A BIOMECHANICAL ANALYSIS OF THE
FORWARD MARATHON CANOE STROKE

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Chapter 1

INTRODUCTION

Statement of the Problem and Significance

Marathon canoe racing has been in existence in North America since World War II and probably before the war. It has never received much notoriety, possibly because it is not conducive to spectatorship and it is limited to certain geographical areas.

For purposes of explanation this type of canoeing can best be compared to flatwater cruising or recreational paddling. The marathon racer and recreational paddler exhibit the same gross motor movement patterns in the forward canoe stroke. Where they differ, however, is in two specific elements of the forward stroke. First, the racer switches sides, whenever necessary, to steer the canoe, while the recreational paddler uses a "J" or rudder stroke for the same purpose. This switching method reduces unnecessary drag which occurs during corrective "J" or rudder phase of the stroke. Secondly, the racer's stroke is shorter and quicker in tempo. The shorter, quicker stroke requires greater strength and allows very little rest between strokes, however it does increase canoe speed.

The marathon racer's canoe and paddle differ considerably from recreational equipment. The racing canoe is designed for the purpose of speed. Therefore, it is longer in length (18½ feet), smaller in width (27 inches at the waterline) and extremely light (35 pounds), similar to a rowing shell. The average racing speed in these canoes is about 5-10
miles per hour or 65-75 strokes per minute. Racing paddles are, generally, 2-4 inches wider and 4-6 inches shorter than a standard paddle. In addition, these paddles have a 14-degree forward bend at the throat. In other words, when the paddle blade is perpendicular to the water, the shaft slants slightly forward. It is believed this bent design provides increased leverage.

In marathon racing the average amateur race is usually 12 miles in length, while an average professional race is 100 miles with a number of portages distancing anywhere from two blocks to two miles.

Marathon canoe racing has seen many innovations over the years with great improvements and advancements made in equipment design. Changes in technique, however, have progressed more slowly, probably because trial and error has been used to analyze and develop new stroking techniques. In this method the racer determines the efficiency of new technique by his:

1. Kinesthetic perception of stroke efficiency.

2. Ability to perform near maximal stroke output for prolonged periods of time without suffering extreme fatigue.

3. Ability to surpass his previous race performance.

Racers using this trial-and-error method recognize its limitations. First, they are aware of the time and effort required to make even small advances. Secondly, they realize that innovations perfected by one racer are not necessarily efficient for all racers. In spite of these limitations however, in the past this has been the most effective means available to them.
Purpose

The purpose of this research was to study and describe the forward marathon canoe stroke through a cinematographic analysis of professional marathon canoe racers. Cinematography and computer graphics analysis were employed in identification of elements in the forward stroke. This research, being descriptive in nature, involved the recording, analysis and interpretation of the racing stroke as it now exists. Any significance derived from this research lies in the findings herein and their future use or application. Conceivably this research could provide knowledge and insight into the basic biomechanics of the stroke, formulation of new instructional methodology and improvement of paddler performance.

Assumptions and Limitations

Assumptions

1. With the speed and quality optics of this camera, it is assumed this camera presented a relatively true and accurate picture in a two-dimensional field (horizontal and vertical) perpendicular to the line of sight of the camera.

2. Because subjects were selected by best race records, experience and knowledge of the sport, it is assumed that they demonstrated an efficient forward marathon canoe stroke.

3. After sufficient warm up, it is assumed that the subjects paddled as they would in a race.

4. After viewing the film of each subject, it is assumed that
this writer, with his experience as a marathon paddler, selected the film sequence which typifies the subjects' best stroke technique.

5. It is assumed wind and water conditions were normal and did not really affect performance. The water was relatively still, without current, and the wind was at five miles per hour.

Limitations

1. Time and scope of this research permitted selection and study of only three male stern paddlers.

2. An analysis was made of two side-view strokes. These side-view strokes were selected with the subject paddling on his left side and then on his right side.

3. The camera's two-dimensional field of view will limit certain types of data collection and create some finite errors in measurements.

4. A slight misalignment of reference points which occurred during filming is thought to be minimal in terms of measuring the gross biomechanical movement in this research.

5. The air phase of Subject 1, side right, is not shown in Figures 4, 6, 8, 10, 12, 14, or 16 because there was a deficiency in the recorded computer data.

Definition of Terms

1. Reference points—The vertical standards within the film which are used to establish a standard of measurement in the film. These standards are located on either side of the film in the side view. Here, the distance between these standards acts as a standard of
measurement. A horizontal rule attached to one of the standards acts as a standard of measurement in the front-view filming of the subjects. See Figure 1.

2. **Paddle**—The bent paddle which the subjects used has a 14-degree forward bend in the shaft just above the blade.

