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Verification of the ROWPERFECT ergometer.

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1. Introduction.

I was once asked to define in a few words why rowing is such an exciting sport for me. My answer was and is:"Rowing is for me the ultimate combination of endurance, brute strength and perfect coordination."
As youu probably all know by your own experience, of these three factors it is the perfect coordination which is most difficult to train. It is therefore surprising that many oarsmen and oarswomen spend a lot of their precious time increasing their endurance and /or strength on machines that are absolutely detrimental to perfect coordination between the main muscle groups that are used in rowing. That it can be done differently and better is the main subject of this paper. This paper is divided into four chapters.

2. The dynamics of the ROWPERFECT ergometer as a boat simulator.

In the autumn of 1989, a critical young girl whom I trained as a sculler made some very clear observations which led to the development of the ROWPERFECT, ergometer. Due to the days getting shorter she had to start to do a major part of her training on a rowing substitute called an ergometer. The club where she was rowing had two types of ergometers available, a Gjessing and a Concept II.

The first week she trained on the Gjessing, and her comment at the end of the week was: "This one is not like a boat. If I try to row on it like I do in the boat, it is too hard for my knees at the catch. " The second week she trained on the Concept II. In this case her comment was: "This one is not like a boat either. If I try to row on it like I do in the boat, I feel slack at arms and back at the beginning of the stroke, and then, a little bit further I suddenly feel a sharp rise in force on arms and back, and it makes my back hurt."
Her observations at that time were accurate, and her comments were in line with remarks of Australian oarswomen and German oarsmen reported in the litterature, Ref. 1 and Ref. 3 respectively.
In order to understand why this is the case we need to analyse the dynamic situation in

a racing shell, which is quite different from that of any ergometer with a stationary stretcher board.

A racing shell is floating freely on the water, and the oarsmen are moving freely along the length axis of the boat; the only fixed place of contact being the stretcher. The mass of a racing shell, including the weight of the coxswain, per oarsman is between approximately 40 kg for a coxed pair and 14 kgs for a single. This difference in ratio between the mass of the crew and the mass of the boat is one of the reasons why the different boats "feel" differently.

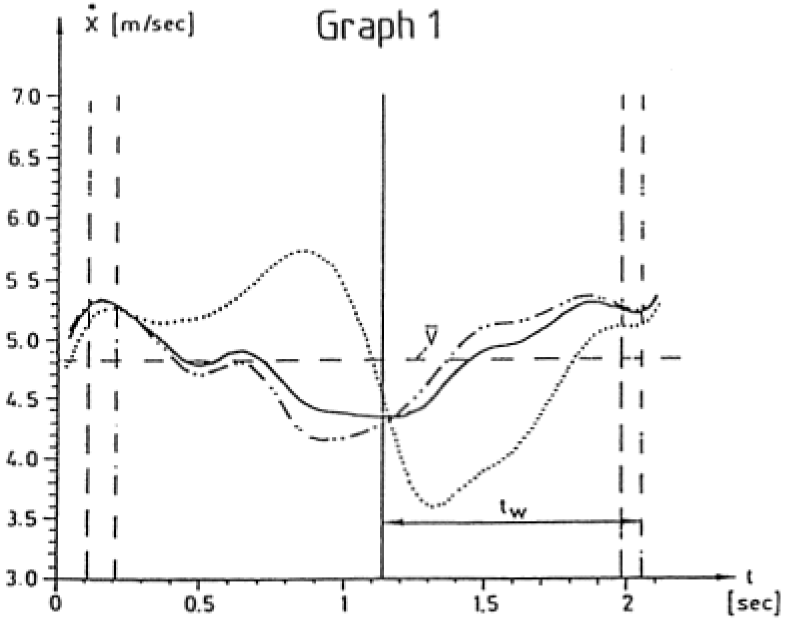
When, with the boat at rest, the crew are moving forwards and backwards in the boat without touching the water with the oars, you all will have noticed that the relatively light boat moves much further forwards and backwards than the crew do, and in a direction opposite to the crew. The laws of mechanics dictate that the ratio between the deplacement of the boat and that of the crew is inversely proportional to the ratio between the mass of the boat versus the mass of the crew and with the common centre of gravity of boat plus crew at rest.

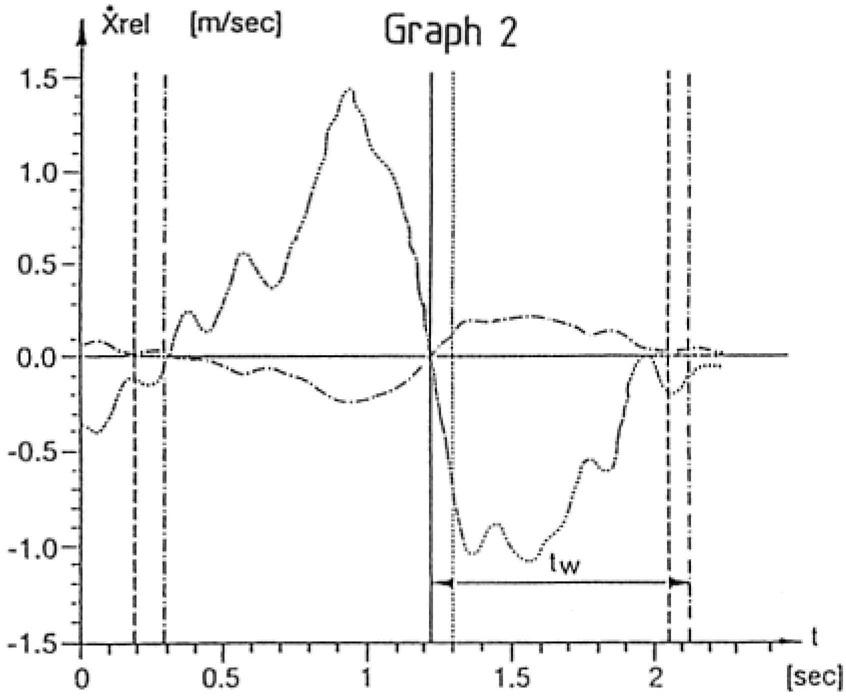
Extensive studies made by Dr. Volker Nolte in Germany (Ref. 2) show that the same relative movement between crew, common centre of gravity and boat, also exist in moving boats, in this case superimposed on the movement of the common centre of gravity. This is the main cause of the fluctuation in velocity of the boat during a stroke/recovery cycle.

Something we have all seen, but perhaps not always have realised.

In the following example the curves of Dr. Noltes test person are used as an illustration of the basic principle. It goes without saying that the same principle is also valid for other boats and other oarsmen.

Graph 1, taken from his thesis shows the measured velocities of the centres of gravity of the boat, (dotted line) the sculler, (stroked line) and the common centre of gravity (drawn line) during one cycle. The time bracket that the blades are in the water is tw. Note that the stroke/recovery cycle takes about 1. 87 seconds and that the oarsman is therefore sculling at a rate of approximately 32 strokes per minute.





