THE MECHANICS AND BIOMECHANICS OF ROWING

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1.0 INTRODUCTION

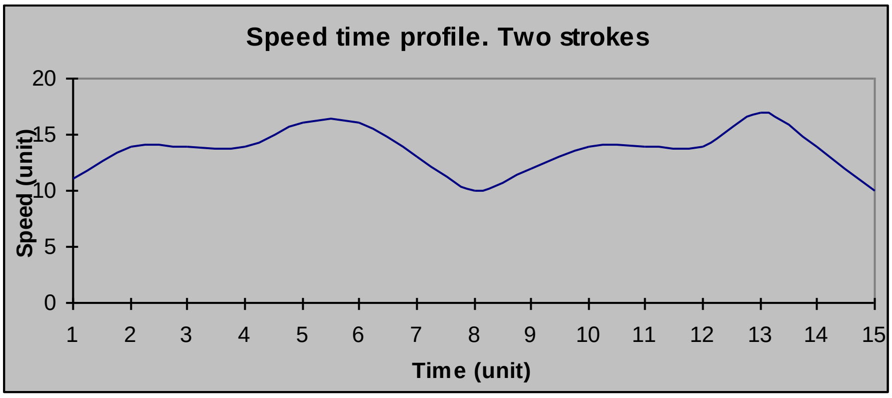
The biomechanics of rowing are complex and have not yet been fully explained, despite research from many different sources. Newton's laws describe the relationship between forces and motion and the motion of a boat resulting from the forces applied by the rower is simple to explain in principle. If the system of boat and rower is assumed to be a closed unit of known mass and dimensions and the forces applied by the rower to the boat can be measured, then it should be possible to predict boat velocity. Similarly, if the style of a rower can be interpreted in terms of the applied forces then it is possible that rowing technique could be altered to improve performance.

1.1 Motion of a boat

Dodd (1992) records that the sliding seat was introduced to rowing between 1857 and 1861 and that one of the possible inventors was Babcock of the Nassau Boat Club in New York. It was Babcock who first commented on the apparent check on a boat's movement resulting from the use of the sliding seat:

> "The opinion of those most competent to judge of the effect of this slide on the speed of the boat was against it, as it seemed to check headway at every stroke on the recovery, and the boat to take a series of leaps instead of that steady headway so essential to speed."

There is a very distinct velocity/time profile of a boat during the period of each stroke and this corresponds to well-defined parts of the drive and recovery. *Figure 1* shows a typical velocity/time profile of two strokes taken from an eight using an "impulse racing meter". The duration of each stroke is approximately 3 seconds and the typical velocity profile shown can be related to the position and activity of the crew members. Martin and Bernfield (1980) have shown that minimum boat velocity occurs approximately 27% into the leg drive, and maximum velocity occurs during the recovery; both of these points are shown in *Figure 1*. The minimum speed of the boat has been shown to deviate -24.4% from the mean, and maximum speed can be +18.6% of the mean.



Time	Phase	Description
7.5	Catch	The blade enters the water
8 -9.5	Drive	The legs apply force and accelerate the boat
9.5 -10	Upper body	The upper body finishes the drive
10 -10.5	Transition	The blade leaves the water
10.5 -12	Back stops	Hands and upper body begin to move forward
12 -14.5	Recovery	The whole body moves down the slide
14.5 -15	Front stops	The rower reaches front stops and the catch

Figure 1: The speed profile of a boat relative to the stroke cycle

2.0 EFFECTS OF MOMENTUM AND CHANGES IN MOMENTUM ON BOAT VELOCITY

In order to understand the reasons behind the changing velocity of the boat, the system of crew and boat has to be looked at in terms of momentum and driving forces. The mass of the boat can be split into three main parts:

i. The crew representing 80% of the total mass;
ii. The boat representing 18% of the total mass;
iii. The oars representing 2% of the total mass.

The boat cannot change velocity relative to the water unless an external force is applied, e.g. through resistance from the water moving over the hull, wind, the action of the oars in the water, or if work is done by the crew. This applies throughout the stroke. However if the crew moves collectively up and down the boat from a stationery point, even though no work is done through the oars the boat will be seen to move in the water in response to Newton's laws.

The influence of the movement and hence the moment of the crew can be simulated on a land based rowing machine such as a Concept II ergometer. The ergometer simulates rowing by the pulling of a chain attached to a fly-wheel. In order to simulate the effect of a crew moving collectively up and down the boat without working, an ergometer at Newcastle University was instrumented to measure the forces (both tensile and compressive) applied under the rower's feet. The forces resulting from the momentum change of the rower moving up and down the ergometer but without moving the fly-wheel are shown in *Figure 2*. A negative applied force (tension) occurred when the rower was moving from back-stops to beginning what would have been the drive. Likewise a positive force (compression) corresponded to the rower changing his momentum at the beginning of the stroke. If this experiment were carried out in a boat, the boat would be seen to move accordingly. If the seat is assumed to be frictionless, and the effects of gravity in drawing the rower to front stops are ignored, then the sum of the positive and negative areas under the graph should be zero.

