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A METHOD OF IMPROVING OAR EFFICIENCY

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Abstract

In boats used for competitive rowing it is traditional for the rowers to use strokes in which the angle between the oar shaft and the perpendicular to the hull centre line is much greater at the catch than it is at the end of the power stroke. As a result, the oar blade is even more inefficient in its action at the catch than it is at the end of the power stroke. This paper shows how boat performance in a race would be improved by reducing the difference in these starting and finishing angles.

The claim of improved race performance is supported by a detailed investigation of the dynamics involved in the case of a particular coxless pair whose performance has been recorded by the Australian Institute of Sport. We also suggest an easy way to make the necessary change in boat design.

2000 *Mathematics subject classification*: primary 92C10; secondary 74L15.

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1. Introduction

The angle of an oar is measured between its shaft and the perpendicular to the centre line of the hull. By convention, the angle is taken to be negative at the catch. The claims made in this paper will be supported by a detailed examination of the performance over a hypothetical 2000 m race of a particular coxless pair whose oarlock forces over a complete power stroke have been measured by the Australian Institute of Sport [1].

Figure 1 shows the forces Q at the oarlocks of the rowers in this coxless pair at times t during the execution of the power stroke, and Figure 2 shows these forces and the angles θ of the oars at the corresponding times t.

2. Oar angle θ as a function of time t

For the oarsman whose graphs are indicated with an asterisk in Figures 1 and 2, the values of Q at $t = 0, 0.1, 0.2, \ldots, 0.9$ seconds were scaled off Figure 1 and transferred to Figure 2 to reveal the corresponding values of the angle θ at these times. The data obtained are shown in the first three columns of Table 1.

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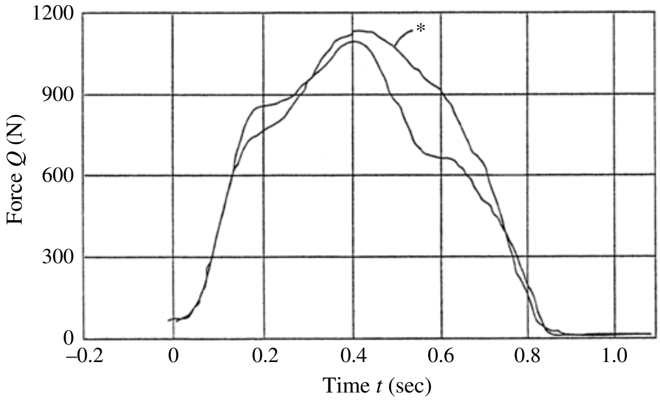

FIGURE 1. Oarlock forces versus time for a coxless pair.

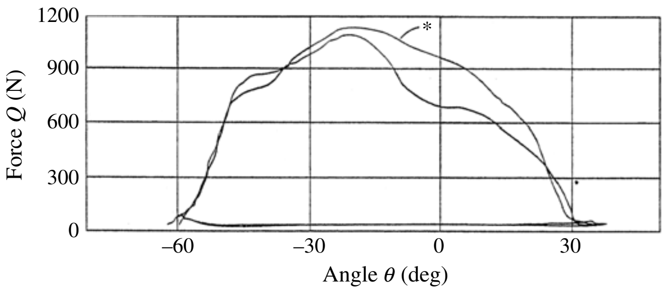

FIGURE 2. Oarlock forces versus oar angle θ for a coxless pair.

TABLE 1. Data for one oarsman (*) during a power stroke.

t (s)	Q (N)	θ(deg)	$Q\cos\theta$ (N)	Simpson
0	72	−58.8	37.3	1
0.1	375	−52.6	227.8	4
0.2	810	−43.9	583.6	2
0.3	930	−34.0	771.0	4
0.4	1106	−23.3	1015.8	2
0.5	1050	−10.2	1033.4	4
0.6	897	4.5	894.2	2
0.7	623	17.3	594.8	4
0.8	143	27.3	127.1	1
0.9	0	34.2	0	

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The magnitudes of θ at the start and finish of the power stroke differ greatly. The efficiency of the stroke would be increased if this difference could be reduced. In what follows, a method of achieving this reduction will be suggested, and an analysis will be made of the effect of the reduction on the performance of the coxless pair over a hypothetical 2000 m race. For this purpose the data of Table 1 are assumed to also apply to the second oarsman, to save repeating all of the calculations done for the first oarsman.

3. The mean forces over one complete stroke

At any instant the forward force F on the boat provided by one oarsman is

$$F = Q\cos\theta. \tag{3.1}$$

The fourth column of Table 1 lists the values of F given by this equation.