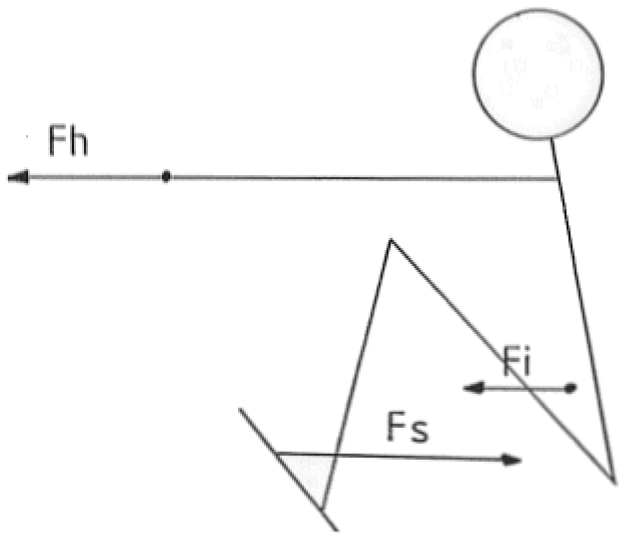
The testperson is indicated as being a very experienced sculler with more than 10 years of international experience, weighing 85 kgs, rowing in a boat of 17 kgs. Graph 2 shows the relative velocities of boat and sculler relative to the common centre of gravity. Clearly it can be seen that, as theory predicts, the two velocities are opposite, and inversely proportial to the masses of boat and sculler. For the acceleration and deceleration of the sculler vis a vis the boat, a certain force is necessary. This inertial force Fi can be mathematically described as

Fi=M*dV/dt

Whereby:

Fi=Force on the oarsman in (N)
M =Mass of the oarsman in (Kgs)
dV/dt=Acceleration of the oarsman in (m/sec2)
V =Velocity of the oarsman in (m/sec)
t =time in (sec)

Fig. 3



When we look at the balance of all forces acting on the oarsman along the length axis of the boat in fig 3, we see the following:

Fh=-(Fs-Fi)

whereby:

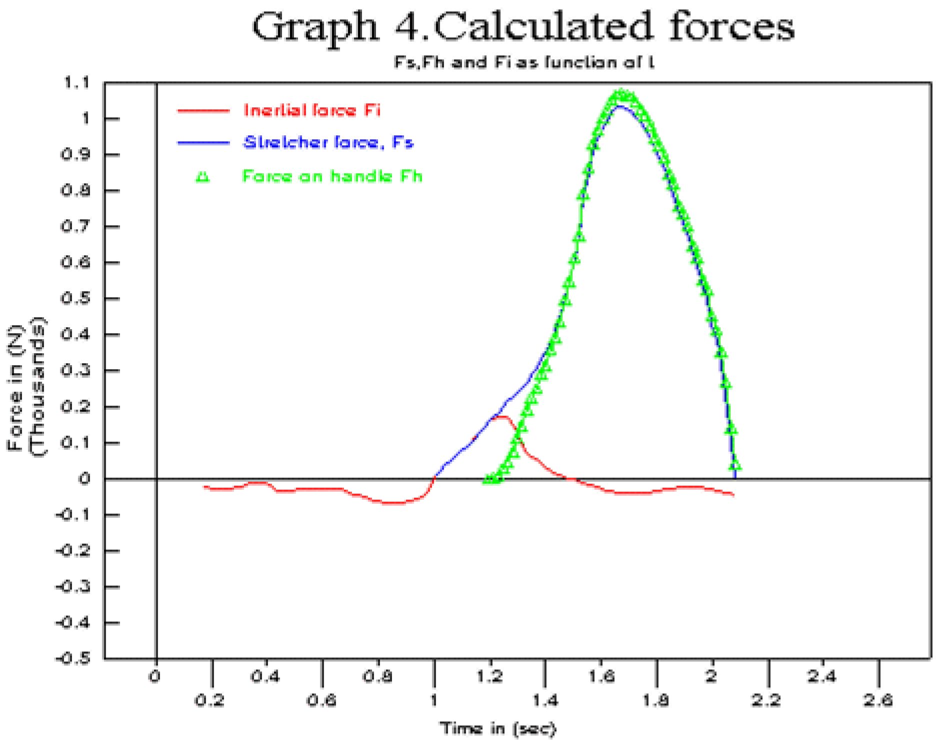
Fs=The force of the stretcher on the oarsman in (N)
Fh=The force of the handle on the arms of the oarsman in (N)

Or in words:

The force excerted by the oarsman on the handle (=-Fh) is what is left of the force on the stretcher after the inertial force necessary to accelerate the body has been subtracted.

What does this teach us about ergometers and about the degree of accuracy with which ergometers are good boat simulators ?

From the curves of graphs 1 and 2 the corresponding force curves for Fh, Fs and Fi have been calculated. These are represented in graph 4, Fh at any time being the difference between Fs and Fi. It can be clearly seen that the inertial force Fi is only a very small fraction of the total force on the stretcher, and that this force in the graph falls completely within the stretcher-force/time curve. Note also that the force on the handle Fh starts approximately 0. 25 sec after the body has started decelerating

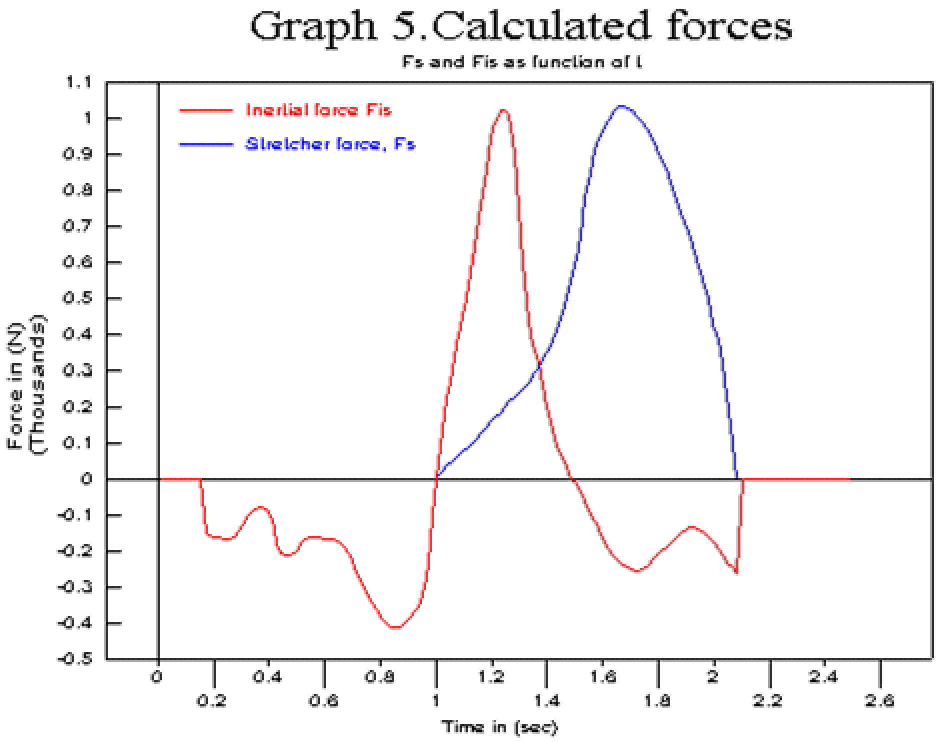


This represents the "dynamic case".