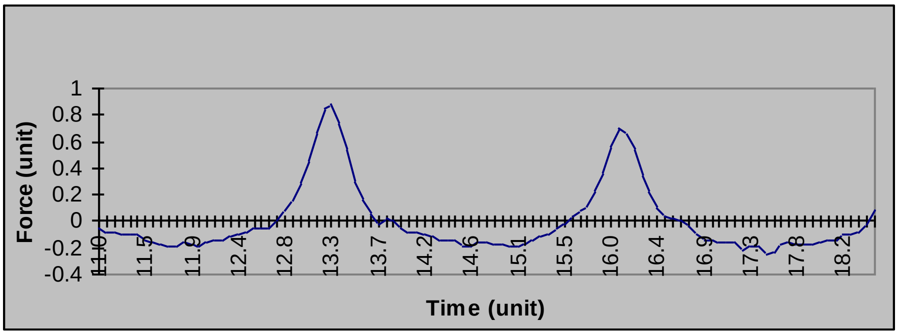
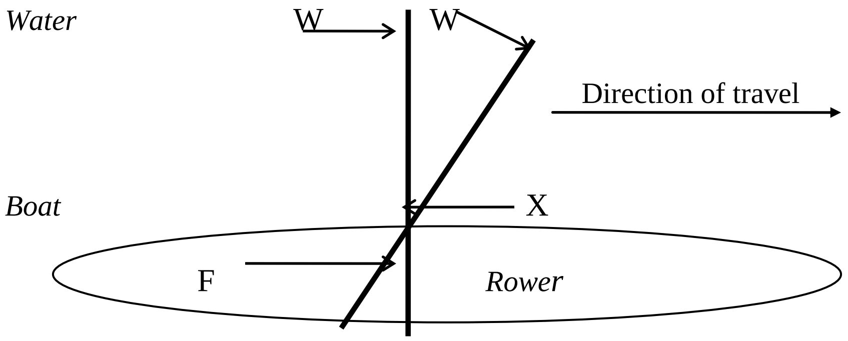


Figure 2: Forces resulting from momentum changes of the rower for two strokes

It was apparent from the tests that the size of the forces developed was proportional to the magnitude of the change in momentum. If the rower were to have been heavier or moving faster along the slide, the areas either side of the zero line would be correspondingly larger. This has important consequences in understanding the force/time profile of the actual stroke.

During the drive phase of the stroke the force of the oar in the water provides the main component of propulsion of the boat (Bompa *et al*, 1985), *Figure 3*. This force is comprised of two parts: one perpendicular to the boat, and one parallel to the line of the boat. These are a function of the angle of the shaft of the oar to the boat, and it is often assumed that the angle through which the most useful power output should occur is with the oar at 90° to the boat. The forces applied to the oar handle by the rower are reacted proportionately by the rowlock attached to the rigger, and the water. Traditionally the force on the rowlock has been regarded as proportional to the resistance of the flow of the boat. However, it must be noted that there is no significant force on the rowlock during the recovery phase of the stroke. During the stroke the oar is seen to rotate about the rigger relative to the rower. For an onlooker the oar is seen to rotate about a point near W, *Figure 3*. This does not affect the force distribution.



W - Reaction force of water on blade
F - Force app1ied by the rower
X - Force of pin against the blade

Figure 3. Forces on the oar

At the catch the oar is placed in the water. The legs apply a force to the boat, and equally to the blade at the handle; this force is reacted proportionally by the water and rowlock. The magnitude of the force determines the acceleration of the boat, and the duration of the application decides the final boat speed when the oar blade leaves the water. When the blade leaves the water the crew will be at back stops, and their velocity for a moment will equal that of the boat. The momentum of the boat and crew (MV) can be described as:

$$MV = m_c V_c + m_b V_b$$

Where m_c = mass of crew
m_b = mass of boat (+ oars)
V_c = velocity of the crew
V_b = velocity of the boat
M = mass of boat and crew
V = velocity of boat and crew

$V = V_c = V_b$ only at back stops at the end of the drive phase of the stroke

At the recovery the crew moves towards front stops and $V_c < V_b$. The total momentum of crew and boat remains the same, but the reducing forward velocity of the crew causes the boat to accelerate proportionately. This is seen in the increase in velocity of the boat after the finish of the stroke, *Figure 1*. As the crew nears front stops, they must again change their direction of travel. As at back-stops this causes a change in boat velocity such that the overall momentum of the boat is conserved. The period around the catch is, as a result, the time when the boat is moving at its slowest. The slowing of the boat is exaggerated when members of the crew do not manage to place the blade into the water for the catch at the same time as the rest of the crew, or when crew members begin to push off for the drive before the blade has entered the water. This is a critical action, which results in a major deceleration of the boat. Crew members who do this are known as "boat stoppers", but due to the speed of the rowing action it is frequently impossible for an onlooker to detect who in the crew is causing this.

2.1 Resistance to the flow of the boat

While the rower generates forces to propel the boat there are a number of other forces acting to restrict this flow. These forces are well documented and include:

- Skin drag
- Form drag
- Wave drag
- Forces resulting from poor technique

In racing boats the predominant source of resistance is skin friction. Skin friction or resistance (R) can be shown from simple laws of fluid dynamics to vary approximately in proportion to the velocity of the boat (V_b) squared.

$$R \propto V_b^2$$

From this simple equation it is apparent that it is good practice to keep the velocity of the boat as constant as possible. The frictional component of force is also proportional to the wetted surface area of the hull. This is directly proportional to the amount of water displaced by the boat and hence to the weight of the boat and crew. An eight appears to rise and fall in the water at the catch and finish however, this is due to the movement of the crew fore and aft. It is therefore assumed that the fall of the bow is matched by a rise at the stern, and the overall wetted surface area remains constant.

Another reason for keeping the velocity of the boat constant is that the power (P) consumed in moving the boat is related to the velocity of the boat cubed.

$$P \propto V_b^3$$

The metabolic cost or the cost to the rower (M_t) increases in a different manner in accordance with (Secher, 1993):

$$M_t \propto V_b^{2.4}$$

This has two effects:

i. A boat going through large accelerations/decelerations to keep the average speed at a given level will consume more energy than one that undergoes smaller velocity changes. Hence minimising the stopping effect at the catch is crucial.

ii. It requires less energy to move a large mass of water slowly through a stroke than a small mass of water fast.

The influence of changes in velocity of the boat on the work required by the crew to sustain an average velocity can be illustrated by considering two simple cases:

Case 1 If boat speed is 3m/s for a period of 3 seconds

The power consumed ($P \alpha V_b^3$) = $P \alpha 3^3 x 3 = 81$

Resistance ($R \alpha V_b^2$) = $R \alpha 3^2 x 3 = 27$

Since R is the resistance to the flow of the boat it must equal the force needed to drive the boat through the water.

Case 2 If the boat speed was 1m/s for 1 second and 4m/s for 2 seconds, the average speed would be the same for the whole stroke and the distance covered would be the same as in Case 1.