3. **Stroke**—The single revolution of the paddle, beginning with the initial insertion of the paddle into the water. After traveling rearward through the water and returning forward through the air, the stroke ends when the paddle blade begins water insertion for the next stroke.

   a. **Water phase**—That portion of the stroke when the paddle blade is touching or in the water.

   b. **Air phase**—That portion of the stroke when the paddle blade is in an air or recovery phase of the stroke.

   c. **Water exit**—The division point between the water phase and the air phase.

   d. **Side right or side left**—Identified the subjects' paddling side.

   e. **Preparatory position**—The position the subject assumes in preparation for the water phase.

4. **Angular velocity**—The time rate of change of angular motion of a body segment, or the first time derivative of the displacement.

5. **Upperarm**—The portion of the arm between the elbow and shoulder joints.

6. **Forearm**—The portion of the arm between the elbow and wrist joints.

7. **Top arm**—The arm that is holding the top handle of the paddle.
8. **Bottom arm**—The arm that is holding the middle throat of the paddle.

9. **Angle of limb**—The body segment's angular relationship to its medially-attached body segment.

10. **Stick figures**—The computer-plotted stick figure drawings in Figures 3 and 4.
An extensive search was made for literature related to the marathon canoe stroke. In terms of documented research, periodicals, microfilm data and research abstracts, there was a scarcity of information. Because of this scarcity, a wider search was made. Consequently a diversity of literature is identified in this review and divided into three categories: subjective, relevant, and incomprehensive literature.

The subjective literature presents observations which are empirical in nature. Nevertheless, this literature describes the biomechanics of the observed forward canoe stroke in sufficient detail to warrant review in this research. The relevant literature is documented research which has a comparative relationship to the forward canoe stroke. For example, certain aspects of research on the kayak stroke could be compared to this research. Finally, the incomprehensive literature is instructional literature too vague for critical analysis but which, historically, has been of some significance to the canoeing public. Therefore, this literature is listed in the bibliography to show it was reviewed but is not discussed further in this research.

Subjective Literature

Harry N. Roberts, editor of Wilderness Magazine, describes the forward canoe stroke in an article on basic flatwater paddling. His description is based on his personal experience and perceptions of the marathon and whitewater racers' technique.
He describes the forward stroke as follows: once the paddle is
inserted in water, it remains anchored at its point of entry while the
canoe moves forward past the paddle. The lack of paddle movement rear-
ward in the water is a sign of efficient technique. At entry the upper
arm cocks rearward as if preparing to throw a jab. Simultaneously, the
lower arm reaches forward while the torso rotates to increase the reach
of the lower arm. From this paddle entry position, the upper arm
thrusts forward, the lower arm pulls rearward, and the torso rotates
back to the neutral position. During the lower arm's pulling phase,
the elbow remains straight and rigid.¹

Mr. Roberts believes with this technique the large muscle
groups within the upper torso can be used. Because of the torso's great
strength and endurance, the paddler can paddle faster and longer. He
further says merrily paddling with arm muscles will quickly tire the
strongest of paddlers. However, using the large torso muscles a person
can sustain an extreme pace for hours at a time.

Bill Riviere and John Malo, noted authors on canoeing, describe
certain aspects of the stroke that are consistent with Mr. Roberts'
observations. Mr. Riviere discusses the controversy of the semi-rigid
lower arm. He is somewhat undecided about the old stiff-arm concept.
This old traditional concept says that during the stroke's water phase
the lower elbow, nearest the water, must be kept straight and rigid to
get the most efficient leverage. His thought is that the arm, at the
elbow, does not necessarily have to be perfectly straight and rigid;
however, there is some lesser degree of this needed to exert force from

¹Harry N. Roberts, "Roberts: Paddling," Wilderness Camping,
the back muscles for greater strength and endurance.2

Mr. Malo writes on the concept of stroke efficiency through proper blade angle. In describing the theory behind this concept, he says it is necessary to reflect upon the physics involved in the action between the paddle blade and the water. When the paddle blade is perpendicular to the water, the greatest possible blade surface area is used to drive the canoe forward in a horizontal plane. If the blade is anything less than perpendicular, a portion of the horizontal force changes to a vertical force. Too much vertical force reduces the canoe's forward movement and may even cause bobbing.3

Relevant Literature

With the scarcity of literature and a further diversified search, documented literature was found bearing a significant indirect relationship to this research. One such report is Andras Toro's hydrodynamic analysis of Olympic flatwater kayaking and canoeing. Mr. Toro's main concern was what effect the propulsive force of the paddle blade would have on the movement of the watercraft. Looking at the propulsive forces on the canoe and kayak, he concluded that since the propulsive force is a function of the horizontal velocity of the paddle blade, the most effective phase in the stroke occurs when the paddle blade is perpendicular to the water. Not only does this agree with Mr. Malo's theory on proper blade angle, but it also provides documented evidence of this


theory. Further, and even more interesting, Mr. Toro investigated ways to increase this effective phase of the stroke. He found that by increasing torso rotation the effective phase could be prolonged. 4

