Portuguese Journal of Sport Sciences
11 (Suppl. 2), 2011

COMPARISON OF WAVE DRAG FOR BOTH THE MALE AND FEMALE FORM

David Pease[1] and Ross Vennell[2]

Australian Institute of Sport, Canberra, Australia[1]
University of Otago, Dunedin, New Zealand[2]

This study measured forces acting male and female mannequins while being towed in a flume in order to quantify the differences in the wave drag contribution to total drag. Substantial differences between the male and female form in terms of the wave drag contribution were found with the female having a substantially lower (by 46.73% at 1.94 ms^{-1}) contribution near the surface while having a greater (by 20.87% at 1.94 ms^{-1}) total drag when deeply submerged. These differences were found despite the smaller frontal area and total surface area of the female. Both the decreased wave drag and increased submerged drag were theorised to be due to the resulting flow field created by the greater curvature of the female torso as compared to the male with the rate of change in curvature of the female being almost double that of the male.

KEYWORDS: Swimming, biomechanics, flume, mannequin.

INTRODUCTION: As with boat models there are a great variety of shapes/anthropometries which are presented by human swimmers. This is particularly true when comparing male and female forms. With their stereotypical differences in curvature and body thicknesses there is potential that athletes of different shapes may present with differences in the magnitudes of the various component forms of hydrodynamic drag across a range of velocities and depths. While this has not been previously investigated it is an aspect that may lead to varying strategies for optimal performance during the underwater phases of swimming races.
Based on the findings in previous research into the relative efficiency between male and female swimmers (Kjendlie & Stallman, 2008; Zamparo, 2006) it has been evident that there are differences between male and female forms in terms of the drag force experienced by the two genders. Therefore the current study was undertaken in order to quantify these differences in wave and total drag experienced by average male and female elite swimmers.

METHODS: All testing was conducted in the aquatic treadmill or 'flume' at the University of Otago, as described by Britton, Rogers, and Reimann (1998). In order to achieve the desired control over position of the body relative to the water flow it was necessary to utilise anatomically accurate mannequins rather than live subjects. The male mannequin used was the same as that described in previous research (B. Bixler & Pease, 2006; B Bixler, Pease, & Fairhurst, 2007; Pease & Vennell, 2010; Vennell, Pease, & Wilson, 2006). The female mannequin was similarly based upon an Olympic level female swimmer whose anthropometry approximated that of the average elite female swimmer. The primary anthropometric measures of the two mannequins are presented in Table 1.

Table 1
Anthropometric characteristics of the male and female mannequins

Mannequin	Height (m)	Finger-Toe Length (m)	Head Circum. (m)	Chest Circum. (m)	Waist Circum. (m)	Hip Circum. (m)	Frontal Area @ 0° deg angle of attack (m^2)	Total Surface Area (m^2)	Chest Depth (m)
Male	1.75	2.36	0.59	1.02	0.84	0.98	0.108	1.859	0.25
Female	1.69	2.32	0.58	0.96	0.72	0.96	0.099	1.669	0.22

The mounting structure used to support the mannequins was the same as that described by Pease and Vennell (2010) and is depicted in Figure 1. This structure, as well as the design of the mannequins allowed for the mannequin's orientation to be precisely controlled and maintained during all test conditions.

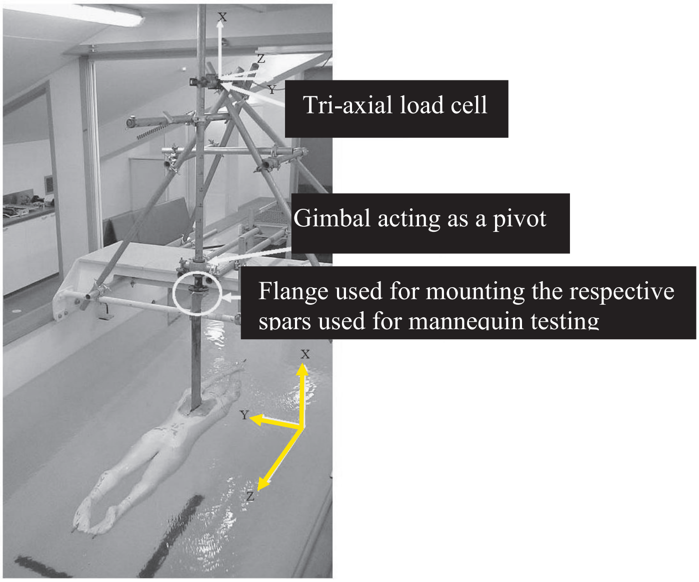

Figure 1: Support structure with prone mounted mannequin attached at a submersion depth of 0.1 m.