But power consumed = $P \alpha (1^3 x 1 + 2 x 4^3) = 129$

Resistance = $R \alpha (1^2 x 1 + 4^2 x 2) = 33$

It can be concluded that keeping the velocity changes of the boat as small as possible is essential, and to this end, having a method of viewing technique, which relates to changes in boat velocity could be useful for coaches.

3.0 QUANTITATIVE ANALYSIS OF ROWING TECHNIQUE

The biomechanics of rowing have been studied from as far back as the 19th century, although the motives at that time were more to do with scientific experimentation than to provide practical tools for training. As a result the systems first devised to monitor the rower were often bulky and cumbersome, requiring the rower to change his technique to suit the intrusions of the scientist. This ignored the individuality of the rower, and as a result could only be of limited use to the improvement of technique.

A number of methods to measure the driving forces on the boat have been employed by researchers. Some show greater degrees of success than others. The usual assumption has been that the forces on the rowlock are proportional to the driving forces applied to the water; as a result there has been a concentration of research into measuring this force through gauges applied to the oars, riggers or the rowlock itself, *Table 1*.

Table 1: Development of rowing assessment methods (After Spinks 1996 and Miller 1997)

Researcher(s)	System Applied	Conclusion
1951 Baird and Soroka	Modified oarlock containing strain gauges to measure driving force	Problems with noise
1967 Cameron	High speed cinematography to measure oar deflection	Concluded that oar force was constant through the stroke
1971 Ishiko	Strain gauged oar, signals radioed to shore	Driving force not constant through the stroke
1974 Celantano *et al*	Rigger based gauges. Signal to shore via cable	Limited distance to row due to cable
1981 Schroder	Same system as Celantano *et al*	More than one rower monitored
1985 Gerber *et al*	Use portable lightweight system of gauges on oars	Provide feedback on torque/angle, velocity and acceleration parameters
1988 Komor and Leonardi	Examination of various parameters of rowing technique on a Giesing-Nilsen ergometer	A performance index developed for crew selection
1988 Smith and Spinks	Force and oar angle measured on an ergometer	Distinction between rowers of different ability identified
1989 Christov *et al*	Comparison of water and land based rowing	Some differences in rowing action, but overall land used systems provide a valid simulation
1989 Duchesnes *et al*	Micro computers used with Baird and Soroka system	Noise filtered out. Concluded that rowers have individual force/time profiles
1995 Smith and Spinks	Performance index used for on water rowing	On water rowing performance analysed
1995 Wing and Woodburn	Gauge four blades in a boat to measure performance	Individuality of force/time profile both on and off water is confirmed
1995 Henry *et al*	Compare ergometer, tank and on water rowing	Conclude that there are differences, but nothing major
1997 Miller and Jones	Measure momentum forces on ergometer and water	Agrees with Wing and Woodburn but momentum forces can be underestimated with some crew members

The purpose of monitoring the force generated by a rower has been to provide feedback to the coach, and in turn to the rower, in such detail that could not otherwise be achieved by an onlooker. Attempts to provide real time feedback in the form of a graphical representation of the stroke on an ergometer have been made (Gauthier, 1985; Spinks and Smith, 1996; Pudlo *et al*, 1996). In these studies the force and body position were monitored directly from the ergometer handle and plotted together. Tests were carried out to assess the impact of having direct feedback on the stroke performance and it was shown to provide a significant improvement to the individual's training.

The force developed, oar angle and timing of the rower are regarded as some of the key aspects to distinguish between rowers of differing standards (Angst, 1984; Gerber *et al*, 1985; Smith and Spinks, 1995), *Figure 4*. These force/time profiles are shown to be unique to the individual and unchanging from ergometer to boat, even under race conditions (Wing and Woodburn, 1995). They are a significant aid to the coach in determining the oarsman's efficiency and also in identifying crew members with poor technique.

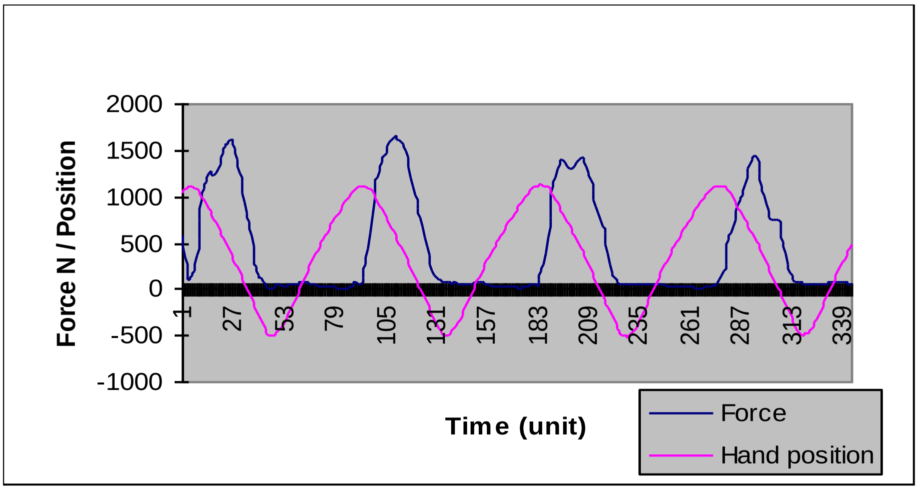


Figure 4. Force and hand position -v- time (After Pudlo, 1997)

Momentum forces do not appear to have received much consideration and have been deliberately ignored in some studies under the argument that movement of the rower within the boat does not significantly affect the overall motion, Millward (1987). However, momentum changes generated by a sculler or the crew of a boat can significantly affect the speed of the boat as the crew accounts for 80% of the total boat, oars and crew weight. This is not measured by rigger, oar or rowlock based force systems, yet the importance of the timing and pressure applied at the catch are emphasised by coaching manuals and should be accounted for by a system used to aid coaches in increasing boat speed.

