Results

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Revision: February 2011

1. Introduction.

With the Scilab model described Theory and Model a number of calculations have been performed.

In the first simulation the maximum force on the blade has been specified and after a stationary situation has been developed energy, power, stroke rate and boat speed have been extracted.

For the following simulations an additional iteration around the simulation model has been used: the maximum force on the blade has been adjusted until a specified power input has been reached. The only fair comparison for alternatives is on the basis of equal power input.

2. Result of a single simulation.

The simulation has been run on one set of input data. The force on the blade and the time for the recovery specifies the effort of the rower. Numbers are thought to represent a single scull. Fig 2.1 is the specification of the required force curve. Fig 2.2 shows the seat speed in the recovery.

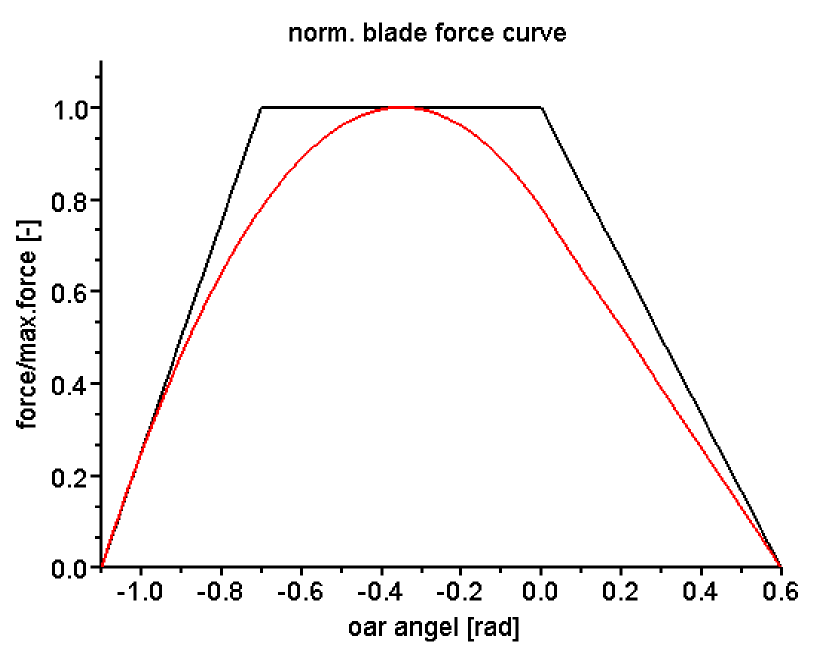

Fig 2.1
Required force curve (normalized)

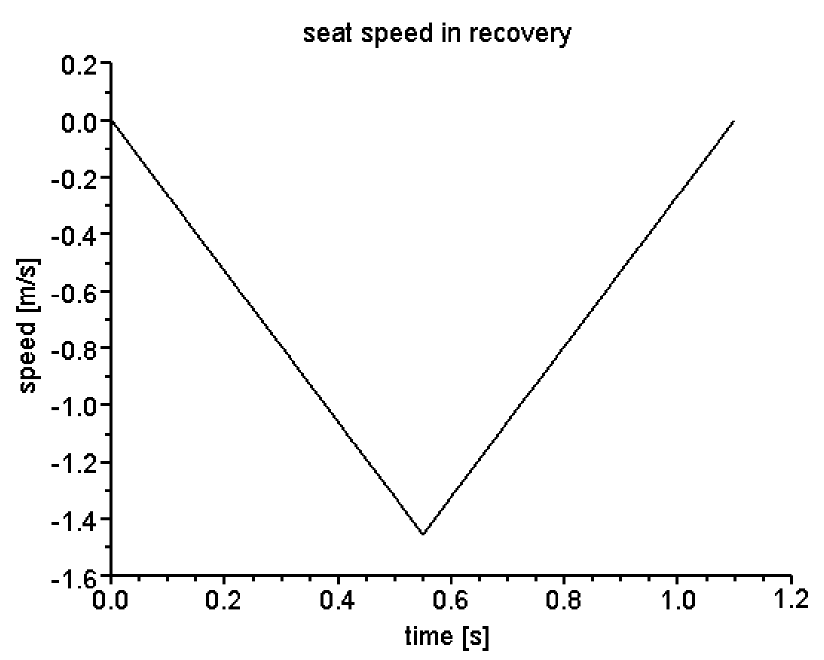

Fig 2.2
Seat speed during recovery

-------- input data --------

m1	m2	Fbl	L	fi1	fi2	sl	TR
kg	kg	N	m	rad	rad	m	s
30.0	70.0	350	1.80	-1.10	0.60	0.80	1.10