Another research which lends itself to this investigation was done by Ralph Mann and Jay Kearney. Using cinematographic and computer analysis, they investigated the biomechanics of flatwater kayaking. The subjects were 11 Olympic-caliber K-1 paddlers. Mann and Kearney's results indicated that during the water phase of the stroke, the horizontal arm action is a push-then-pull action with the push coming from the upper arm (thrust segments) followed by the pull coming from the lower arm (draw segments). During this action the paddle's rotation center shifts up the paddle shaft as the stroke progresses through its water phase, which increases the power portion of the stroke. The horizontal movement patterns of the individual segments indicated that the push is accomplished by an integrated movement of the thrust wrist and elbow, with minimal shoulder involvement. Subsequently, the pull is accomplished by an integrated movement of the draw wrist, elbow and lower draw shoulder, as well as the upper thrust shoulder. During the latter water phase stage of the stroke, the paddler is unable to generate additional useful power. Therefore the paddle is rapidly withdrawn vertically to avoid dragging. The subject's stability in the frontal plane is maintained by shifting the body mass toward the water stroke side at paddle entry and away from it at exit. This action opposes the vertical forces produced as a by-product of the

In the opinion of this writer, Mann and Kearney's research findings are applicable to the marathon canoe stroke. Certain similarities within the two skills (kayaking and canoeing) substantiate this relationship. For instance, the crafts and paddles share more similarities than dissimilarities. Both crafts travel in water and are propelled by a paddle with similar blades. Further, the stroke taken by these two blades during the water phase resemble each other. They may, however, differ during the air phase because of a variation in the number of continuous strokes taken on a side.

In conclusion, the relevant water phase findings of Mann and Kearney's research might also be reviewed in an analysis of the canoe stroke. For example, does the push-then-pull and vertical blade concept exist, and how does it vary from the kayak stroke?

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Chapter 3

DESIGN OF THE STUDY

Procedures

Site Selection

Selection of the water and shoreline area was given careful consideration. The area selected was chosen for four reasons. First, the cove-shaped area was well protected from strong winds. Second, this selected lake sight was chosen over a river sight to eliminate the effects of river current. Third, the depth along the shoreline was sufficiently deep to prevent any unnecessary drag on the canoe’s forward momentum. Lastly, the gradual sloping shoreline permitted easy placement of the camera.

Selection of Subjects

Three male professional marathon canoe racers, who are stern paddlers, were selected on the basis of race records and years of experience. Subjects' mean weight was 161.25 pounds, ranging from 155 to 170 pounds, and their mean height was 68.5 inches, ranging from 67 to 70 inches. See Table 1. The subjects had a minimum of ten years professional racing experience and a total of 67 years experience for the group. In addition, the subjects had achieved notable race records in the last ten years.
Filming Procedures

In preparation for filming, two markers were anchored in five feet of water parallel to the shoreline. See Figure 1. Distance between markers was determined by the distance necessary for the subjects to complete three strokes. Thus, three complete strokes were filmed as the subjects paddled from marker to marker.

Subjects were filmed from two views: front and side. In the front view the camera was located on-line with the markers and in the water. This location allowed paddlers a run-out after passing the camera. For the side view the camera was located on shore perpendicular to the imaginary line between markers. Marker and camera location, as well as distance measurements, are shown in Figure 1.

Measurement of Subjects

Using Dempster's anatomical data, subjects' body segments were measured and joint centers marked for filming. Joint centers were identified with Dempster's method of locating planes of joint centers. Once located, black-and-white stick-on markers were applied to the subjects' joint centers for ease of identification in the film. After the markers were in place, each subject's body measurements were taken and are shown in Table 1.

Methods of Gathering Data

Review of Developed Film

The primary concerns in this film review were film quality and accurate reproduction of paddler technique. The specific factors

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necessary for good film quality were (1) sufficient lighting, (2) good visual acuity, and (3) an undistorted stroke reproduction. With these qualities present, body segments and reference points could be accurately computed. After careful review, it was decided a second filming was necessary for better quality. Except for a slight lighting problem, the second filming provided the necessary quality for this research.

Specific strokes within this film were selected for detailed analysis. Selection was done on the basis of two factors, film quality and technique reproduction. The film's visual quality of the subject had to be sufficient to clearly identify the stick-on markers. Secondly, the selected stroke had to best portray the subject's paddling style. This writer's years of professional experience within this sport provided the necessary knowledge to identify the style of each subject.

**Digitize Data**

With the use of a stop-action projector, the developed motion picture film was projected onto a computer digitizer tablet. This data tablet has wire grid embedded in the digitizer surface (14" by 14"). Positioning a digitizer "puck" with cross-hairs over the desired position and depressing a button on the puck produces a pair of X,Y coordinates which represent the horizontal and vertical dimensions relative to the lower left corner of the tablet. The data was digitized and stored in logical units to allow for access by the computer program. A single unit contained the data representing one complete stroke of an individual subject. Each unit began with a section identifying the subject and the specific stroke. The points digitized on each frame, in sequential order, are shown in Figure 2.
Having digitized the reference points and joint coordinates frame by frame, this data was stored on a cartridge tape recorder and later converted into a usable form through the use of a computer program prepared specifically for this research.