A plot of force and boat speed against time from an oar based force sensing system is shown in *Figure 5,* (Smith and Spinks, 1995). It is apparent that the oar based force sensing methods are unable to explain the changes in the boat velocity profile during the stroke cycle. There appears to be only one place in the boat where the majority of the forces generated by the rower constantly pass through, which is the foot stretcher (assuming the friction of the sliding seat in the direction of travel is zero). The force applied to drive the boat through the water is directly proportional to the force at the stretcher. During the period after the oar blade leaves the water and just before it enters at the catch, there will be zero force on the oar, rigger or rowlock. In terms of elapsed time this accounts for more than half of the stroke, and this period sees the largest changes in overall boat speed. A force sensing system at the feet should therefore be able to measure both the drive and recovery forces, thereby providing a better understanding of the changing speed of the boat during the stroke cycle.

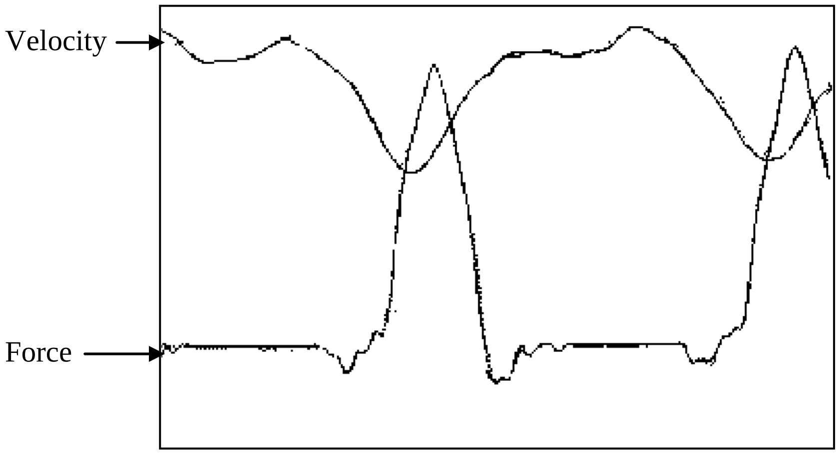


Figure 5. Boat speed and force on the oar handle -v- time (After Smith & Spinks, 1995)

4.0 OBJECTIVES OF THE TESTING AND TESTING METHODOLOGY

The objectives in measuring the forces applied by the rower through the foot stretcher were to:

i. Measure the size and direction of the interaction force between rower and boat
ii. Explain the speed profile of the boat in terms of the actions of the rower; and
iii. Highlight the implications for rowing technique.

The basic assumption made in selecting the foot stretcher as the point of measurement was that all of the principal forces associated with the movement of the rower, which contribute to the acceleration and deceleration of the boat, are covered. This is not entirely true, but those movements not considered, such as the influence of pitch and yaw of the hull, are of secondary importance, which can largely be eliminated by boat design. The seat was assumed to be frictionless.

The design required the following attributes:

(a) Be able to detect the forces applied to the stretcher (if possible the forces parallel to the line of the boat should be isolated from vertical forces);
(b) Cause no appreciable difference to the "feel" of the stretcher;
(c) Require no permanent changes to the stretcher;
(d) Provide a suitable interface for digital representation of the applied forces;
(e) Take up minimal space;
(f) Be of simple lightweight rigid construction.

The system, which was developed and tested on a Concept Model IIc ergometer, was formed from specially designed load cells placed under the ball and heel of each foot. Design of the load cells followed previous research which indicated that the force produced by any rower is unlikely to exceed 1,500 N at the start of a race and 1,000 N for the majority of the time (Hartmann *et al*, 1993).

[Note: details of the design and testing of the load cells are not provided in these notes.]

4.1 Kinematic information feedback

The use of kinematic information feedback has been shown to provide rowers with an enhanced ability to improve technique (Gauthier, 1985). The force profile of a rower using the ergometer was viewed by use of an oscilloscope attached to the signal from the amplifier. An appropriate time base setting resulted in the profile of one or more strokes being drawn, and refreshed on screen throughout the period of testing. The oscilloscope then provided the rower with the chance to more easily interpret the purpose of the project than looking at a print out after the test period. The use of the oscilloscope or some similar system can provide a facility for rowers to coach themselves, and understand how certain movements influence boat speed.

5.0 RESULTS FROM TESTING

Once the load cells had been developed and shown to provide consistent results, the on-boat system was produced. Initial tests showed that similar results from the laboratory tests and boat tests were produced, confirming the previous findings of Christov *et al* (1989) and Henry *et al* (1995) that the force/time profiles of rowers are consistent on and off the water. The on water tests proved to be time consuming for rowers and laborious; as a result the main research effort was concentrated on the laboratory studies. With the laboratory work, individual or small groups of rowers could be studied efficiently to develop a database of results.

5.1 Results from ergometer testing

The decision to construct a database of stroke profiles was based on the findings of a number of earlier researchers including Roth (1993), Smith and Spinks (1995) and Wing and Woodburn (1995). This research suggests that rowers display individual or signature stroke profiles and indicated that different classes of rower can be distinguished by certain encompassing characteristics. Using a database approach it was possible to:

i. Assess individual stroke profiles;
ii. Identify key distinguishing features in the stroke;

iii. Identifying individual rowing characteristics;

iv. Provide a base from which to compare boat results;

v. Confirm the idea that separate individuals have unique signature profiles, and that these do not change with rating or level of work; and

vi. Provide input to rowers in the form of kinematic information on stroke performance by a visual feedback during ergometer training.

The Concept II ergometer provided facilities to measure work output and was used to compare and calibrate the force cells. It also provided an accepted measure of performance when making comparisons between two different rowers in that it provided an on-line readout of stroke rate and "speed" in the form of split times for simulated distances rowed.

The first stage in testing aimed to show that the system was capable of detecting differing styles (Roth, 1993, Spinks and Smith, 1995). To this extent four oarsmen were asked to perform a six minute exercise keeping the rating at 23 strokes per minute and the time for 500m constant at 1:43 seconds. All were experienced University oarsmen including one who later became an Olympic gold medallist, *Figure 6*.