area	C1	C2
m2	N.s2/m2	-
0.130	3.50	1.00

------- results -------

Ebls	Exs	Et	eff	ST
J	J	J	-	s
173.9	665.7	839.6	0.793	1.94

SR	T2000	Pt	Pbl	vel
s^{-1}	s	W	W	m/s
31.00	444.1	433.9	89.6	4.503

Table 2.1
Input and results

m_1=	mass of the boat + that part of the mass of the rower that does not move with respect to the boat + hydrodynamic added mass
m_2=	that part of the mass of the sculler that moves with respect to the boat
Fbl =	force perpendicular on blade
L=	distance pin to point of application of force on blade
fi1=	value of φ at the catch
fi2=	value of φ at the finish
sl =	distance covered by m_2 with respect to m_1 (sliding length)
TR=	time for the recovery
area=	area of two blades
C1=	resistance coefficient of boat hull
C2=	maximum lift coefficient of blade (actual value depends on angle of attack)
Ebls=	energy delivered at the blade
Exs=	energy dissipated by boat resistance
Et=	sum of Ebls and Exs
eff=	overall efficiency
ST=	time for one stroke
SR=	strokes per minut
T2000=	time to cover 2000m
Pt=	total energy flow (power) to be delivered to the system
Pbl=	energy flow dissipated at the blade (puddle energy)
vel=	mean velocity of the boat

Table 2.2
Explanation of used names

Remarks
The stroke extends from –1.1rad (-63^o) to 0.6rad (34^o), a total angle of 1,7rad (97^o).
The maximum force on the blade is 350 N with an outboard lever of 1.80 m. When the inboard lever is 0.8 m, then the handle force perpendicular to the scull is 18/8 * 350 = 788 N. The delivered power is 433.9 W. These figures indicate a medium strong competition rower (not belonging to the international top) who realises a time of 427 s (= 7 min 24 sec) over 2000 m. A realistic time for him. His stroke rate is 31 strokes/min. He has a relatively quite recovery. Ratio recovery time/drive time is 1.1/0.84 = 1.31. The variation of the boat speed in one rowing cycle is rather realistic.

The maximum velocity of the seat during the recovery, was reached after 0.5 times the total time for the recovery TR.

The graph of the boat velocity during one complete cycle is shown in Fig 2.3 below.

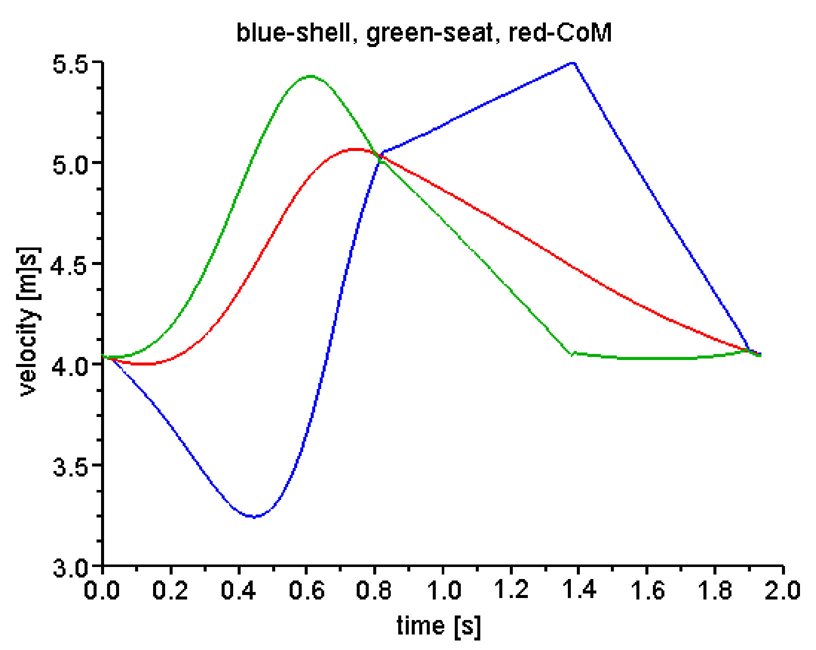

Fig 2.3
Velocity variations during one cycle of shell, seat and centre of mass in earth fixed reference system.