The ROWPERFECT ergometer has been designed to simulate this dynamic case most accurately. It consists of an essentially horizontal bar simulating the water, and two moving parts each floating freely on this bar. The first moving part being the seat, and the second moving part being a flywheel/stretcher assembly weighing about 15 kgs. This second part simulates the boat. It has a flywheel with fan blades designed to have approximately the same inertia as a rowing shell and an adjustable resistance factor covering the whole range of resistances between an eight and a coxed pair.

The ROWPERFECT ergometer is unique in it's dynamic simulation of the situation in the boat. The mass of the "floating" flywheel/ stretcher combination equals that of a single, and can be adjusted, by adding weight, to accurately simulate every type of boat. Therefore the inertial forces are the same as in the boat.

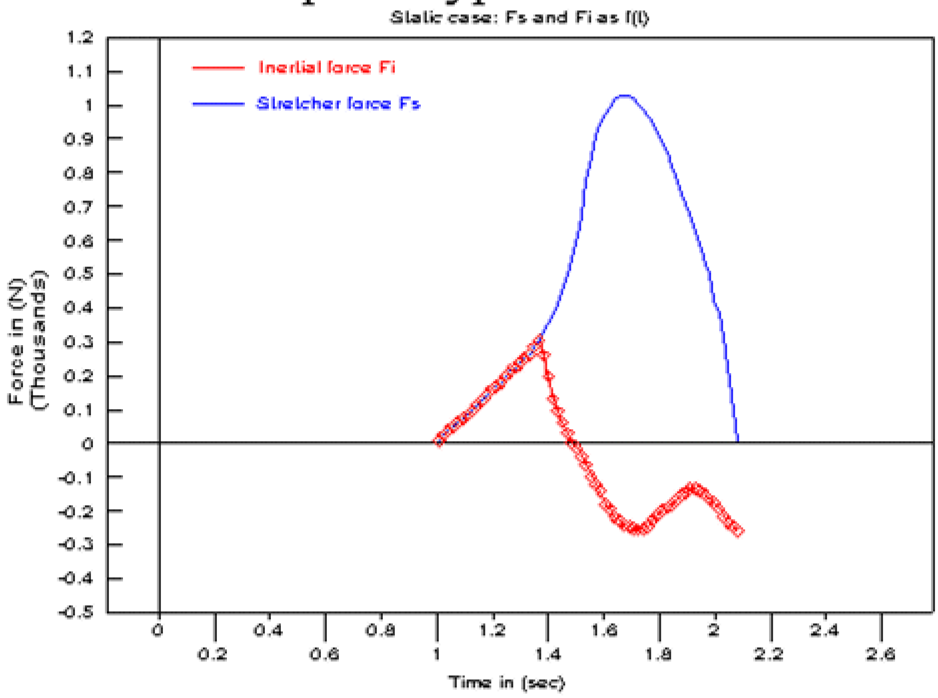
Now assume that the 17 kg racing shell this sculler was rowing in, suddenly gets an infinite mass, maintaining the same friction.
This means that, whereas in the "dynamic case" the main part of the relative movement is done by the boat or the boat simulating "floating" stretcher, in this "static" case it is the oarsman who moves relative to the common centre of gravity. This is equivalent to an ergometer with a fixed stretcher or a rowing basin.
In this "static" case, the oarsman tries to maintain the same coordination pattern between legs, body and hands as in the dynamic case. Also in this case, the force on the handle is equal to the force on the stretcher, less the inertial force necessary to accelerate the body.



In graph 5 the calculated inertial time/force profile necessary to maintain the same coordination pattern in this "static" case is compared to the total force on the stretcher in the dynamic case. It can be clearly seen that, in order to maintain the same movement pattern vis a vis the stretcher in this "static" case, during the first four tenths of a second of the stroke, the oarsman has to provide an inertial force to the stretcher far greater than what he normally does in the boat, and in a much shorter time. If the boatcurve is close to the maximum he can do, it is far greater than he is capable of.

The conclusion therefore is that his coordination pattern is going to shift so that the maximum of the inertial force on the stretcher falls within the limits of his physical capabilities. How this is done exactly depends very much upon the individual. Assuming the oarsman tries to adhere as closely to his coordination pattern as possible, the resulting curve could look something like the curve in graph 6.