In order to obtain the optimal drag-velocity curves for the mannequin, data was collected for 13 velocities: 0, 0.34, 0.55, 0.75, 0.95, 1.16, 1.36, 1.57, 1.77, 1.94, 2.15, 2.36, and 2.55 ms^{-1} respectively at tow depths of 0.2 – 0.8 m at 0.1 m increments. Decomposition into the component forms of drag was then undertaken as per the methods described in Pease and Vennell (2010).

RESULTS: The first step in determining the differences between the male and female mannequin was to examine the total drag force across all velocities. These results are presented in Figure 2 for the female and male respectively.

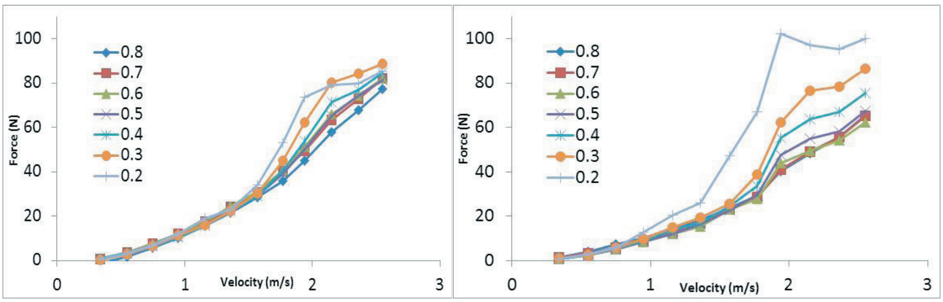

Figure 2: Total drag (N) at all depths and velocities for female (left) and male (right) mannequin.

In order to test the hypothesis that there would be a difference in wave drag contributions, the component drag forces were determined for each mannequin. The wave drag components for all depths and velocities are given in Figure 3.

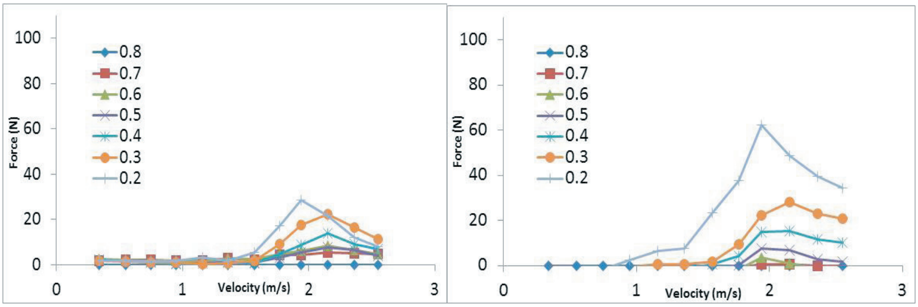

Figure 3: Wave drag force at all depths and velocities for female (left) and male (right) mannequin.

DISCUSSION: From the total drag data it is evident that the female mannequin actually exhibits a higher absolute total drag than the male mannequin in virtually all conditions other than at the shallowest depths where the male mannequin's drag increases quite markedly and reaches a level approximately 40% greater than the female. This finding was confirmed by subsequent unpublished computational fluid dynamic (CFD) analyses of the two mannequins. In that analysis the two mannequins were normalised to the same total surface area, and therefore skin friction drag. From that analysis it was found that the female mannequin exhibited about 10% more drag than the male in a fully submerged condition. The reason for this greater drag force was unclear. One possible theory is that, due to the greater curvature of the female, the water flow was required to change direction more frequently as it passed along the surface of the body. Due to the forces required, and therefore the acceleration normal to the surface of the mannequin, for this change in direction to occur, there was an increase to the pressure drag. From the wave drag results it is clear that the male mannequin exhibited approximately double the absolute wave drag force to that found for the female mannequin. While this body curvature seems to have been a detriment when fully submerged it is possible that the same curvature allowed for a reduction in the wave drag contribution as per the findings of Eng and Hu (1963) where the narrowing of the mid-section of an ellipsoid in conditions where the Froude number was greater than 0.32, allowed for a reduction in wave drag. In order to try and quantify this different curvature the rate of change of body cross sectional area was determined. This data is presented in Figure 4. As can be seen the rate of change in curvature for the female mannequin in the torso region is approximately twice that of the male.