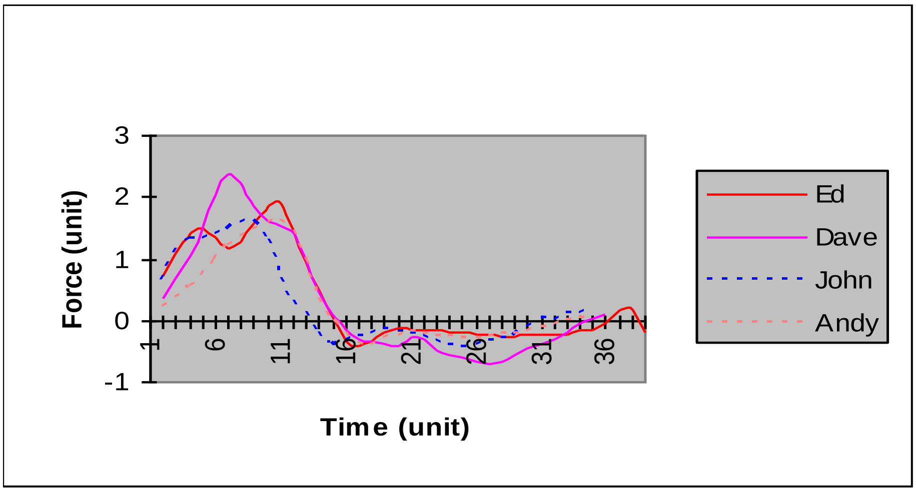


Figure 6. Comparing average stroke profiles

Figure 6 shows considerable difference in the force/time profiles and confirms the presence of different techniques; a number of features may be observed:

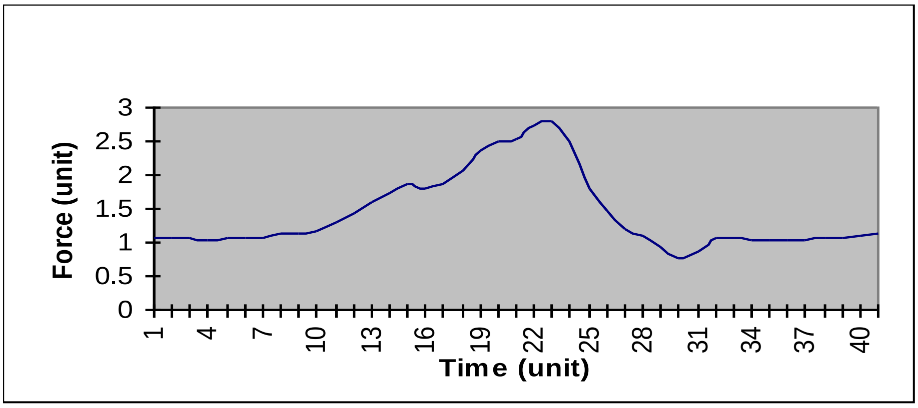
i. Two rowers produced marked double hump profiles. The first hump occurred when the rower arrived at front stops and the second occurred during the drive;

ii. As the applied force is related to energy consumed in the rowing motion then, for the same speed and rating, the smaller the area under the curve the less energy consumed, and hence the more efficient the stroke;

iii The presence of two humps suggested that the rower was reaching front stops, pausing and then driving.

5.2 Assessing the stroke profile

The assessment of a typical stroke profile built up in a laboratory test was used to provide the means of linking features on individual profiles to known parts of the stroke. *Figure 7* is a typical plot used to relate force as measured through the pressure on the feet to body position.



Time	Action	Time	Action
1 - 9	Recovery	22 – 30	Back stops, drive ends
9 - 15	Arrival at front stops	30 - 32	Changing direction of motion
16 - 22	Drive	32 - 40	Recovery

Figure 7. Typical stroke profile

Figure 7 records the results of two forces: the driving force where useful work is done in accelerating the boat, and the force resulting from the change of momentum of the rower. These two forces overlap and the exact point of the start of the stroke is masked by the arrival of the rower at front stops. In order to distinguish these two forces a test was carried out to measure the force arising solely from the changing momentum of the rower. This was then used in conjunction with a plot of similar period where the ergometer flywheel was turned through a normal drive; the results of the tests are shown in *Figure 8*. The first set of strokes illustrates the importance of the concept of the crew momentum being included in the stroke profile. It also explains the presence of double humps on some of the force/time curves, a feature which is more apparent in some rowers' profiles than in others.

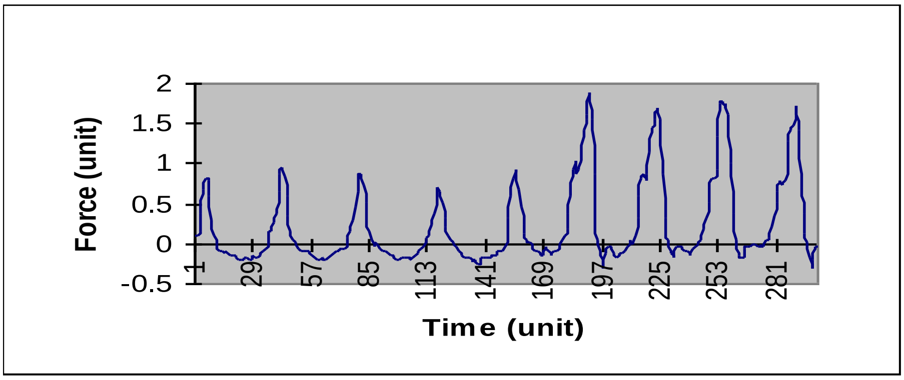
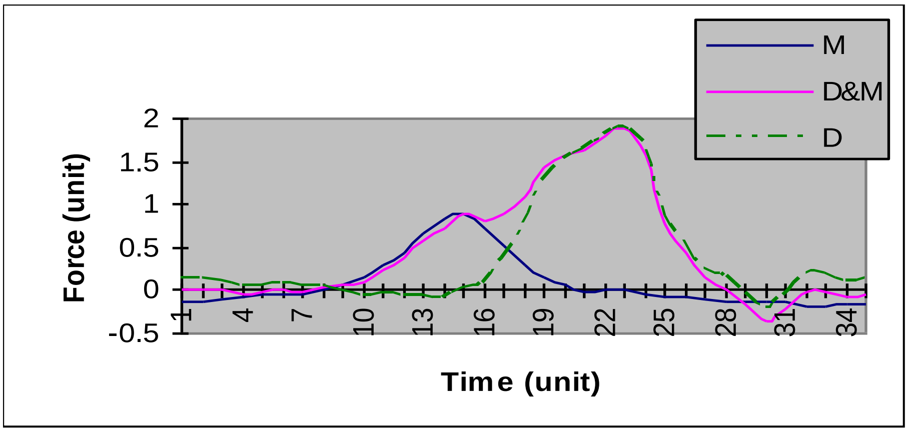