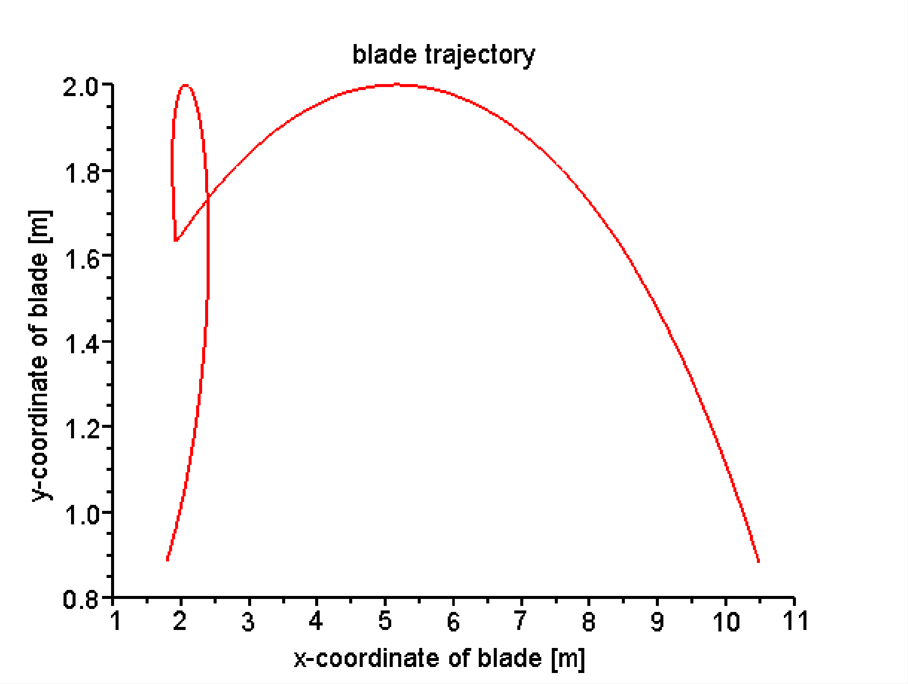

Fig 2.4
Trajectory of the blade tip, projected on the water.

In Fig 2.4 the trajectory of the blade tip (0.2m outwards of the point of application of the blade force) has been plotted. This plot does not support the opinion that at the finish position the blade has moved with respect to the catch position over a considerable distance (e.g. 1m) although the blade in the first part of the stroke moves clearly into the heading direction. Note the different length scales for x- and y-axis.

Fig 2.5 shows the instantaneous propulsion efficiency.
The instantaneous propulsion efficiency is calculated from:

$$\eta = \frac{P_u}{P_{in}}$$

where:

$$P_{in} = F_n.\dot{\varphi}.L$$

$$P_u = F_{n.}v_B.\cos\varphi$$

P_{in} = power supplied to the oar
P_u = power used for the propulsion of the boat

In this simulation model the instantaneous propulsion efficiency will always equal unity at the catch and at the finish irrespective of the catch and finish angle, because the blade force is zero at these oar positions. The relative flow velocity vector is parallel to the oar axis.

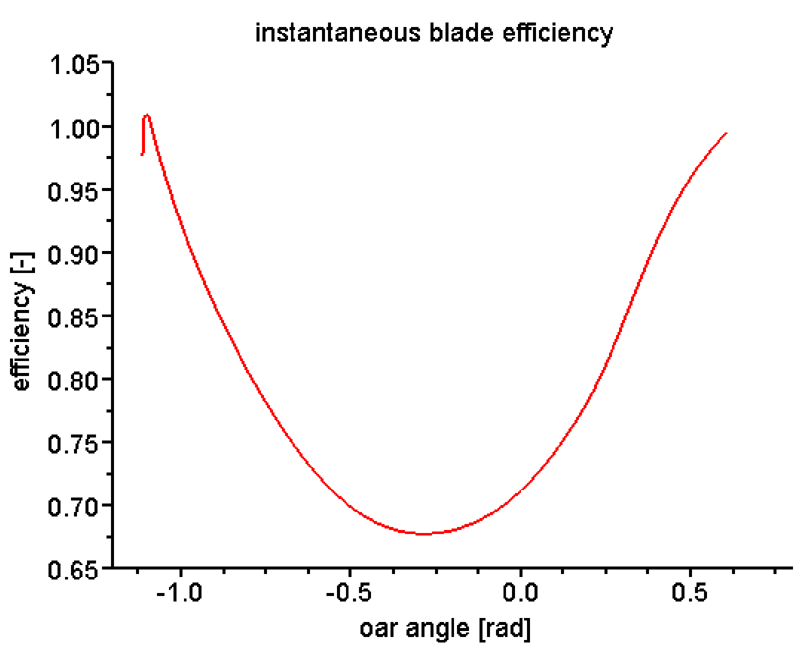

Fig 2.5
Blade efficiency variation during one cycle.

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3. Variation of seat speed during recovery.

The question of how to distribute the seat speed during the recovery has been raised very often among rowers. The classic way is to move away quickly from the back stops (finish position) and to decelerate towards the front stops (catch position). This method results in a shell velocity peak in the beginning of the recovery and as the hull resistance is a quadratic function of the hull speed extra resistance is generated.

The opposite method is to start slowly and to accelerate towards the front stops. This results in a more even speed of the hull during the recovery and consequently a reduction of the resistance with respect to the first method. This reasoning is completely correct but expressed quantitatively the difference is very small.

In the literature of rowing the subject of loss of kinetic energy as a result of the moving rower has not received much attention but has much more influence than the effect described above. See the website of Bill Atkinson. He argues and shows by simulation that the most efficient way to roll to the catch position is to maintain a seat speed as constant as possible. (“Management of the free return” ,in his words).See also Kinetic energy dissipated by the moving rower.

In my simulations (for practical purpose) a triangular seat speed graph will be used. The purpose of the next simulation is to show that it matters very little where the top of the triangle is positioned. Fig 3.1 shows three modes of return in a time T (TR in table 2.1). In all three modes the same distance (the area of the triangle) is covered. The position of the top speed is given by the coefficient p. The top speed is reached after p.T with p = 0.2, 0.5 and 0.8.