**Computer Program**

The computer program for this research was prepared by Dr. D. R. Riley, Professor of Mechanical Engineering. This program was adapted from a previous program and uses Dempster's data for analysis. The program computes centers of gravity, linear and angular displacements, velocities, accelerations, and kinetic energies of each body segment and of the whole body. In addition to numeric results, the program produces graphical display on a Tektronix graphics CRT terminal. A stick-figure representation of the digitized data was plotted, as well as graphs for time versus horizontal displacement. These displays were then used for comparison or contrast of subjects and/or their body segments.

**Investigation/Interpretation**

The investigative strategy was to review computer data for general patterns of motion which were easily discernable. This was followed with a comparative analysis of the identified patterns of movement. The general patterns provided insight into the direction to be taken for specific detailed pattern analysis. Specific analysis looked at angular degree movement and angular velocities of the digitized body segments in relationship to the horizontal. These angular movement patterns were compared to time interval and predetermined phases of the canoe stroke.

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Following this analysis an interpretation of the data was prepared. The interpretation was a synthesis of the observations and measurements of graphs and stick figures and became the descriptive conclusions of this research.

Description of Data-Gathering Instruments

1. Camera—16 mm Canon movie camera.
2. Film—100-foot, Kodak, 16 mm Black and White Plus-X, ASA 400.
3. Projector—16 mm Lafayette Analyzer (stop-action).
4. Digitizer—Summagraphics Digitizer Tablet.
6. Stick figures—The title of each drawing (Figures 3 and 4) identifies the subject, number of strokes taken, filming date, and number of frames filmed. Subjects' direction of travel across the page changes with respect to the side they are paddling on. In other words, movement is right to left on side left (Figure 3) and left to right on side right (Figure 4). For purposes of clarity, only every fifth frame of the total number of frames filmed are displayed. The dots in the lower portion of the picture represent a reference point on the stern of the canoe. These dots follow in consecutive order with the stick figures.

The paddle also needs explanation. The paddle does not connect directly to each stick figure's forearm because the hands were not digitized. Therefore there is a slight space between forearm and paddle. Also, the portion of the blade below the water could not be digitized and is not shown. Because of this the water exit can be easily located by finding the blade midway in the stroke that is the same length as the first blade. Shoulders were digitized but are difficult to differentiate
from the upperarms in certain segments of the stroke because the third dimension, depth, is not visible.

In conclusion, these stick-figure drawings are computer generated for the purpose of investigating patterns of movement. When reading graphs in this research, these stick figures provide a visual picture of the plotted movement.

7. Graphs—These graphs were computer generated for the purpose of measuring specific degree movement of limbs and identifying comparative patterns of movement. The heading identifies the limb and stroke side. See Figures 5-16. All three subjects are shown on each graph and identified in the lower left. The graph measures angular degree movement versus percentage of stroke completion.

8. Table—Table 2 was made as an aid in analyzing the graphs. The respective degree measurement at each tenth percentage point is listed according to limb and subject.

9. Bar graph—This graph shows the mean pattern of extension and flexion with respect to percentage of stroke completion. Further, it lists, within the bar itself, the mean degrees of movement found in each extension and flexion.
Chapter 4

PRESENTATION AND ANALYSIS OF DATA

Findings

The cinematography and computer graphics analysis used in this research provided the findings. There were, however, two computer data files that had to be eliminated. First, the front view data was removed because of its distortion and inaccuracy caused by a combination of filming and computer graphics limitations. And second, the angular velocity data was removed. The graphic curves within this data could not be smoothed enough for accurate interpretation. Despite these eliminations, the graphs and stick figures from the Angle of Limb data provided valuable information.

Since the propulsive forces culminate at the paddle, the explanation of findings will begin with the paddle. The explanation of body segments will begin with the distal forearms and end with the most medial segment, the trunk. Following these specific descriptions, a general description of the stroke will be given to provide a comprehensive picture of the stroke. For purposes of clarification, description of the stroke begins with the water phase and ends with the termination of the air phase. Further, the first 60% of the stroke constitutes the water phase and the last 40% constitutes the air phase.

Paddle

The action of the paddle is seen quite vividly in Figures 3 and 4. Note the portion of the paddle blade below the water surface is not
shown. Therefore, the blade's action must be assessed by viewing the action of the shaft and that part of the blade above water. Visual inspection shows that the paddle blade remains in a relatively stationary position and that the canoe and paddler move past this position during the water phase.

In the preparatory position, the paddle blade is extended forward while the shaft is angled backward. As the paddle blade sinks into the water, the shaft angles forward in a slight downward arc. The juncture point between blade and water remains stationary, at least during mid-water phase. This would indicate that for the paddle blade a pivot or axis point exists near the water surface. It should be noted here that there is a small amount of pivot point movement at the beginning and at the end of the water phase; at the start it moves forward and at the end it moves backward.