Figure 8. No drive to driven

The effective force time curve can be assembled from the two plots of momentum and total force on the footplate, *Figure 9*. The drive alone was shown to bear resemblance to force/time profiles of published work, Smith and Spinks (1995), Wing and Woodburn (1995).



Time	Action
9	Arrival at front stops
17	Drive
29	Arrival at back stops
33	Stoke ends

Where (D + M) = the drive including momentum, as seen under normal test conditions.
D = the drive less momentum.
M = the force resulting from momentum changes.

Figure 9. The different elements of the force profile

In *Figure 9* (D + M) represents the total force measured under normal test conditions, D is the drive force and M is the force resulting from momentum changes. It can be shown that the driving element of the stroke begins at time 17. The force generated by the rower under the feet due to the momentum changes associated with arrival at front stops covers period 9-15, and the stroke ends at approximately time 33.

Martin and Bernfield (1980) have shown that the minimum boat velocity usually occurs at 27% of the way into the drive. If the plot of the momentum and driving forces is taken, the drive lasts from approximately time 15 to 27. Twenty-seven percent of the way into the drive is time 18, *Figure 9*. This corresponds roughly to the point between the two peaks on the time/force curve.

The plot of drive force against time for the force applied through the feet does not show the two forces separately. However a drive occurring after an arrival at front stops will show as a separate event or peak in time. The two forces resulting from the drive and the momentum changes cause the boat to move in different directions despite their sign (positive or negative) being the same. The force developed when arriving at front stops acts to slow the boat, while the driving force acting in the same direction propels the boat forward. By accounting for this sign the effect or resultant force on the boat, retarding or propulsive, can be estimated, *Figure 10*. In *Figure 10*, D-M represents *the overall force applied by the rower acting on the boat.* The positive force acts in the direction of travel; the negative force is retarding the motion. The plot is an estimate and as a result is not expected to be exact. However, it can be seen to correlate approximately with the speed profile of the boat and with the periods of acceleration and deceleration. *Figure 11* is a plot of boat speed and the overall force applied by the rower, built up from test data to illustrate this point. The speed is seen to reduce as the force goes negative.

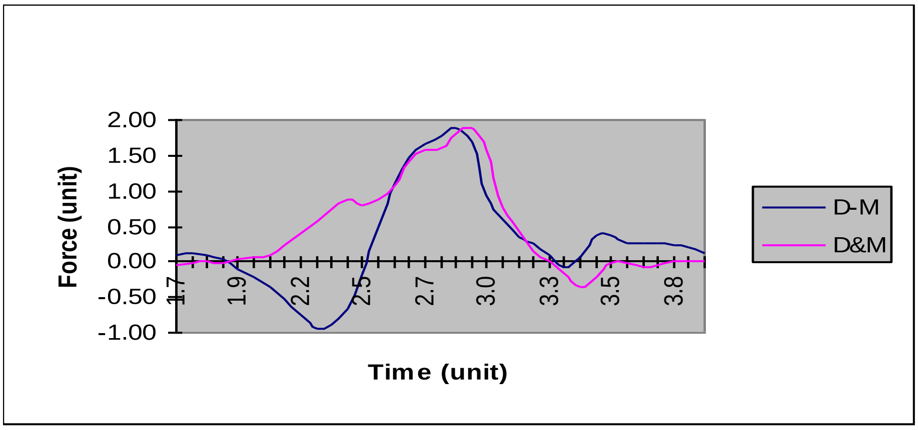


Figure 10. Overall force acting on the boat

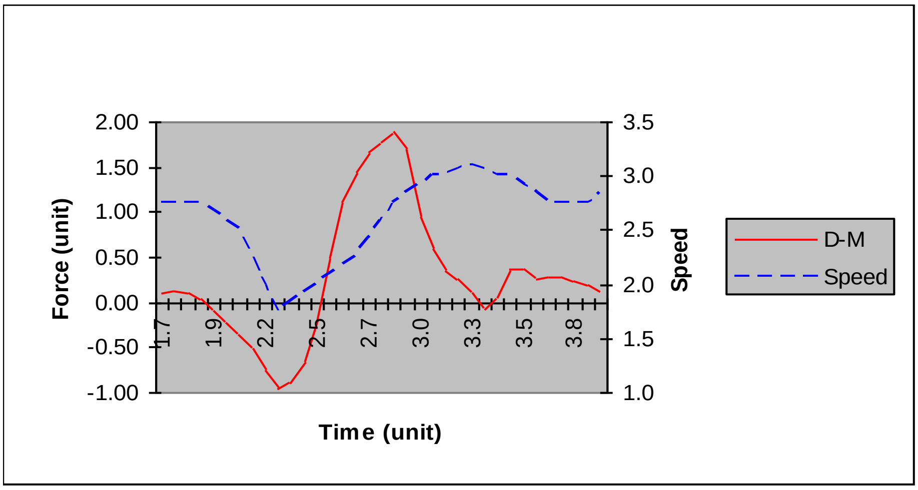


Figure 11, Force and resulting speed

Using the instrumented ergometer, where forces are measured at the feet, it is possible to develop useful profiles of individual rowers, *Figure 6*. *Figure 6* shows the average of one hundred individual strokes per rower. Observation of the profiles and the previous analysis indicates that any rower producing a large force on arriving at front stops, relative to the driving force, would slow the boat considerably more than a rower producing a smaller force at front stops; rower D develops the maximum force under the feet when coming forward rather than during the drive phase. During the test to develop *Figure 6* all four rowers rowed at the same rate with the same split time and nominally covered the same distance. However, a measure of the area under the time/force graph shows considerable differences. The implication is that the ergometer results cannot be used as a true indication of on water performance.