(It can be proved that the top speed also is at p.sl, where sl is the sliding length.)

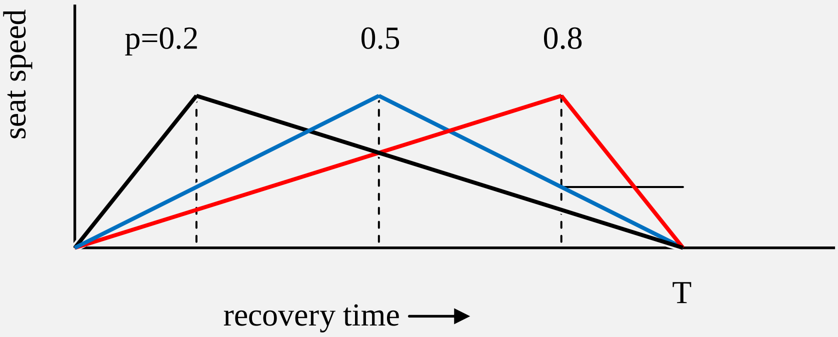

Fig 3.1
Seat speed with max speed at different times

The graph of the boat speed is shown in Fig 3.2. The curves have the same colour as in Fig 3.1.

The instantaneous boat speed during the recovery is very different and can certainly be observed by a coach. In the red mode he will observe a strong increase of speed immediately after the start of the recovery. The following speed decrease will probably remain unnoticed because of its gradual nature. In the black mode the coach will probably be alarmed by the sharp decrease of boat speed towards the next catch. The average speed however is for the three variations (almost) the same. Conclusion: nothing can be won or lost, for *given recovery time.*

This has been shown for a triangular speed distribution but it is believed to be true for any speed distribution.

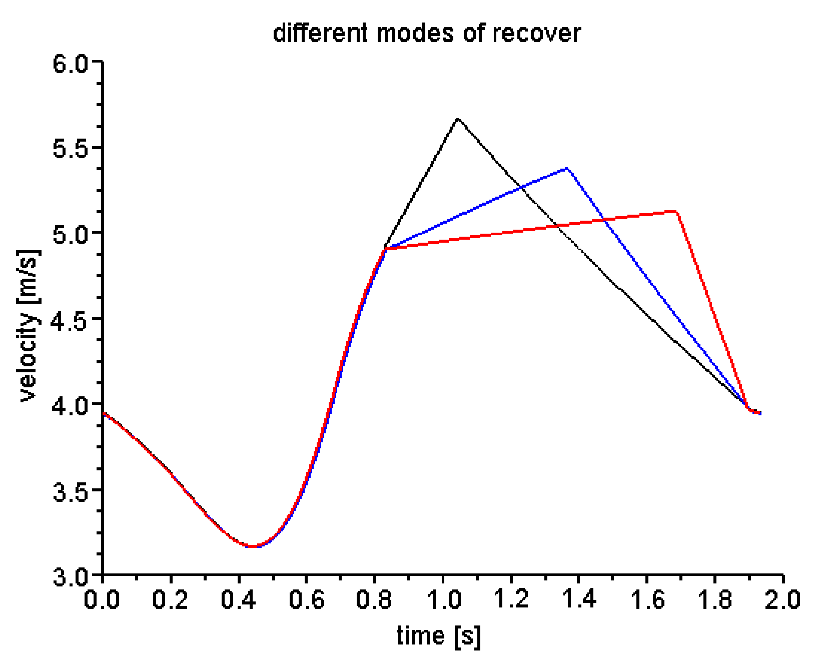

Fig 3.2
Variation of recovery mode at 400W power input
black: p = 0.2 blue: p = 0.5 red: p = 0.8

In digital form, see Table 3.1, some small and non-systematic differences can be observed. It is believed that they are partly due to inaccuracies and rounding during the simulation.

p	T_{2000}	P_{row}	SR	F_{bl}	eff

-	sec	W	min^{-1}	N	-
0.2	458.7	399.1	31.0	322.5	0.794
0.5	458.1	398.3	31.0	322.5	0.793
0.8	456.1	401.2	31.1	325.0	0.792

Table 3.1
Variation of recovery mode at 400W power input

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4.Variation of blade area.

The blade area has been set consecutively at 0.1, 0.2, 0.3 and 0.4 m2. The higher values have no practical meaning but have been included for demonstration only. The power input has been set at 400W±0.5%. This is value is approximated by iteration of the blade force. The other input quantities have the same value as in paragraph 2. This results in the following values in Table 4.1. For information the number of iterations n has been added.