During the air phase the paddle blade swings forward in preparation for the next stroke. During this movement, the blade tip skirts the water surface and angles slightly away from the canoe.

**Top Forearm**

In the preparatory position the top forearm is extended to within 25% of full extension. See Figures 3, 4, 5, and 6. From this position it continues a very gradual extension until reaching the end of the water phase. During this gradual extension all subjects showed some fluctuation in the extending pattern, with one exception (Subject 3, Figure 5). On the left paddling side, Subject 3 showed that some flexion preceded the extending pattern. The observed fluctuation in the extension pattern occurred in the middle 40% of the water phase and showed no consistent comparative pattern between subjects or strokes.
Commencing with the air phase, the top forearm flexes. The flexion lasts for the first 30% of the air phase. Extension takes place in the last 10% of the air phase. Subject 3 (Figure 6) is the one exception to this extension pattern. The subject showed no extension, only flexion for the last 10% of the stroke. The direction and degrees of movement are shown in Figure 17 and Table 2.

**Bottom Forearm**

In the preparatory position the bottom forearm is near full extension. See Figures 3, 4, 7 and 8. The forearm begins to flex, and flexion continues throughout the water phase. Extension begins with the air phase and continues throughout the air phase. As in the top forearm, there is a fluctuation of movement at the middle 40% of the water phase. Here again there was no consistent comparative pattern of this fluctuating movement between strokes. The direction and degrees of movement are shown in Figure 17 and Table 2.

**Top Upperarm**

In the preparatory position the top upperarm is extended above the shoulder girdle. From the preparatory position the top upperarm begins flexion and continues throughout the water phase. It is interesting to note that in all cases but two there is a slight extension for the first 10% of the water phase. The two exceptions were as follows: Subject 3 (Figure 9) flexed four degrees, and Subject 1 (Figure 10) showed no movement. As the air phase begins the movement is reversed to extension, and the extension continues throughout the air phase. The direction and degrees of movement are shown in Figure 17 and Table 2.
Bottom Upperarm

In the preparatory position the bottom upperarm is at or slightly below shoulder level. See Figures 3, 4, 11 and 12. From this position flexion takes place and continues throughout the water phase. From water exit extension begins and continues throughout the air phase. The direction and degrees of movement are shown in Figure 17 and Table 2.

There are several points of interest with regard to movement in the top and bottom upperarms. First, during the water phase the movement within these segments was almost identical between subjects (Figures 8, 9, 10, 11 and 12). In no other body segment was there a closer comparison. Further, this identical pattern showed its greatest similarity during the middle 40% of the water phase, which is also the point of greatest leverage for the paddle blade. Lastly, these segments had the greatest angular degree of movement (Figure 17).

Trunk

The trunk showed a variety of angular movements, some of which could not be graphed accurately. See Figures 3, 4, 13 and 14. Two areas of trunk movement not graphed but observable in Figures 3 and 4 were rotation of the thoracic segment and elevation and depression of the shoulder girdle. Note: the pectoral girdle designated as the lower shoulder or lower pectoral girdle corresponds with the bottom arm; the upper shoulder or upper pectoral girdle conversely corresponds with the top arm. In the preparatory position, the thoracic trunk segment is either facing the bow or is rotated slightly away from the paddling side. Concurrently, the lower shoulder is depressed and the upper shoulder is elevated. During the water phase the thoracic segment
rotates towards the paddling side while the shoulders return to their normal position. In the air phase, the thoracic segment, as well as the shoulders, return to the preparatory position in anticipation of the next stroke. There is one exception to the movement just described. Subjects 2 and 3 (Figures 3 and 4), during the transition between the water and air phases, go beyond the normal position. They elevate the lower shoulder and depress the upper shoulder before returning to the preparatory position.

The trunk's angular movement at the waist was graphable. The preparatory position at the waist is one of slight forward flexion from a normal 90-degree upright position. The trunk flexes for 10-30% of the water phase and then extends until reaching approximately mid-air phase. Subjects showed considerable variation in this flexion and extension movement during the water phase. During the air phase flexion took place to bring the trunk back to the preparatory position for the next stroke. In two cases, Subjects 1 and 2 (Figure 13), there was a brief extension for the last 10% of the stroke. The direction and degrees of movement are shown in Figure 17 and Table 2.

Head/Neck

Review of this segment showed no comparable pattern of movement between subjects. However, the head/neck's movement did show some relationship with the trunk's movement. The movement of the head/neck was always opposite to the movement of the trunk. For example, when the head/neck flexed the trunk extended. It was further found that the head/neck was the initiator of this movement pattern. See Figures 3, 4, 15 and 16.
General Description

In the preparatory position the paddle blade is extended forward while the shaft is angled backward. Both forearms are approaching full extension. The upperarms are at about shoulder level. At the same time, the trunk is flexed forward with the lower shoulder depressed and the upper shoulder elevated.