Let τ_1, τ_2 be the durations of the power stroke and the recovery stroke, respectively. Then the total forward impulse on the boat provided by one of the oarsmen during the power stroke is $\int_0^{\tau_1} F\,dt$, and the mean forward force on the boat by one oarsman during a complete stroke is

$$\bar{F} = (\tau_1 + \tau_2)^{-1}\int_0^{\tau_1} Q\cos\theta\,dt. \tag{3.2}$$

The stroke rate while the data in Figures 1 and 2 were obtained was 28 strokes per minute, which corresponds to a time of about 2.1 seconds for a complete stroke, hence $\tau_1 + \tau_2 = 2.1$ seconds. Table 1 shows the duration τ_1 of the power stroke to be 0.9 seconds. So (3.2) in this case is

$$\bar{F} = (2.1)^{-1}\int_0^{0.9} Q\cos\theta\,dt. \tag{3.3}$$

The integral was evaluated numerically from the data of Table 1. For the interval $0 \le t \le 0.8$, Simpsons one-third rule was used, and for the last sub-interval $0.8 \le t \le 0.9$, the trapezoidal rule was used. The mean forward force was found to be

$$\bar{F} = 251.6\ \text{N}. \tag{3.4}$$

To simplify the analysis, the forces contributed by the two oarsmen will be assumed to be the same. The mean forward force on the boat over one complete stroke is then $2\bar{F}$. When the boat has reached a "steady state" (in the sense that its mean speed $\bar{v}$ is constant), the force $2\bar{F}$ will be equal and opposite to the mean water resistance $\bar{D}$ (if air resistance is neglected). That is,

$$2\bar{F} = \bar{D}.$$

From data presented in a report of the National Physical Laboratory [3] it can be deduced that when a boat is travelling at racing speed the drag D is nearly proportional to the square of the boat speed v, so that

$$2\bar{F} = k\bar{v}^2, \tag{3.5}$$

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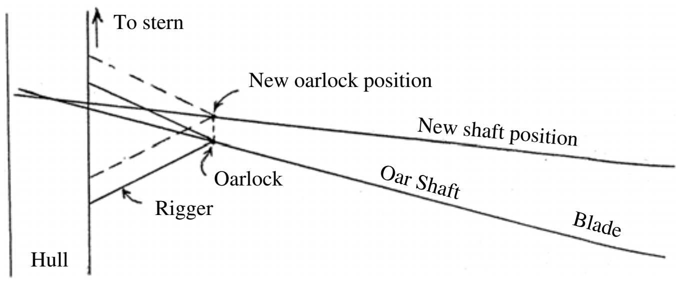

FIGURE 3. Plan view of oar angles in two oarlock positions.

the value of the constant k being adjusted to take into account the very small difference between $\bar{v}^2$ and the mean of v^2.

4. The modified oarlock design

As mentioned in Section 2, the large value of the oar angle θ at the start of the power stroke detracts from the efficiency of the stroke. One way of reducing this large value is to locate the oarlocks slightly more towards the stern of the boat, something which could easily be achieved by bolting the riggers to the hull a little further sternwards. The effect on the angle of the oar is shown in Figure 3 at one particular oar position during the power stroke, with the change of position of the oarlock exaggerated.

The position of the hands of the oarsman on the oar handle remains unchanged. Figure 3 shows how the new position of the oarlock reduces the magnitude of the angle of the oar. This occurs to some degree throughout much of the power stroke. Of course the proposed change also has the undesirable effect of increasing the angle of the oar during the latter part of the power stroke, but this is more than offset by the benefit it provides during the early part.

To determine the magnitude of the improvement, the analysis conducted in Sections 2 and 3 was repeated for the same pair of oarsmen in boats with oarlocks moved sternwards by a distance of 20 cm. A graphical method, on diagrams such as that in Figure 3, was used to determine the new values of the angle θ at each of the times t of the stroke. The results are shown in Table 2, in which θ_1 denotes the modified values of the angle θ when the oarlocks are moved sternwards by 20 cm.

5. The effect on boat performance of a 20 cm oarlock move

The calculations described in Sections 2 and 3 are now repeated for the coxless pair with the oarlocks moved 20 cm towards the stern. The force Q exerted by the oarsman is taken to be the same as in Table 1, so that any change in boat performance will be solely the result of the relocation of the oarlocks. The last two columns of Table 2 show the force Q and its forward component $Q \cos \theta_1$ during the power stroke.