A	T_{2000}	P_{row}	SR	F_{bl}	eff	n
m^2	sec	W	min^{-1}	N	-	-
0.1	464.3	399.7	31.0	322.5	0.763	9
0.2	447.7	400.5	30.4	330.0	0.842	7
0.3	441.0	400.0	30.2	332.5	0.880	10
0.4	436.7	401.1	30.0	335.0	0.902	9
0.5	434.3	400.3	29.9	335.0	0.917	9

Table 4.1
Blade area variation

The various boat speed graphs are presented in Fig 4.1.

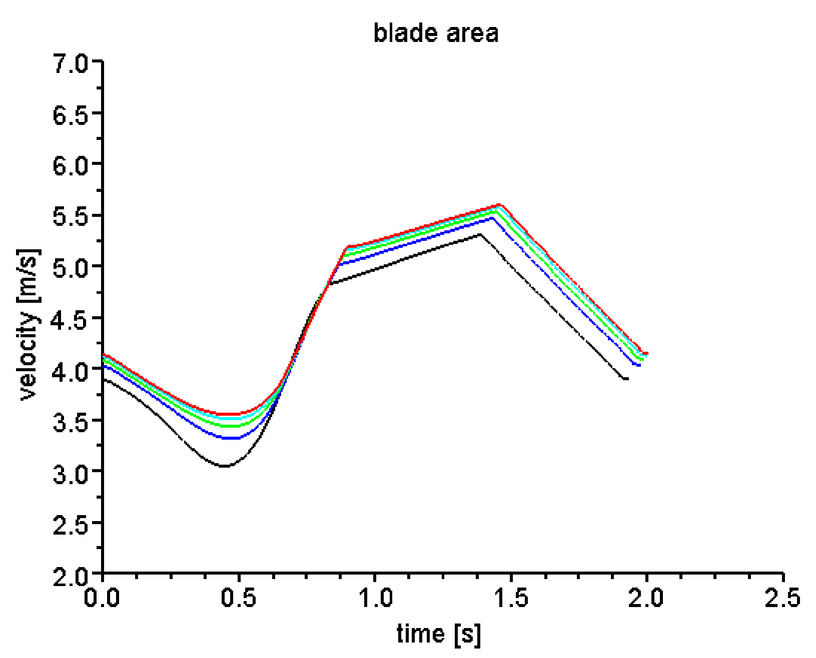

Fig 4.1
Boat speeds for various blade areas.
black: 0.1m^2 red:0.5m^2

The relation between blade area and the time to cover 2000m is presented in Fig 4.2.
The areas of two Macon blades and two big blades are approximately indicated with the reading of the 2000m times. This is about 8s, more than 4 lengths in the single.

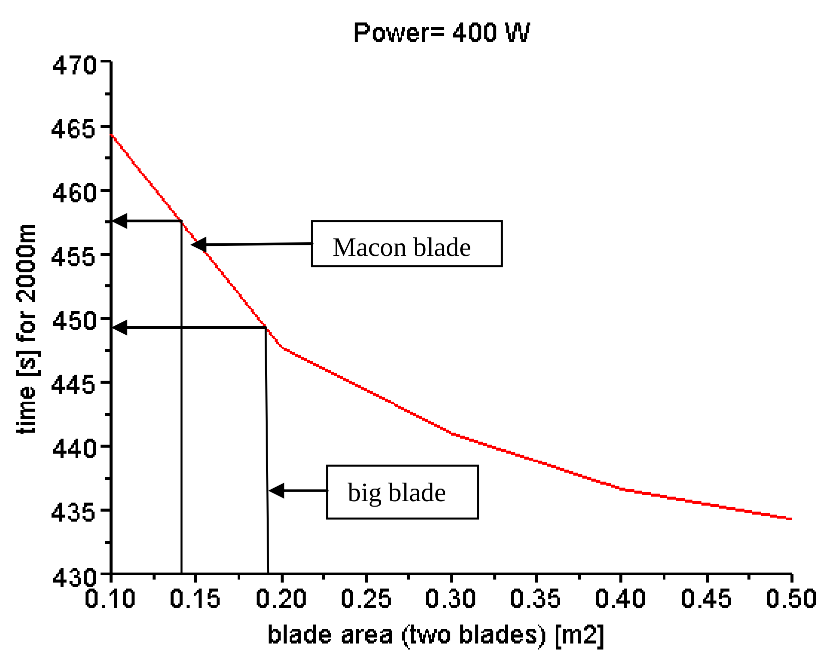

Fig 4.2
2000m time as function of blade area.

Remarks

The advantage of a bigger blade area is widely accepted. It can easily made clear in a simple simulation as here and practice has proved it.
According to the simulation results moving from Macon blades to big blades results in an important gain of velocity but further increasing the blade area shows diminishing returns. The general tendency with an increasing area at constant power input is: greater speed, lower stroke rate, and better efficiency, while the blade force hardly grows. See also in Fig 4.1 that the bigger blade results in less speed loss immediately after the catch, which in turn is a result of lower seat speed.

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5. Variation of outboard length of the oar.

The outboard length of the lever arm of the blade force has been varied: 2.0, 1.8 and 1.6m without changing anything else in the configuration. The results are listed in
Table 5.1.