As the water phase begins, the paddle blade arcs downward. The top forearm begins extension and the bottom forearm begins flexion. The upperarms have begun flexion. The thoracic trunk segment has begun a rotation towards the paddling side while the shoulders return to their normal position. Lastly, the trunk has begun a forward flexion at the waist.

In the mid-water phase, the paddle blade has reached a perpendicular position in the water. Both forearms are continuing their respective movements of extension and flexion with some fluctuation in the movement pattern. The upperarms are moving in a sharp downward flexion. Lastly, the thoracic trunk continues its movement while the waist ends its flexion and begins extension.

The water phase ends when the paddle blade leaves the water. At this point 60% of the stroke has been completed and the paddle has begun its air return in preparation for the next stroke. The forearms continue their respective flexion and extension movements. The upperarms have completed their flexion and now begin extension. Finally, the trunk reverses its movement, rotating away from the paddle and flexing at the waist.

In the mid-air phase the paddle blade is halfway through its forward air return. During this movement the blade tip skirts the water
surface and angles slightly away from the canoe. The forearms reverse their respective movements; the top forearm begins flexion and the bottom forearm begins extension. The upperarms continue extension. And the trunk continues its rotational flexion.

When the air phase ends, the paddler has assumed the preparatory position—paddle blade extended forward and shaft angled backward. The forearms are again in an extended position, and the upperarms have returned to shoulder level. And finally, the trunk is flexed forward with the lower shoulder depressed and the upper shoulder elevated.

Discussion of Findings

During the performance of the marathon canoe stroke, the subjects showed many similar patterns of motor movement within the body segments that were analyzed. This writer believes that each of these observed and recorded movements serve a specific purpose in the completion and propulsive force of the stroke.

It would seem that for the marathon paddler to achieve his objective, moving the canoe faster, several things must be achieved. During the water phase, the time duration of the propulsion phase and leverage of the paddle blade against the water must be maximized. Further, leverage from the body segments must be maximized by increasing the number of working levers and further increasing the use of those body levers which impart the greatest leverage.

During the preparatory position, the forearms are extended, the upperarms are extended to shoulder level, the lower shoulder is depressed, the upper shoulder is elevated, the trunk is flexed forward and the upper torso is rotated away from the paddling side. In this position the
paddle blade is extended forward and the shaft is angled back towards the paddler. This preparatory positioning of the body levers serves to increase the forward reach of the paddle, which in turn lengthens the lever action of the arms during the water phase. Further, the trunk and shoulders' preparatory positioning serves to place the arms in a position to exert greater force. It is interesting to note that Roberts made mention of the torso rotation found here. He stated that the rotation served to increase the reach of the bottom arm.

In the beginning of the water phase, the paddle blade slices forward into the water. Throughout the water phase there is a lever action of the paddle. During this action the shaft arcs forward while the blade arcs backward. This blade action is similar to the action of a river boat paddle wheel. In the mid-water phase the paddle's lever axis point, which is near the water surface, remains stationary while the tip of the blade moves through the water in an arc. Finally, at the end of the water phase, the paddle blade drifts backwards as it exits the water.

The lever action of the paddle described above was produced by the angular movements of the arms and trunk. The specific movements were as follows: (1) extension of the top forearm, (2) flexion of the bottom forearm, (3) flexion of the upperarms, (4) rotation of the upper torso towards the paddling side, and (5) flexion-then-extension of the trunk at the waist. The paddler's movements just described, and the lever action of the paddle, correspond with Mann and Kearney's push-then-pull concept, with one exception. In this study the top arm push and bottom arm pull were concurrent movements, as seen in Figure 17, whereas Mann and Kearney found that a maximum velocity of push came first and was then followed by a maximum velocity of pull.
The uniform flexion of the upperarms was one of the most significant findings of this research. The importance of this movement is recognized in the fact that it occurs when the paddle blade is in a position to exert maximum leverage on the water. It was further noted that the upperarms showed the greatest degree of movement. Considering this large degree of movement and the paddle blade's maximum leverage angle, it is reasonable to suggest that the upperarm exerts the greatest leverage on the paddle.

Movement within the trunk allows the upperarms to achieve a maximum range of flexion as well as maximum leverage. As the water phase beings, the trunk flexes, which assists the upperarms in submerging the paddle blade. As the paddle blade becomes submerged, the trunk extends, which allows the upperarms to continue flexion without uselessly submerging the blade deeper. The torso rotation and the shoulders' return action also aid the upperarm. Mr. Toro spoke to a torso rotation which increased the effective perpendicular phase.

In the air phase it was observed that the paddle blade whisks straight forward, rather than circumnavigating a lengthy sweep as might be performed by a recreational paddler. It was the forearms' movement which served to shorten the distance the paddle blade had to travel in reaching forward for the next stroke. This shorter distance of travel served to decrease the duration of time spent in the nonpropulsive recovery phase.