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TABLE 2. Data for one oarsman (*) with 20 cm oarlock displacement.

t (s)	θ(deg)	θ_1(deg)	Q (N)	$Q\cos\theta_1$ (N)
0	−58.8	−52.8	72	43.5
0.1	−52.6	−45.5	375	262.8
0.2	−43.9	−35.5	810	659.4
0.3	−34.0	−24.5	930	846.3
0.4	−23.3	−12.6	1106	1079.4
0.5	−10.2	0.9	1050	1049.9
0.6	4.5	16.8	897	858.7
0.7	17.3	28.4	623	548.0
0.8	27.3	37.8	143	113.0
0.9	34.2	43.8	0	0

The calculation of the mean value $\bar{F}_1$ of the forward force over a complete stroke proceeds exactly as was done for $\bar{F}$ in Section 3, using Simpsons one-third rule and the trapezoidal rule on the data of Table 2. This gives

$$\int_0^{0.8} Q\cos\theta_1\,dt = 539.3\text{ Ns},\qquad \int_{0.8}^{0.9} Q\cos\theta_1\,dt = 5.7\text{ Ns}.$$

Then

$$\bar{F}_1 = (2.1)^{-1}\times(539.3+5.7) = 259.5\text{ N}. \tag{5.1}$$

Analogous to (3.5),

$$2\bar{F}_1 = k\bar{v}_1{}^2, \tag{5.2}$$

where $\bar{v}_1$ denotes the mean speed of the boat with the modified oarlock positions.

Equations (3.4) and (3.5) give

$$k\bar{v}^2 = 503.2, \tag{5.3}$$

while (5.1) and (5.2) yield

$$k\bar{v}_1{}^2 = 519.0. \tag{5.4}$$

Eliminating k between (5.3) and (5.4) gives

$$\frac{\bar{v}_1}{\bar{v}} = \left[\frac{519.0}{503.2}\right]^{1/2} = 1.016 \tag{5.5}$$

which represents an increase of 1.6% in mean boat speed as a result of moving the oarlocks sternwards by 20 cm. If this “steady state” improvement also applied during the initial acceleration of the boat, the position of the pair at the end of a 2000 m race would be improved by

$$0.016\times 2000 = 32\text{ m},$$

or about three boat lengths.

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TABLE 3. Data for one oarsman (*) with 20 cm, 15 cm and 10 cm oarlock displacement represented by θ_1, θ_2 and θ_3, respectively.

t (s)	θ(deg)	θ_1(deg)	θ_2(deg)	θ_3(deg)
0	−58.8	−52.8	−54.3	−55.7
0.1	−56.2	−45.5	−47.3	−48.9
0.2	−43.9	−35.5	−37.5	−39.5
0.3	−34.0	−24.5	−26.9	−29.0
0.4	−23.3	−12.6	−15.0	−17.8
0.5	−10.2	0.9	−1.7	−4.5
0.6	4.5	16.8	13.0	10.3
0.7	17.3	28.4	25.3	22.8
0.8	27.3	37.8	35.0	32.5
0.9	34.2	43.8	41.4	39.1

TABLE 4. Improvements over a 2000 m race for a pair with oarlock displacements.

		Oarlock displacement (cm)		
		10	15	20
Race improvement	(metres)	22	28	32
	(lengths)	2	2.5	3

The effectiveness of the new oarlock position does not vary with boat speed, so it is reasonable to assume that the result in (5.5) will apply throughout a race. In any case, the duration of the acceleration phase of a race is small compared with that of the "steady state" part.

The foregoing analysis may be repeated for other oarlock displacement distances. If this is done for the two distances 10 cm and 15 cm, the oar angles which result throughout the power stroke can be calculated (Table 3). The effects on boat performance can then be calculated for these two cases, just as was done for the 20 cm displacement. A summary of the improvements in the position of a pair in a 2000 m race is shown in Table 4.

6. Summary and conclusions

The usual design of racing shells causes the angle of the oars to the hull to be very great at the start of the power stroke. This reduces the efficiency of the action of the oar blades. One way of improving the efficiency of the power stroke is to move the oarlocks towards the stern of the boat by a small distance, since this will reduce the angle of the oars during the important early part of the power stroke. The move will also increase the angle of the oars during the latter part of the power stroke, but this

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effect is more than offset by the gain during the early part. An analysis has been made of the effect of a move of the oarlocks by distances of 20, 15 and 10 cm, and Table 4 shows the improvements that would result in the performance of a particular coxless pair in a 2000 m race. Similar improvements would result for all types of boats over all distances.

The suggested design change will alter the action of the rowers. At the catch they will not need to reach so far over to the side of the boat, resulting in an easier and more natural action. At the end of the power stroke the oar handles will come into the bodies at a greater angle. This seems unlikely to cause problems, but practical experience would be needed to verify this.

The suggested change in oarlock position would be very easy to achieve. The riggers, on which the oarlocks are mounted, can be bolted to the hull nearer to the stern by the required distance. It would be possible to achieve the desired changes in oar angle by moving the seats and footrests towards the bow instead of moving the riggers sternward, but this would change the position of the weights of the rowers to a perhaps undesirable degree.

Oarlock displacement is a simple way of achieving the benefits produced by the concept of blade lead angle suggested in an earlier paper by Brearley and de Mestre [2], but without the disadvantages attending that method.

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