L	T_{2000}	P_{row}	SR	F_{bl}	eff
m	sec	W	min^{-1}	N	-
2.0	455.2	400.0	29.4	312.5	0.801
1.8	457.1	400.0	30.8	325.0	0.795
1.6	460.3	398.7	31.9	342.5	0.787

Table 5.1
Outboard length variation

The velocity graphs are shown in Fig 5.1

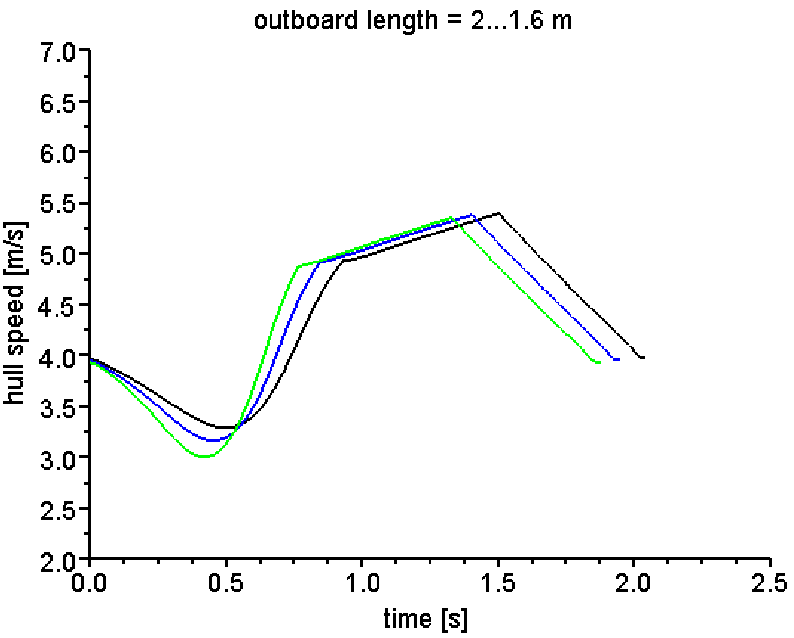

Fig 5.1
Shell velocities for varying outboard length.
black: 2.0m blue: 1.8m green: 1.6m

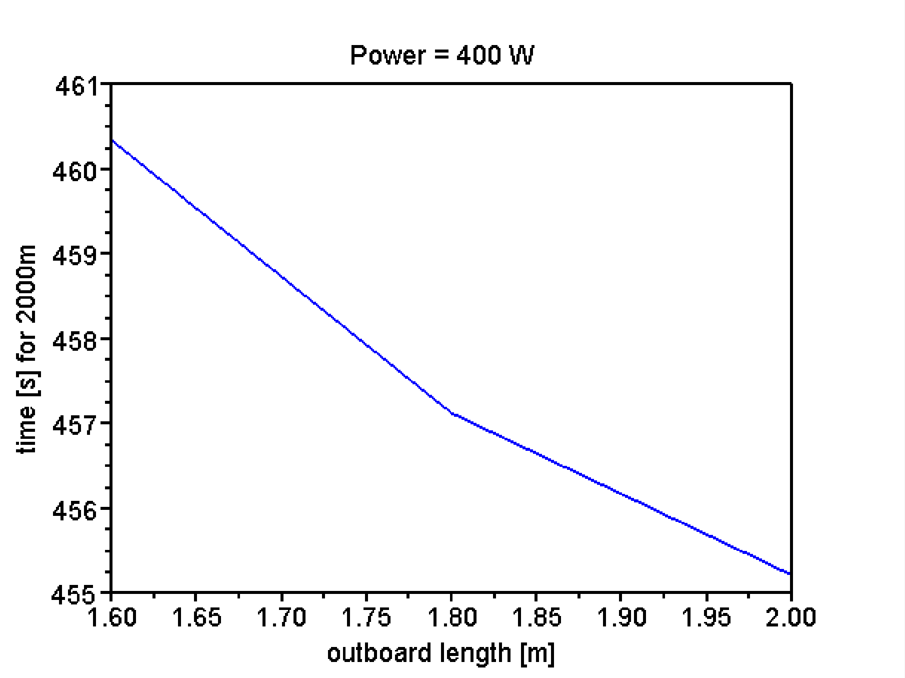

Fig 5.2
T2000 for varying outboard length.

Remarks.
Table 5.1 shows a decrease of T2000 by roughly 5s by increasing the outboard length from 1.6m to 2.0m. The efficiency increases 1% point. The stroke rate decreases from 32 to 29 strokes/min. One might wonder how it is possible that the average boat speed increases while there is a decrease in blade force. The answer is of course that the blade is longer in the water (see Fig 5.1) and thus the impulse is greater.
A greater outboard length results is a smaller blade force but due to the leverage the handle force will be greater.
In practice changing the outboard length is usually combined with a change of the inboard length and possibly also with the span width. Then the catch- and finish angle will probably change too. See also Rowing Biomechanics Newsletter, August 2003.