There are two factors in stroke technique which also warrant consideration in the analysis of these variations. First, marathon paddlers are aware of stroke differences between paddling sides within their own stroke. The cause, they believe, is a difference in muscle
strength/flexibility on the two sides of the body. Second, during a race the marathon paddler intentionally varies his stroke technique to give tired muscles a rest and still maintain race pace.

The observed action of the paddle in the water requires further discussion. In the beginning of the water phase, the paddle blade slices forward. The evidence of forward movement suggests the paddle has not begun exerting propulsive force against the water. It further suggests that the paddle blade is quickly submerging to a sufficient depth and angle where it can exert efficient leverage. In the mid-water phase the paddle's lever axis point, which is near the water surface, remains stationary while the blade tip moves through the water in an arc. This stationary position may indicate that maximum leverage is achieved at this point. At the end of the water phase, the paddle blade drifts backwards as it exits the water. The backward drift alludes to the possibility that efficient leverage is not and cannot be exerted at this point. Instead the blade attempts to exit the water without causing a drag.

After observing the stationary paddle during the mid-water phase, the question arises, "Could stroke efficiency best be achieved by exerting maximum leverage against a fluid without moving that fluid?" This question has been researched in another study, and that study merits consideration in this discussion.

Dr. James E. Counsilman, a noted authority on competitive swimming, has found evidence within the principles of fluid dynamics that will lend support. In the past it was thought that, when propelling

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against a fluid, the object would move forward as the water gradually
moved backwards. Equally important was the belief that greater backward
movement of the fluid would result in a greater reduction of the pro-
pelled object's forward momentum. Counsilman believed that these two
theories were in contradiction to each other in terms of efficient pro-
pulsion. He researched the matter and found, based on Newton's Laws of
Motion and the Bernoulli Principle, the following:

"Maximum efficiency in water is achieved by moving a large
amount of water a short distance without much acceleration
than by moving a small amount of water a great distance."

He explains that, according to Bernoulli's Principle, an aerodynamic lift
occurs as is seen in the propeller-driven boat or airplane. He further
states that a large amount of water is moved a short distance by the
blade's continuous movement into new still water.

The blade action in the marathon canoe stroke is consistent with
Counsilman's theory. The vertical lift occurs as the paddle blade begins
its downward arc. The movement into new still water takes place as the
blade tip follows a downward arc.

In examining the vertical lift and the downward arc of the blade
tip, it would seem there is a combination of forces at work. Commencing
with water entrance, the paddle blade exerts vertical force. As the
blade moves towards a perpendicular position in the water, the vertical
force gradually diminishes and is replaced by a gradually-increasing
horizontal force. If this is a true picture of what is taking place in
the marathon canoe stroke, then Malo and Toro's perpendicular-phase
concept is true only if Counsilman's theory is also included. Without
Counsilman's theory, the extension of the perpendicular phase for maxi-
mum propulsion would cause water movement and a loss of traction for the
paddle blade.
Using Counsilman's theory and observing the water's action around the paddle, the efficiency of a stroke can be determined. The stroke is efficient if the water near the paddle blade remains calm during the maximum propulsion phase. If, however, a depression or hole forms in front of the paddle, and the water boils upward behind it, the stroke is considered inefficient because the water moves backward, thus the paddle loses traction.

In conclusion, this writer believes stroke efficiency is determined by the paddler's ability to exert leverage against a fluid without moving that fluid while propelling the canoe forward. This efficiency is further increased by (1) maximizing the time duration of the propulsion phase, (2) increasing the number of working body levers, and (3) maximizing the use of those body levers which impart the greatest leverage.
Chapter 5

SUMMARY AND CONCLUSION

Restatement of the Purpose

The purpose of this research was to examine the forward marathon canoe stroke as performed by three professional marathon canoe racers. Further, it was believed this research would provide insight into the stroke's biomechanical movement as well as a basis for more effective instructional information.

Description of Procedures

Three noted professional marathon canoe racers were selected as subjects for this research. Their strokes were filmed with a high-speed camera in a prearranged site and setting. Two strokes from each subject were selected for analysis. It was assumed that these strokes were characteristic of each subject's paddling style. These selected strokes were then digitized for computer analysis. And finally, this digitized data in the form of graphs, stick figures, and tables was examined and recorded as the findings of this research.

Principle Findings and Conclusions

The principle findings of this research were the descriptive movements of a stern paddler. The three subjects studied in this research had many years experience as well as notable race records. Therefore, the movements described below are believed to be representative of efficient stroke technique.
In the preparatory position, the paddle blade is reaching forward with both forearms near full extension. The upperarms are raised to about shoulder level, with the lower shoulder depressed and the upper shoulder elevated. And, at the waist, the trunk is bent forward slightly.