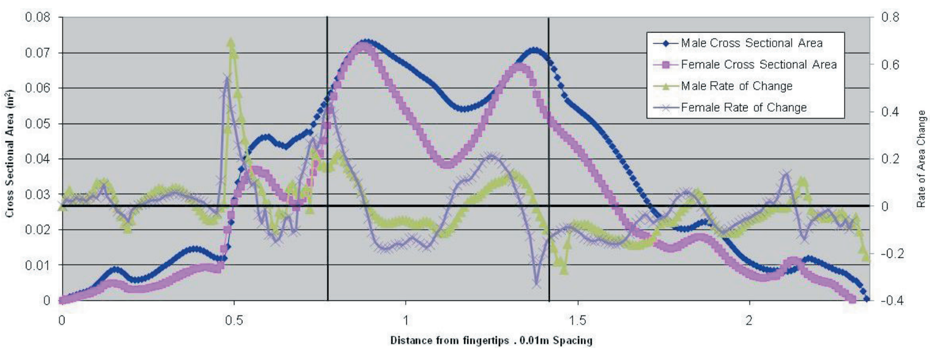

Figure 4: Cross Sectional Area Rate of Change: Vertical lines denote torso of the athlete with the neck on the left and gluteal fold on the right.

Portuguese Journal of Sport Sciences
11 (Suppl. 2), 2011

CONCLUSION: The principal finding from the comparison undertaken in this study is that the female form utilised had a significantly lower contribution from wave drag to the total drag force. This difference becomes ever more apparent as depth decreases. While the reason for this difference is unclear, the proposed theory of the greater 'hour glass' shape of the female torso having some bearing, seems to have some foundation in the theoretical fluids literature (Eng & Hu, 1963). Whether this is due to the introduction of new pressure points along the length of the body which then generate additional wave forms which create interfering wave patterns which help to cancel out some of the principal bow wave, or from some other hydrodynamic effect, the potential for wave drag reduction is intriguing. If this mechanism is proved to be valid it may explain some of the effects found with the now banned competition suits which greatly compressed athletes around the abdomen. These results also highlight the importance of more accurately describing the anthropometry of subjects utilised in drag studies and not just utilising cross sectional area.

REFERENCES:

Bixler, B., & Pease, D. L. (2006). *The analysis and test methods used to develop the Speedo FSII swimsuit.* Paper presented at the Third International Symposium on Aero Aqua Bio-mechanisms, Ginowan, Okinawa, Japan.

Bixler, B., Pease, D. L., & Fairhurst, F. (2007). The accuracy of computational fluid dynamics analysis of the passive drag of a male swimmer. *Sports Biomechanics, 6*(1), 81-98.

Britton, R., Rogers, N., & Reimann, P. (1998). Swimming flume for Otago University. *IPENZ Transactions, 25*(1), 20-28.

Eng, K., & Hu, P. N. (1963). Wave-resistance reduction of near-surface bodies (D. O. Defense, Trans.) (pp. 36). Hoboken, NJ: Stevens Institute of Technology, Davidson Lab.

Kjendlie, P. L., & Stallman, R. K. (2008). Drag characteristics of competitive swimming children and adults. *Journal of Applied Biomechanics, 24*, 35-42.

Pease, D. L., & Vennell, R. (2010). The effect of angle of attack and depth on passive drag. In P. Kjendlie, R. K. Stallman & J. Cabri (Eds.), *Biomechanics and Medicine in Swimming XI* (pp. 145-147). Oslo, Norway: Norwegian School of Sport Sciences.

Vennell, R., Pease, D. L., & Wilson, B. D. (2006). Wave drag on human swimmers. *Journal of Biomechanics, 39*(4), 664-671.

Zamparo, P. (2006). Effects of age and gender on the propelling efficiency of the arm stroke. *European Journal of Applied Physiology, 97*(1), 52-58.