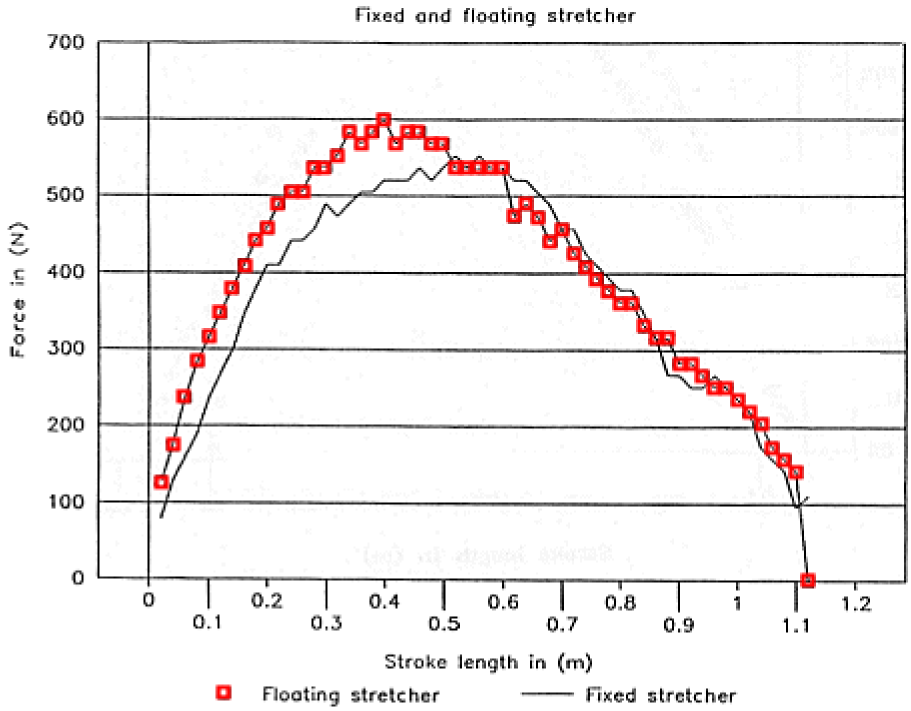
Graph 6.Hypothetical forces



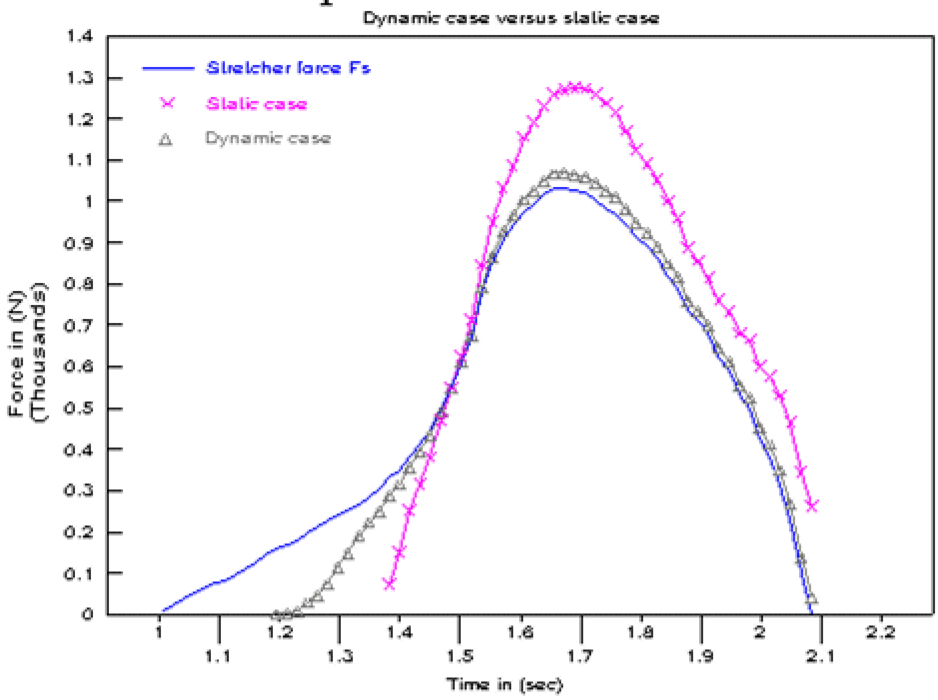
In this graph it is assumed that the stretcher force curve of the test person in the boat was the maximum he could do. Therefore that part of the inertial force curve surpassing the stretcher force curve arbitrarily has been cut off. Further it is assumed that the part of the inertial force curve inside the envelope of the stretcher force curve keeps the same shape, which is the least bad approximation.

On this basis the resulting force on the handle for this "static case", being the stretcher force less the inertial force, has been calculated. The result of this calculation is represented in graph 8 together with the force on the handle in the boat (dynamic case).

Graph 7.ROWPERFECT Goebel 12-8-93



Graph 8.Forces on handle



From this graph one can clearly see that in this "static" case the force on the handle is very small during the first phase of the stroke, comes approximately 0, 2 seconds later, and rises much more steeply as compared to the dynamic case. (graph 8) Hence the feel of "slack" at the beginning of the stroke and the punch at the back a fraction later at Concept II type ergometers.

An actual example of how this shift in coordination takes place is given in graph 7, which represents two force-length curves made on a ROWPERFECT ergometer by the most proficient sculler of the Netherlands, Frans Goebel, on August 12, 1993 at the laboratory of the Academy for Physical Education in the Hague. The first curve is the curve in the "dynamic" case. For the second curve, the floating stretcher has been fixed to the frame to obtain the "static" case. In both cases the curves represent the force on the handle. The shift in force between the two cases is quite noticable and in agreement with the above. From a video made at the same time the difference in coordination between the muscles of shoulders, back and legs can be clearly seen.

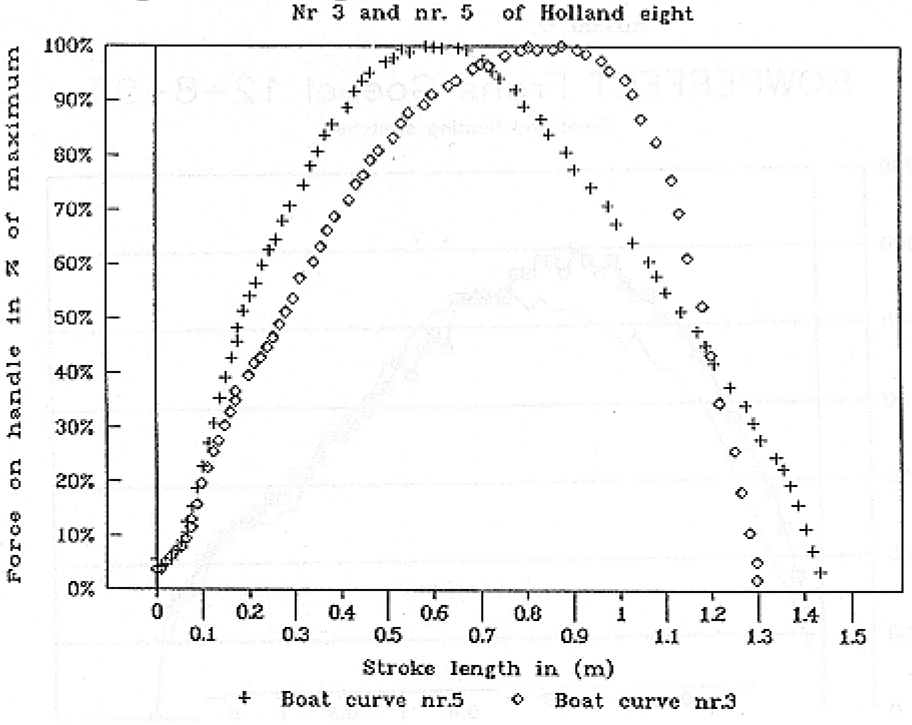
Note: A more accurate example is given in the addendum with two curves of exactly the same work

In the Gjessing ergometer one has tried to prevent this effect of slack at the beginning of the stroke by a higher gearing in the first part of the stroke, making the apparent inertia of the flywheel bigger at the beginning of the stroke, resulting in a higher force on the handle at the same displacement of the hands.
This makes the feel for arms and back better, but makes the situation for the legs worse, hence the hard feel on the legs at the catch on this type of ergometer.