It can be useful to study the force/time curves and negative momentum forces developed by individual potential crew members. *Figure 12* shows the results of tests on four senior University oarswomen. Again the profiles suggest that some individuals might be better boat movers than others; in particular, rower Z at high ratings produces greater force under the feet **before** the drive phase than during the drive phase. In addition, the consistency of the effective force applied at different rates can be seen

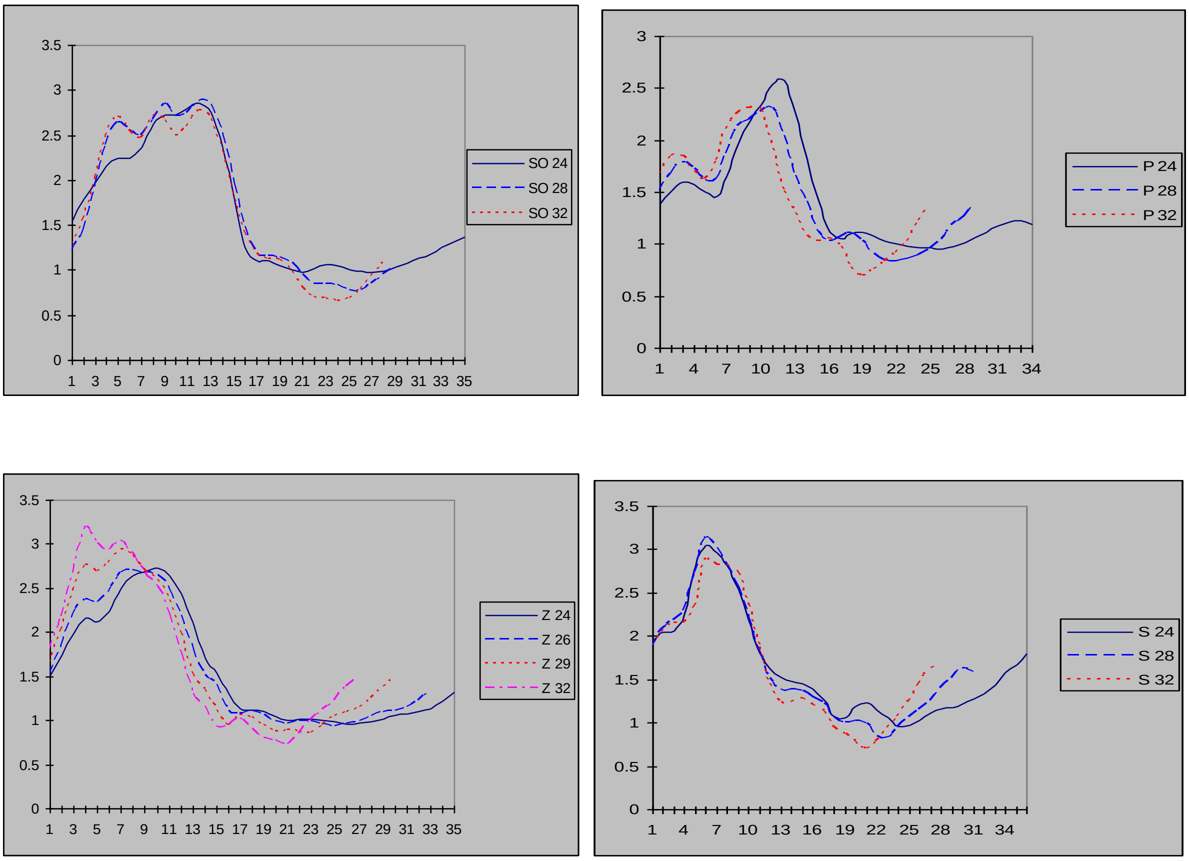


Figure 12 The ergometer profiles of four University women rowers

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The consistency of an international rower when working at different stroke rates is shown in *Figure 13*. The low initial hump representing negative moment is maintained at different stroke rates.

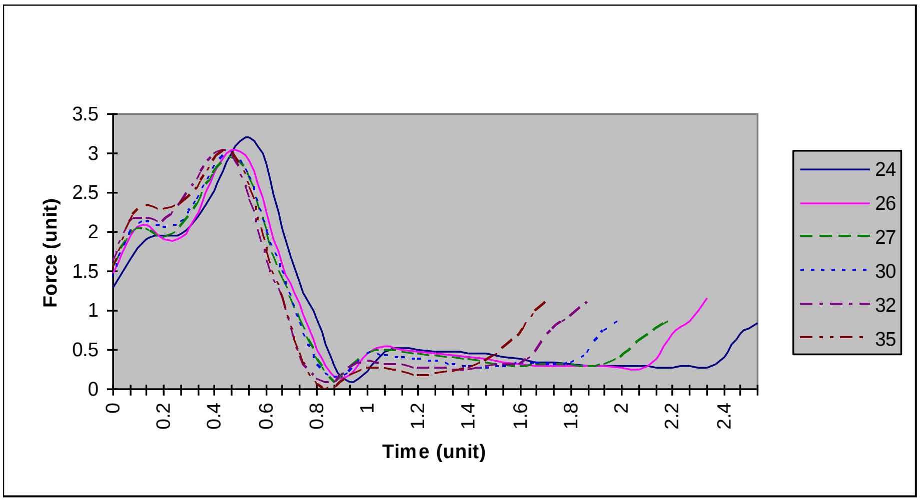

Figure 13. Consistency of international rower at different stroke rates

Figure 14 shows the effect of changing technique (varying the time of application of maximum force) by a veteran rower.