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6. Variation of recovery time

The time for the recovery Trec has been varied: 0.8, 1.0 and 1.2s. The other parameters have the same value as before. The results are listed in Table 6.1.

T_r	T_{2000}	P_{row}	SR	F_{bl}	eff	n
sec	sec	W	min^{-1}	N	-	-
0.8	456.3	401.0	35.9	275.0	0.816	8
0.9	456.4	400.6	33.9	292.2	0.809	8
1.0	456.5	401.9	32.3	310.4	0.801	8
1.1	457.4	400.5	30.7	326.0	0.795	5
1.2	458.5	400.0	29.3	342.3	0.789	5

Table 6.1

Varying recovery time T_r . Power input 400W.

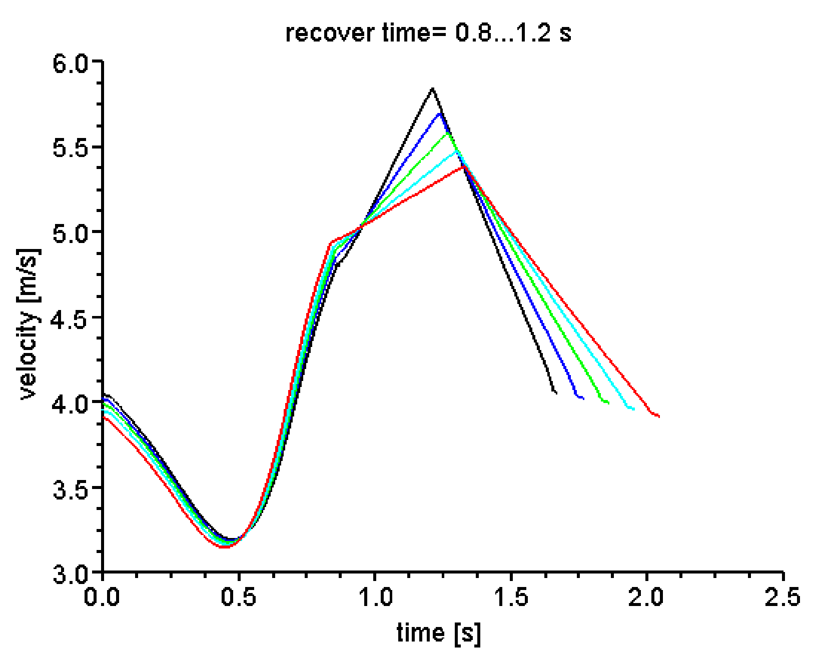

Fig 6.1

Shell speed for varying recovery time.

black: 0.8s red: 1.2s

The time for the 2000m track is plotted in Fig 6.2.

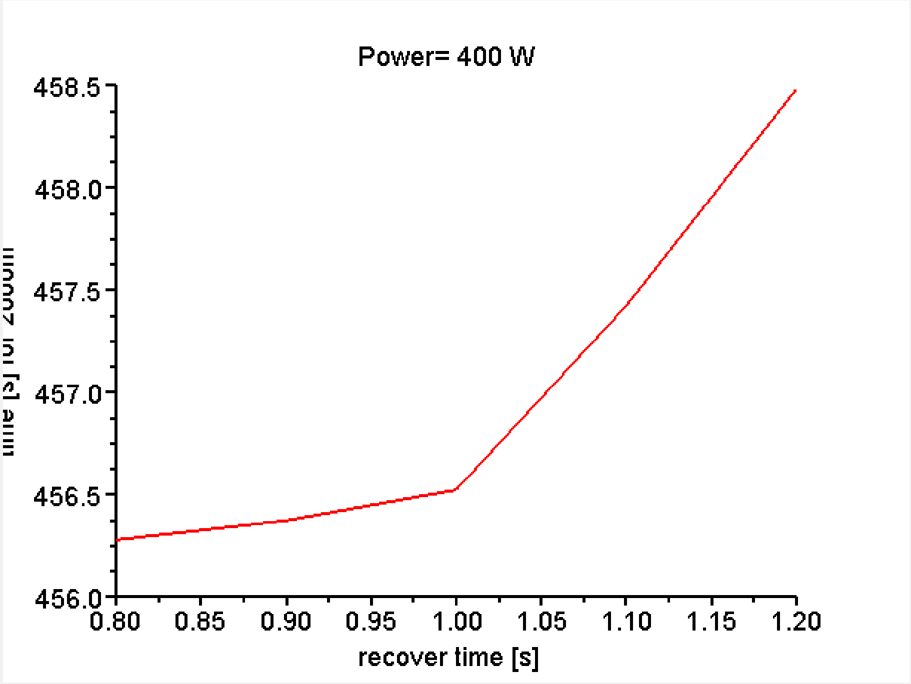

Fig 6.2
Time for 2000m [s] as function of recovery time

Remarks
The variation of the recovery time shows that it is efficient to take your time for the recovery. Fortunately this is in agreement with the opinion of the majority of coaches and rowers. Table 6.1 shows however that you will gain little. Table 6.1 also shows that in order to deliver the required power the force on the blade is considerable greater for the slow recovery. A strong rower is better capable to row with a slow return. The small difference in this simulation makes it less reliable.