3. Verification of stroke profiles made on the ROWPERFECT ergometer versus those in the boat.

To verify the stroke profiles made on the ROWPERFECT ergometer to those in a boat, a test run has been made by the crew of the Holland Eight. This run was made on the 23 rd of July. After an outing in the eight, the crew were asked to row on the ROWPERFECT ergometer, at a stroke rate of approximately 30 at standard strokes. The ROWPERFECT ergometer was then tuned to give the "feel" of the eight. To the opinion of the crew the best simulation was obtained using sprocket 1, with the fan set at a resistance factor of 26.
With this tuning, each member of the crew was asked to row at a rate of 30 strokes per minute, with their eyes closed, imagining they were rowing in the eight. It was shown that after a couple of strokes each individual reproduced his own curve with high accuracy. A surprisingly big difference however between the curves of the different individuals was found. Graph 9 shows for example the curves of the nr. 3 and the nr. 5 of the crew.

Graph 9.Comparison of boat force curves



Two weeks later at an outing of the Holland Eight the boat had been equipped with measuring equipment developed by mr. W. Mook et al. at the University of Groningen. Typical curves from the crew rowing at a rate of 33 strokes per minute were recorded on disk. Also these records were made without any feedback to the oarsman.

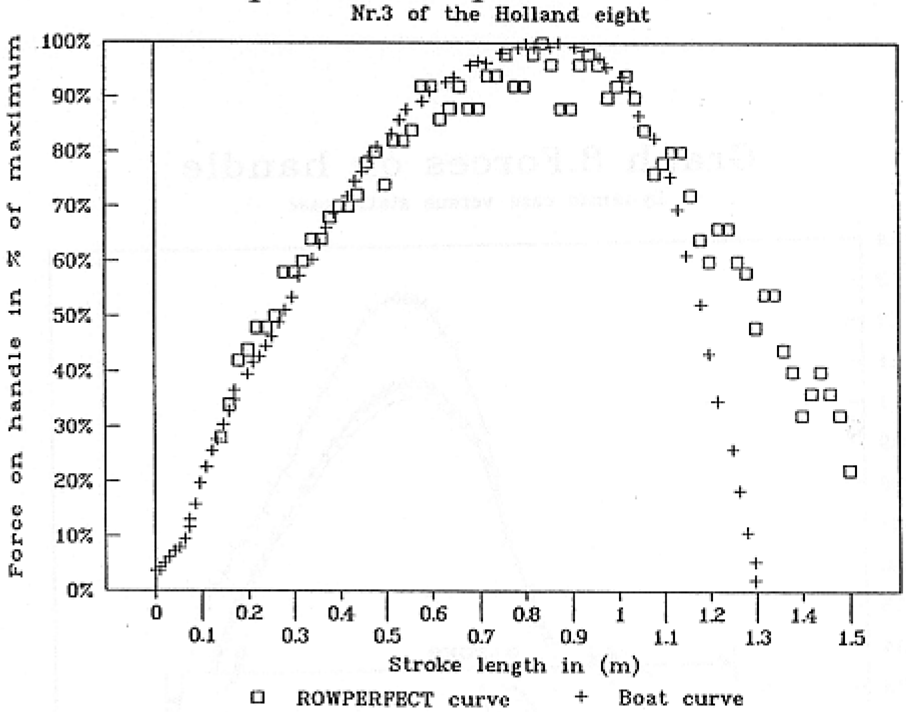
The records were kindly made available to me by mr. Mook.

Also in this case there were big differences between the curves of the different individuals.

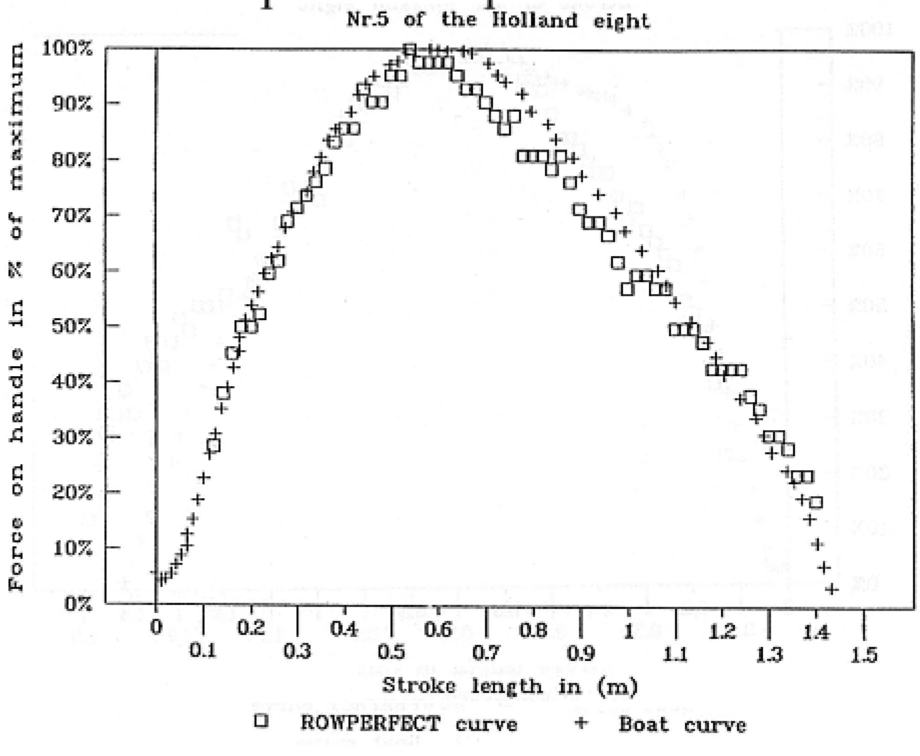
Both the ROWPERFECT curves and the Boat curves have been formatted in the same manner. The force on the handle of the oar in the direction of the length axis of the boat has been expressed as a fraction of the maximum during the stroke, and this relative force has been plotted against the length of the stroke.

For six of the oarsmen a very good similarity exists between the ROWPERFECT curve and the Boat curve. Typical examples arerepresented in graphs 10 and 11 giving the ROWPERFECT curves and the Boat curves for nrs. 3 and 5. A completely different example where there is a big difference between the ROWPERFECT curve and the boat curve is given in graph 12 representing the graphs of the stroke of the crew.

