INTRODUCTION

For a recreational rower, rowing is a peaceful, harmonious movement and no matter how long he rows, throughout the entire activity he has done nothing but repeat a unique simple cycle. However a competitive rower is concerned about the speed of the rowing shell. Since a number of mechanical principles and rowing parameters have an effect on the movement of the shell, they should be investigated to improve the shell speed. There are a lot of studies that deal with each of these principles separately and analyse the influence of rowing parameters like stroke rate, rhythm, etc. on the movement of the shell. However, although a rowing cycle takes place in a few seconds, all these principles become active at the same time and are dependent on each other. Therefore, they should be analysed together to better understand the philosophy of shell movement and to predict acceptable results. The aim of this study is, to combine all mechanical principles that accelerates the shell or counteract it to decrease the velocity in a single ordinary differential equation. This study also aims to improve the rowing technique by designing a computer model and proposing an optimum value for stroke rate.

METHODS

Three methods were used in this study – a mechanical study was used to combine all mechanical principles (‘Conservation of Linear Momentum’ and ‘Equation of Motion’) into a unique ordinary differential equation. Rowing parameters obtained from the Experimental Research were put into the derived equation and, as the last step, all the data obtained were modelled using computer software.

Mechanical Study

The shell moves forward as a result of force applied to the oar. When the force on the pin overcomes both the shell’s inertia and the drag force, it accelerates forward. When the oar is locked in the water at the start of the stroke, the direction of the force is perpendicular to the blade, but should be divided into two components - one away from the shell, and the other toward the stern. This sternward component at the pin is responsible for the forward movement of the shell.\(^1\)

\[ F_n(t) = F(t) \cdot \cos(\Theta(t)) \cdot \frac{\pi}{180} \]  
\[ (1) \]

where;

\[ F_n(t) \] is the sternward force component on the pin,
\[ \Theta(t) \] is the angular velocity of the oar.

The shell movement should be analysed using the principle of conservation of linear momentum formula,

\[ \sum m_i \cdot V_i = P \]  
\[ (2) \]

In the absence of a net external force, the total linear momentum of a system remains constant. Since there are external forces such as the drag of the shell and muscular force;

\[ \frac{dP}{dt} = F_{ext} \]  
\[ (3) \]

Although there is no external propulsive force applied in the recovery part of the cycle, the shell continues to accelerate because of sternward movement of rower. It should be noted that the mass of the rower is high with respect to the mass of shell, and since the rower moves back and forth in a short time interval, it causes reasonably high accelerations. Considering this fact and rewriting the equation yields;

\[ m_r \cdot \frac{dV_r(t)}{dt} + (m_r + m_b) \cdot \frac{dV_b(t)}{dt} = F_n(t) - D(V_b) \]  
\[ (4) \]

where;

\[ m_r \] and \( m_b \) are mass of rower and shell, respectively,
\[ V_r(t) \] is the experimentally-obtained rower’s centre of mass velocity with respect to the shell’s velocity,
\[ F_n(t) \] is the sternward component of the force exerted on the pin, obtained from Eq.1,
\[ D(V_b) = 1.3 \cdot 9.81 \cdot V_b^2 \]  \(^2\) is the drag force acting to decrease the velocity of the shell.

Experimental Research

The experiment was performed on Pancharevo Lake, near Sofia. There were 6 scullers, 4 women and 2 men, from the Bulgarian national team under observation. The shell used in the experiment was 1X class EMPACHER® racing shell and oars were Concept II®. Applying maximum effort on the grip, each sculler performed four distances of 500m at different stroke rates. For full recovery of the scullers, the rest between the laps was over 5 minutes and the pace was given by speedcoach.\(^3\).

The data obtained from the experimental research were angular speed of the oar, centre of mass velocity of the rower and force applied. The same process was repeated for six different stroke rates, namely 20, 24, 28, 32, 36, 40 per minute. The power curve vs. stroke rate graph was drawn with curve fitting method. All data were used as input for the mechanical study.

Numerical Solutions and Computer Modelling

Finding the analytical solution of Eq.4 is complex work and furthermore, repetition of this progress for every input and different parameters takes a lot of time. However, computer model significantly decreases the amount of time required to achieve a solution. Thus Eq.4 was numerically solved by using computer modelling. To make the results more
understandable, these results were turned into visual graphics.

**RESULTS**

As expected, power increases with increasing stroke rate. However the gradient of power curve decreases with higher rates (Figure 1).

Figure 1: Power vs. Stroke Rate

Measurements showed hand grip velocity increases in both directions (Figure 2). Although the power value is greater for higher stroke rates, grip force decreases because of the increase in grip velocity.

Figure 2a: Grip velocities at different stroke rates

Figure 2b: Grip Force vs. Stroke Rate

Figure 3 shows the shell velocity from rest to an equilibrium state. As seen after approximately 8 strokes, the shell reaches its maximum velocity.

Figure 3: Computer modelling of shell velocity at stroke rate of 30

The required inputs for the computer modeling to calculate the variation of shell velocity in one cycle at different stroke rates were directly taken from Figures 1, 2 and 3.

Figure 4: Variation of shell velocity in one cycle

**DISCUSSION**

This study shows that, since the shell mean velocity is the main goal, maximum stroke rate is not necessarily the optimum rate. Power tends to increase with the increasing stroke rate, but grip force does not follow this trend and decreases after a certain value. Although this value is 38 in this study, it may be affected by the rower’s body weight, power curve and seat velocity that is a part of his/her rowing technique.

**REFERENCES**

Bachev, V. (1999), *Rowing and Bulgarian Sport Science*, 38 – 45