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7. Variation of blade force curve.

Fig 7.1 shows the (unit) blade force curves used for this variation exercise. The finish angle is 0.6 rad and the catch angle is -1.1 rad as before. The The position of the oar for the maximum blade force varies from -0.709 (front loaded catch) to -0.233 (back loaded catch). See Fig 7.1.
This simulation does not show a clear difference between the three shapes of the force curve. But the front loaded catch requires a bigger maximum blade force.

Max force at	T_{2000}	P_{row}	SR	F_{bl}	eff
rad	sec	W	min^{-1}	N	-
-0.709	456.6	401.1	31.1	390.0	0.789
-0.471	457.8	400.3	30.8	352.5	0.790
-0.233	458.3	401.8	30.5	350.0	0.790

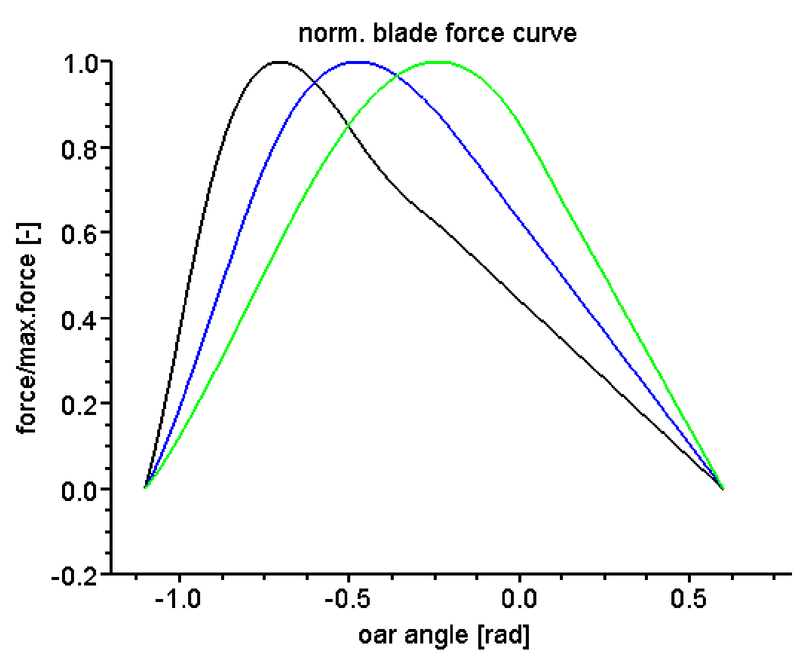
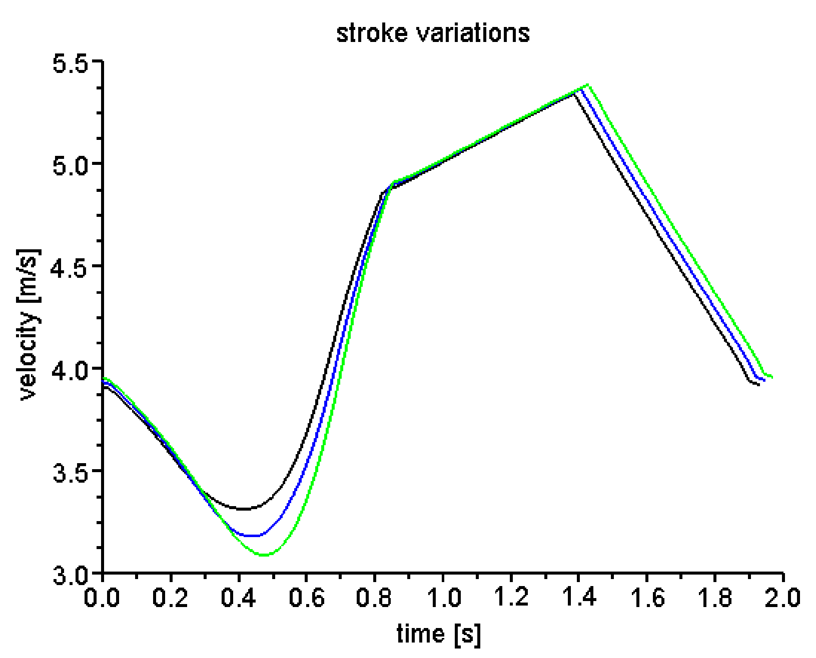


Fig 7.1
Variation in blade force curve.
Various oar angles for maximum blade force.

Fig 7.2 displays the boat speed variations that show no spectacular differences for the three force shapes considered.
Practice has shown that crews with different styles of drive can deliver a comparable performance. In this sense this simulation in accordance with practice.


stroke variations
velocity [m/s]
time [s]
5.5
5.0
4.5
4.0
3.5
3.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0

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