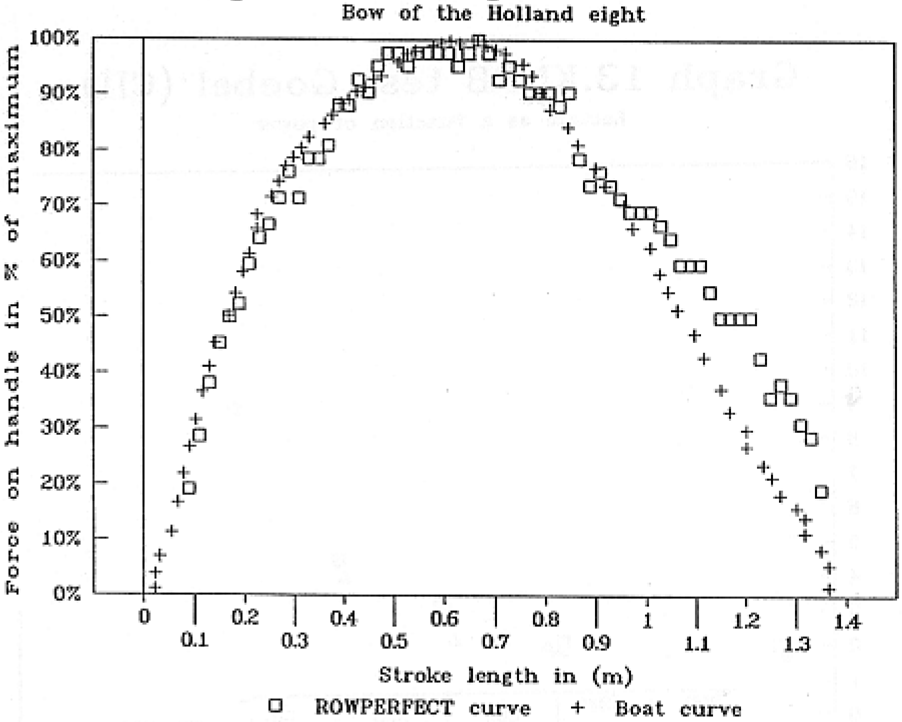
Graph 10.Comparison of curves



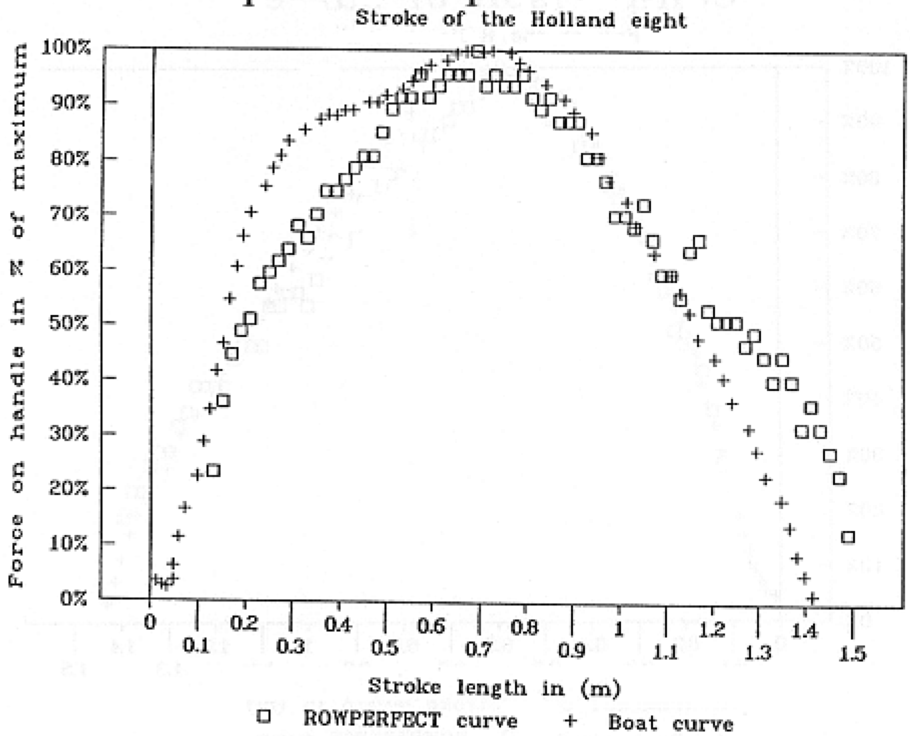
Graph 11.Comparison of curves



Graph 11B.Comparison of curves



Graph 12.Comparison of curves

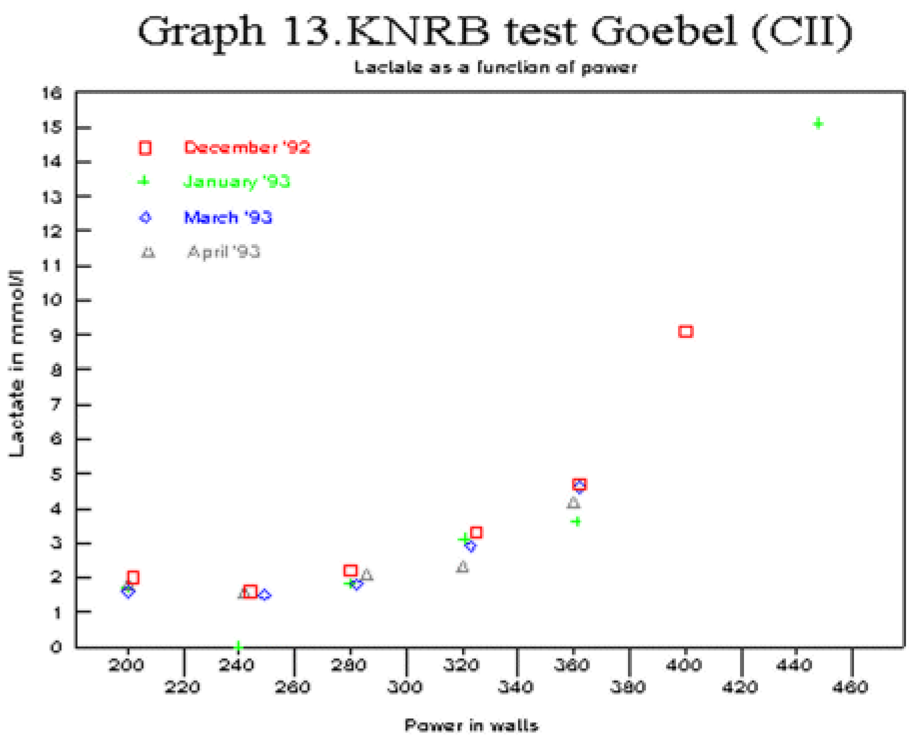


From these experiments it can be concluded that there is a very good similarity between the force length curves of the ROWPERFECT ergometer and the curves made in an eight, the actual differences between boat and ergometer per individual being much smaller than the difference between individuals, either in the boat or on the ROWPERFECT ergometer. Therefore the conclusion from these curves is that for an eight the ROWPERFECT is a perfect simulator and can be a very usefull tool in

eliminating differences within a crew during wintertime.
With regard to the same question for a single, there have not been any similar measurements made to date.
Perhaps a better indication than any measurement, that this is also the case for a single, is the statement made to me by Frans Goebel when I asked him this question, and which he allowed me to quote. He said: "For me the ROWPERFECT ergometer is a very good boat simulator. I have never told it before, but from five weeks before the world championships in 1990 in Bled until two weeks before, I have been training for a period of three weeks on the ROWPERFECT exclusively. This gave me an advantage over my main competitors, because I could hone my timing at the catch to perfection, not hindered by weather conditions or waves, and this certainly contributed to my world championship of that year. "