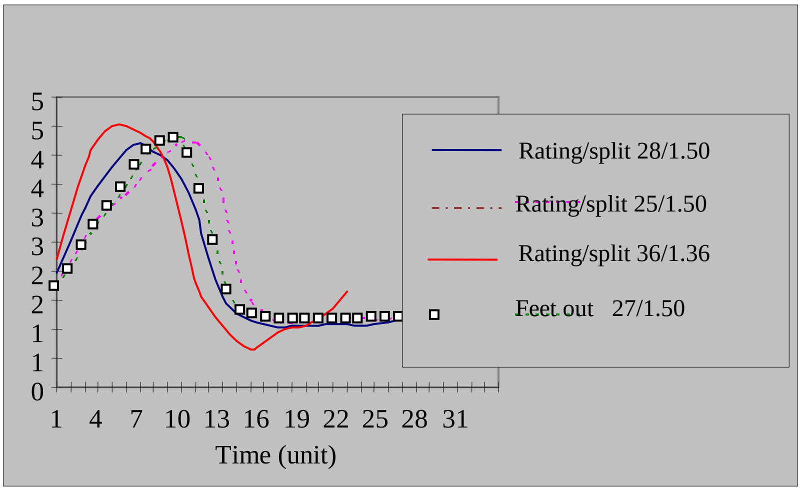

Figure 14. Comparing technique at different rate and style

6.0 BIOMECHANICS IN ROWING

The objective of the study of biomechanics in rowing is to make boats go faster. Biomechanics is interested in how the rower converts his/her physiological capacity into moving the boat. Research has shown that there are certain indicators, which point to an individual's aptitude for the sport (body height, arm length, lean body mass), and a number of biomechanical principles, have been identified which apply to all rowers (tall or small, sweep oar or scullers), Nolte (1991).

6.1 Biomechanical principles

Principle 1

> "All movements have to be performed in a way that the rower is able to transfer his/her physiological performance into optimal propulsion."

Principle 2

> "A long stroke is necessary to produce a high level of rowing performance."

The faster the boat the longer the length of stroke can be; the more powerful the rower the longer the length. Speed is related to a large force developed over a long distance in as short a time as possible.

It has been found that the angle of oar at the finish is similar with most rowers, and body height has little influence, Nolte (1984). Thus, the length of stroke can only be changed at the entry. The current teaching is that the most effective use of the rower's strength is in the early dive phase of the stroke, before the oar reaches the orthogonal position. To produce the maximum force the rower has to move his/her body weight. Power is required to do this and it is used in the following ratio: 75% to move the oar; 9% to support the horizontal movement; 16% to produce vertical movement of the body.

Principle 3

> "The movement of the rower has to be as horizontal as possible, so that the vertical displacement of the centre of gravity is minimised without losing length in the stroke."

Vertical movement is caused by: flexion of the legs, swing of the upper part of the body for the hips, and vertical movement of the arms. Vertical displacement can be reduced and a position with a naturally round back with minimal vertical movement of the hands are "signs of a physically correct technique", Nolte (1991).

Principle 4

> "The horizontal velocity of the rower relative to the boat should be as small as possible (i.e. the displacement of the centre of gravity in the horizontal plane should be minimised without losing length of the stroke and there should be no lost time with stops or pauses)."

To follow Principle 4, the horizontal distance of the centre of gravity must be reduced as much as possible and horizontal movements have to be performed with as little change in acceleration as possible. The current thinking is that the fully compressed technique, which involves large changes in momentum (i.e. Karl Adams technique), is incorrect. Principle 4 is confirmed by the Newcastle studies.

7.0 TECHNIQUE, RIGGING AND BIOMECHANICS

It is possible to make changes in rigging to assist the rower in adhering to the four biomechanical principles associated with rowing.

7.1 Principle 1

Make the rower as comfortable as possible. Also the rower has to be fit and flexible, and at optimum body weight (i.e. lose weight).

7.2 Principle 2

Long strokes can be achieved, by changing the outboard measurement of the rig, and by raising the rig. Perry Chuter (1991) argues that most women rowers in the UK have spreads, which are too large and also oars, which are too long. Weaker/smaller rowers need larger arcs as they cannot develop the power over a limited stroke length to accelerate the boat. A longer stroke forward also reduces the influence of the catch and the finish.

7.3 Principle 3

The horizontal movement of the crew, can be reduced by adopting the "reach" technique (essentially the modern British technique). The reach technique has biomechanical benefits over the "compressed" technique in that the catch is taken with the legs, there is less fatigue build-up in the leg muscles and the power can be developed at the beginning of the stroke.

It is argued that the compressed technique can lead to: reduced stroke length, uncontrolled sliding, the catch being taken on the back and rapid fatigue.

7.4 Principle 4

The reach technique is compatible with this requirement, whilst the compressed technique is not.

7.5 Sliding Riggers

An alternative method of eliminating or reducing the effects of crew momentum on the movement of the boat is through changes in boat design, such that the crew is not required to move relative to the boat. This can be achieved by eliminating the sliding seat and substituting the sliding rigger. As the riggers of a boat are significantly lighter than the crew, the momentum effect generated by moving the rig relative to the boat will be small.

Sliding rigger boats were introduced in the 1970s and Kolbe won the world sculling title using this system in 1981. In 1983 all six finalists at the world championships used sliding-rigger boats, after which they became ineligible for competition on the grounds of expense.

It was argued that the sliding rigger provided only a slight reduction in drag due to the elimination of the pitch and yaw of the boat. However, the Newcastle research suggests that the benefit derived from the use of the sliding rigger was more significant. Support for this argument can be seen by studying the motion of some of the new play boats now offered on the market. At least two of these use sliding riggers and a feature of their performance is the complete elimination of any "check" during the stroke irrespective of the skill of the rower.

7.6 Sculling

Smaller rowers need shorter oars, less overlap and shorter spreads. Length of arc needs to be 60-65° forward and 35° at the finish. Raising the rig increases the length of the stroke, but reduces the power of the finish. Finally elbows “out” is bio-mechanically more efficient than elbows back.

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