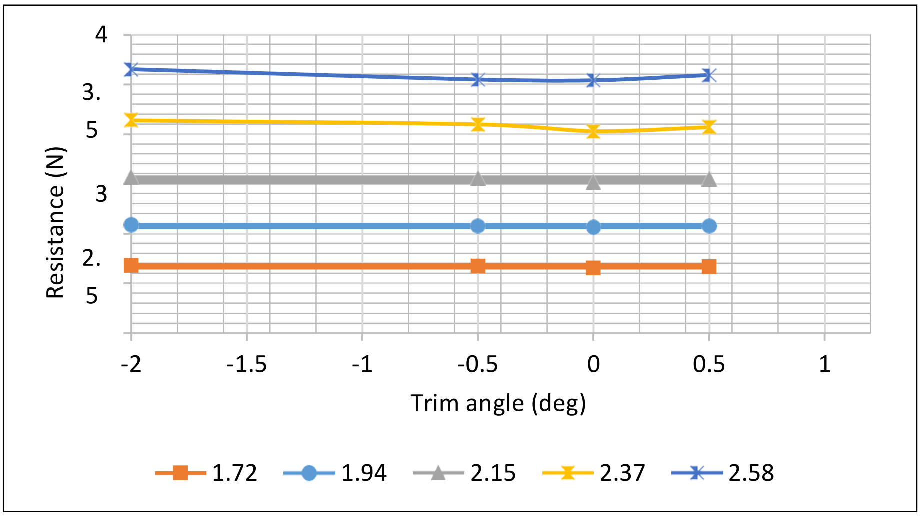

Fig. 6. Results from the CFD: Resistance of the rowing eight's shell at various speed and trim.

The mass fraction and global wave pattern around the hull were given in Figure 7 and 8, respectively. Looking at Figure 8, it is apparent low the wave height (m) is generated by the boat. That means the frictional forces dominating, as expected, at speeds lower than 2.15m/s. It is also apparent from Figure 5 and 6 that trim has almost no contribution to the boat performance below 2.15 m/s.

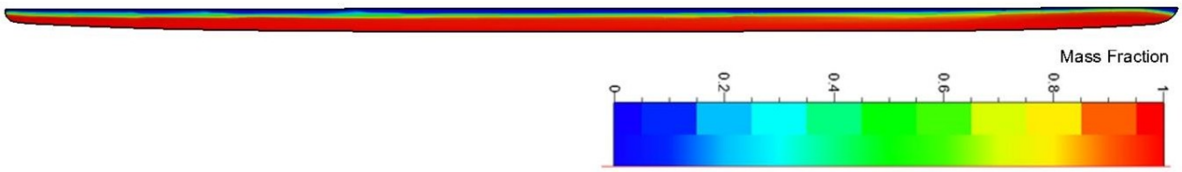

Fig. 7. Mass fraction on the hull surface @ 2.37 m/s model speed.

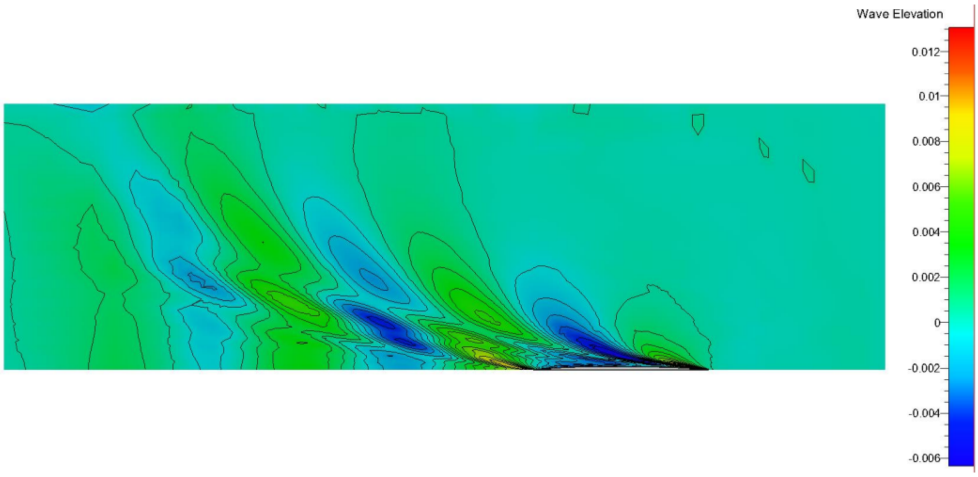

Fig. 8. Global wave pattern (in meter) around the hull @ 2.37 m/s model speed.

4. Conclusions

By employing scaled model experiment and RANS based computational fluid dynamic methods, this study aimed to improve an eights racing shell performance. Results from towing tank test demonstrate a consistent association between trim and resistance at speeds higher than 2.15m/s. Nevertheless, both methods showed trim optimization can be beneficial for the boat performance. According to towing tank results, 0.5 -0.6 º trim by stern decreased the resistance. That means the crew would be able to save 5% of their power. This condition can be set by changing the rower number 3 with number 7, and rower number 4 with number 8. The CFD simulation showed low resistance at zero degree trim condition. The result differences between two methods might be caused by assuming fix trim and sinkage. Therefore, further study needs to be done for computational part of this study.

5. References

Barrett, R. S. and Manning, J. M. (2004). Rowing: Relationships between rigging set-up, Anthropometry, physical capacity, Rowing kinematics and Rowing performance. Sports Biomechanics, Vol. 3, no. 2, pp. 221-235.

Buckeridge, E. M., Weinert-Aplin, R. A., Bull, A.M.J. and McGregor, A. H. (2016). Influence of foot-stretcher height on rowing technique and performance. Sports biomechanics, Vol. 15, no. 4), pp. 513-526.

Empacher (2018). Empacher Boats. Retrieved 03 April 2018, from www.empacher.de.

Filippi (2018). "Filippi Boats." Retrieved 03 April 2018, from http://www.filippiboats.com/en/.

FISA (2015). FISA Rule Book. Retrieved 03 April 2018, from http://www.worldrowing.com/mm//Document/General/General/11/95/06/FISArulebookEN2015COMPLET_Neutral.pdf.

Hodge, A. (2016). An optimization of rower positioning in an eights racing shell by using towing tank model tests to measure resistance in different loading conditions. Newcastle upon Tyne, UK, School of Marine Science and Technology, Newcastle University.

Hudson (2018). Hudson Boat Works. Retrieved 03 April 2018, from https://www.hudsonboatworks.com.

Smith, T. B. and Hopkins, W. G. (2012). Measures of rowing performance. Sports Medicine, Vol. 42, no. 4, pp.343-358.

Serveto S., Barré, S., Kobus, J. M. and Mariot, J. P. (2009). A model of oar–boat–rower system to optimise rowing performance. Computer Methods in Biomechanics and Biomedical Engineering, Vol. 12, no. S1, pp. 229– 230.

Weitao, Z., Yong, M. and Haifeng., H. (2007). Hydrodynamic analysis of rowing hull based on the float pose. ISBS-Conference Proceedings Archive, Vol. 1, No. 1

Day, A., Campbell, I., Cichowicz, J., Clelland, D. and Doctors, L., J. (2011). Realistic Evaluation of hull performance for rowing shells, canoes, and kayaks in unsteady flow. Journal of Sports Sciences, vol. 29, 2011.