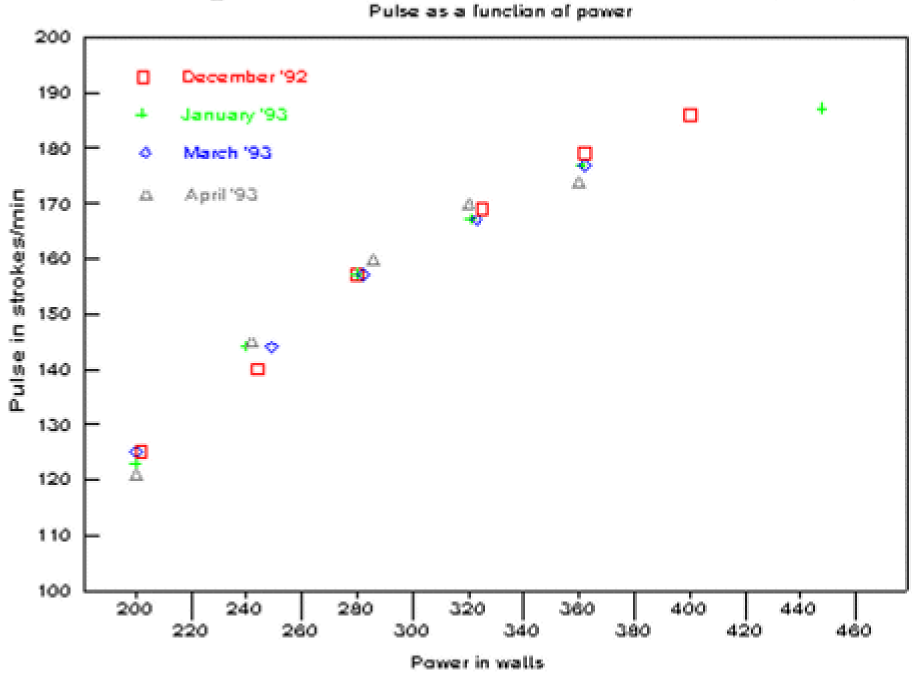
4. Verification of the sportspecificity of the ROWPERFECT ergometer.

To obtain an indication of to what extent the floating stretcher of the ROWPERFECT makes it more sportspecific, tests have been run at the Laboratory of the Haagse Academie voor Lichamelijke Opvoeding (HALO), the Sport Academy in the Hague. Frans Goebel was asked to participate in these tests as testperson, because at the conditiontests of the Royal Dutch Rowing Association (K. N. R. B.), he always has shown the most reproducible test results. This is indicated by the results in graphs 13 and 14. These graphs represent the lactate in blood and the pulse frequency as a function of the energy dissipation during condition tests run by the Dutch rowing association.

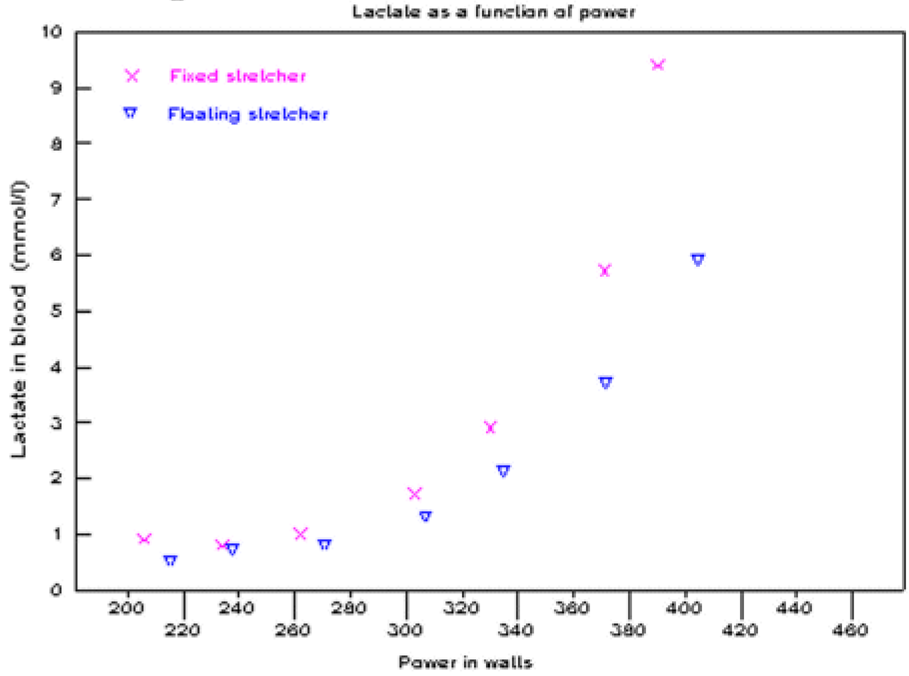


On August 11 and 12 1993 Frans Goebel ran two condition tests at the HALO laboratory. The first day on the ROWPERFECT ergometer with the stretcher fixed, simulating a Concept II ergometer, the second day on the ROWPERFECT ergometer with the floating stretcher.

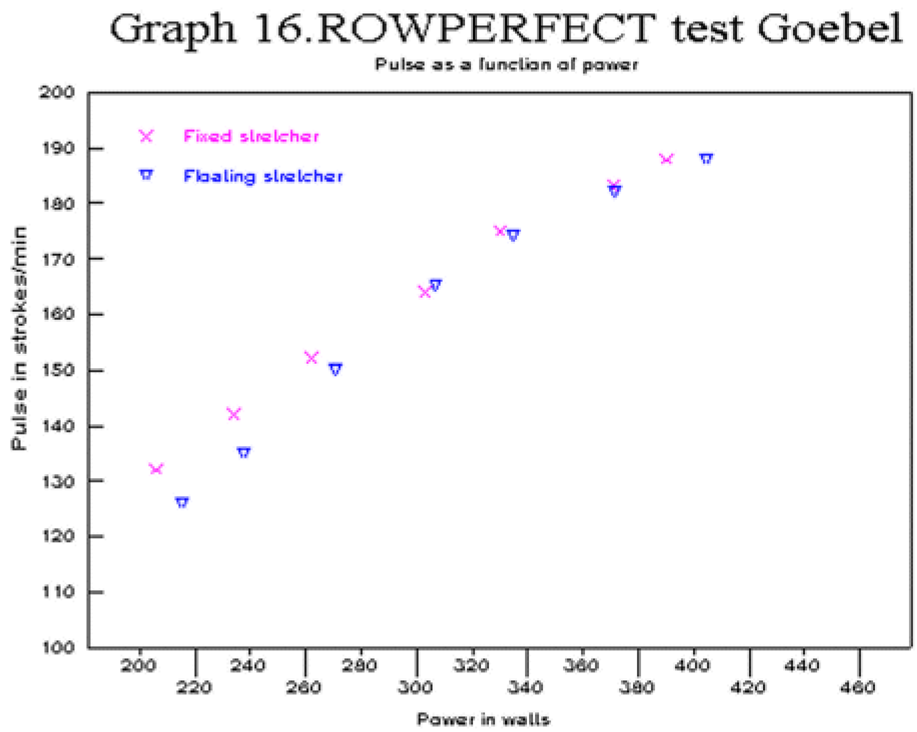
Graph 14.KNRB tests Goebel (CII)



Graph 15.ROWPERFECT test Goebel



Graphs 14 and 15 give the lactates and the pulse frequencies as a function of energy dissipation. Although this concerns a testrun on one single testperson only, a clear indication is given that both lactate and pulse frequency in the dynamic case are lower than in the static case at the same energy dissipation, while maximum oxygen uptake in the dynamic case was 5. 17 l/min compared to 5. 05 l/min in the static case. This indicates a more sportspecific character of the ROWPERFECT ergometer with the floating stretcher.

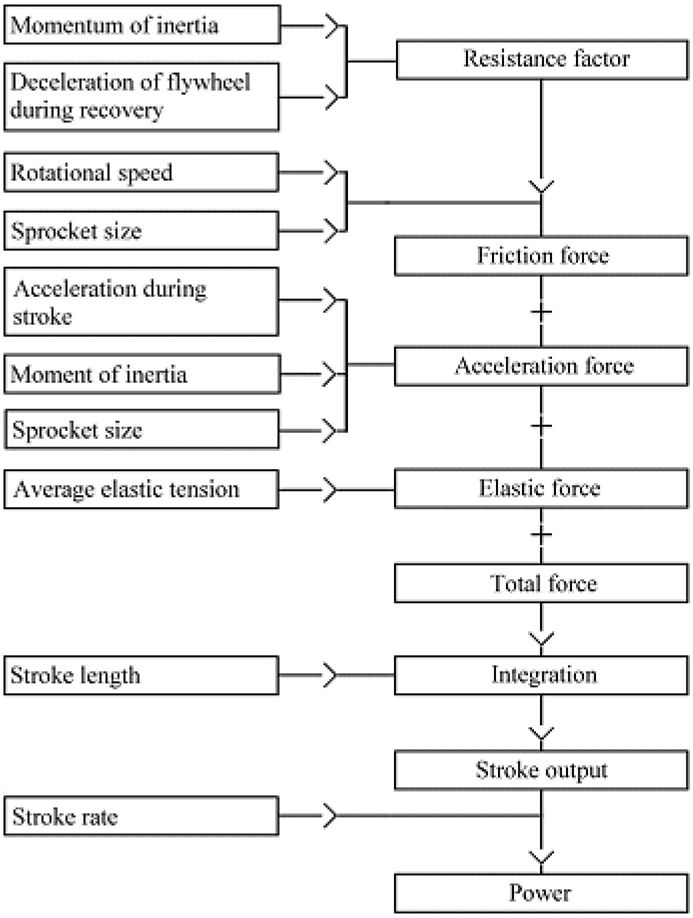


5. Measuring principles.

The measuring principle of the ROWPERFECT ergometer is based on the moment of inertia of the flywheel, which can be determined very accurately. The fan of the ROWPERFECT ergometer is provided with magnets that induce an electric signal when passing a sensor. To obtain sufficient accuracy there are four magnets on a circumference. During the recovery no power is transferred from the oarsman to the fan. The decrease in rotational speed of the fan during this period is due to the friction of the air. The ROWPERFECT computer calculates during this period the resistance factor from the known moment of inertia and the decline in rotational speed.
During the stroke, the oarsman is excerting force on the handle and thereby accelerates the flywheel.
At any moment the total force he applies to the chain consists of three components:

- The friction of the fan with the surrounding air
- The force used for accelerating the flywheel
- The force of the elastic.

During the stroke at each 1/4 revolution of the flywheel these three components are calculated and added to give the total force at that moment. Integration of this force over the whole length of the stroke then gives the Stroke Output in Joules, which, divided by the time necessary for the stroke/recovery cycle, gives the Power excerted by the oarsman, in Watts.
This is illustrated by the following diagram.



Other than the Concept II ergometer the ROWPERFECT ergometer takes the tension in the elastic into account.

The power dissipated by the oarsman or oarswoman is converted to a virtual speed. For the ROWPERFECT ergometer the conversion is taking the type of boat, the sex and the weight of the person who is rowing into account. For the correction for weight the Adam formula has been used. The corrections for type of boat and sex are based on the work done by J. J. Hoedjer et al. who were kind enough to make this information available to me.
It is well understood that the conversion of power generated, to boat speed is highly arbitrary. We think the ROWPERFECT approach is the best approximation currently available, as it takes weight, boat type and sex into account. Therefore in comparing results it does not automatically favorize a slow heavyweight to the expense of a more agile lightweight and is thus a better tool to select the real boatmovers.
According to the users, the times and distances that are calculated are generally within a margin of less than 10 seconds of the real boat-times over 2000 meters at neutral conditions.
We will be glad to receive any aditional data from ROWPERFECT users to either strengthen this statement, or enable us to improve our match between calculated times and real times.

6. Conclusions.

From the foregoing it can be concluded that:

- The dynamically balanced ROWPERFECT ergometer is superior to stationary type ergometers in its boat simulating properties.
- There is a strong indication that this type of ergometer is more sportspecific for rowing than other types of ergometers.
- It enables oarsmen and oarswomen to combine physical and technical training and improve the technique of coordination of the main muscle groups that are used in rowing.
- The force-length curves made on the ROWPERFECT ergometer coincide very well with similar curves made in the boat and give an immediate feed-back to the oarsman. Therefore this ergometer is an essential tool for synchronising crews during the winter time.
- The weight related correction factor makes it a better tool to select real boatmovers.

7. Acknowledgements.

I wish to thank the following persons without whose help the preparation of this paper would not have been possible:

- Mr. A. B. P. J. van Diemen of the H. A. L. O in the Hague for running and evaluating the condition tests of Frans Goebel on the ROWPERFECT ergometer.
- Mr. J. J. Hoedjer for his contribution to converting ergometer power to virtual boat speed.
- The Dutch Rowing Association (K. N. R. B.) for the test results of their ergometer tests.
- Mr. W. Mook for the records with the boat force-time curves of the Holland Eight.
- The crew of the Holland Eight and last but not least Mr. F. Goebel for being so kind as to serve as "Guinea Pigs".

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<u>Addendum</u>

The two curves marked "Robin van Kleef" have been produced in December 1994, on a ROWPERFECT rowing simulator, equipped with the ROWPERFECT interface and software. Two test runs were made on the same machine, the first run the "dynamic case" with the stretcher moving freely along thr main bar (voetenbord los), thus simulating the dynamics of a boat; the second run the "static case" with the stretcher in a fixed position (voetenbord vast), thus simulating the dynamics of a rowing tank or any fixed stretcher ergometer.