During the water phase, the tip of the paddle blade moves through the water in an arc similar to a river boat paddle wheel. The forearms are exerting a lever action, with the top forearm extending and the bottom forearm flexing. The upperarms flex downward and the upper torso rotates towards the paddling side as the subject moves past the stationary paddle blade. During this movement the trunk also flexes and extends, and the shoulders return to their normal position.

When the paddle blade exits the water, 60% of the stroke has been completed and the air phase begins. During the air phase, the paddle blade swings forward in preparation for the next stroke. All movements of the paddler, at this point, are reversed to accommodate the paddle's return.

Further Research

With the culmination of the propulsive forces placed on the paddle to exert leverage against the water, it becomes obvious that the paddle's fluid dynamic action is critical and deserves further scientific analysis. A number of questions need answering. For example, what arc and blade angle during water insertion is most efficient? Could the paddle be modified to improve propulsion? What ratio between the water insertion force and the backward force is most desirable?
The paddler's biomechanical movement needs further analysis. For example, a three-dimensional analysis of the torso rotation should be performed. In addition, there is leg action, recognized by the paddlers, that should be studied.

Finally, the findings of this research should be further tested. Two suggestions for additional research are (1) increase the number of professional paddler subjects and (2) compare novice and expert paddlers.
BIBLIOGRAPHY

General


Subjective Literature


Relevant Literature


Incomprehensive Literature


33


Discussion of Findings Literature

### Appendix A

#### Table 1

**SUBJECT MEASUREMENTS**

<table>
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<th>Subject</th>
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<td>31</td>
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<td>11-3/4</td>
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<td>14</td>
<td>16</td>
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<td>8-1/2—8-3/16</td>
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## Appendix A

### Table 2

**DEGREE ANGLE OF LIMB**

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<td>Head/Neck</td>
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Appendix B

Figure 1

SITE LOGISTICS

Camera location 1 and 2

Reference markers 1 and 2

→ → → Direction subjects paddle canoe
Appendix B
Figure 2

POINTS DIGITIZED

1. Left reference point
2. Right reference point
3. Reference point on canoe

Lower arm

4. Wrist
5. Elbow
6. Shoulder
7. Center point on head
8. Center point on trunk

Upper arm

9. Wrist
10. Elbow
11. Shoulder

Paddle

12. Top
13. Throat
14. Bottom tip of blade or juncture of blade tip and water
Appendix B

Figure 3

STICK FIGURES—SIDE LEFT

SUBJECT 1. SIDE LEFT. ONE STROKE. 081278
43 FRAMES

SUBJECT 2. SIDE LEFT. ONE STROKE. 081278
34 FRAMES

SUBJECT 3. SIDE LEFT. ONE STROKE. 081278
33 FRAMES
Appendix B
Figure 4
STICK FIGURES—SIDE RIGHT

SUBJECT 1, SIDE RIGHT, ONE STROKE, 081278
27 FRAMES

SUBJECT 2, SIDE RIGHT, ONE STROKE, 081278
37 FRAMES

SUBJECT 3, SIDE RIGHT, ONE STROKE, 081278
35 FRAMES
Figure 6

TOP FOREARM - SIDE RIGHT

PERCENTAGE OF STROKE

--- SUBJECT 1
----- SUBJECT 2
------ SUBJECT 3
Figure 7

BOTTOM FOREARM - SIDE LEFT

PERCENTAGE OF STROKE

DEGREE ANGLE OF LIMB

SUBJECT 1
SUBJECT 2
SUBJECT 3
Figure 8

BOTTOM FOREARM - SIDE RIGHT

Percentage of Stroke

Degree Angle of Limb

--- Subject 1
---- Subject 2
----- Subject 3

Percentage of Stroke
Figure 9

TOP UPPERARM - SIDE LEFT

DEGREE ANGLE OF LIMB

PERCENTAGE OF STROKE

SUBJECT 1

SUBJECT 2

SUBJECT 3
Figure 10

TOP UPPERARM - SIDE RIGHT

DEGREE ANGLE OF LIMB

PERCENTAGE OF STROKE

--- SUBJECT 1
----- SUBJECT 2
##### SUBJECT 3
Figure 11
BOTTOM UPPERARM - SIDE LEFT

DEGREE ANGLE OF LIMB

PERCENTAGE OF STROKE

--- SUBJECT 1
----- SUBJECT 2
----- SUBJECT 3
Figure 12

BOTTOM UPPERARM - SIDE RIGHT

DEGREE ANGLE OF LIMB

PERCENTAGE OF STROKE

--- SUBJECT 1
---- SUBJECT 2
----- SUBJECT 3
Figure 13

TRUNK - SIDE LEFT

Percentage of Stroke

Degree of Angle of Limb

Subject 1

Subject 2

Subject 3
Figure 15

HEAD/NECK - SIDE LEFT

---

PERCENTAGE OF STROKE

---

SUBJECT 1

---

SUBJECT 2

---

SUBJECT 3

---

PERCENTAGE OF STROKE
Figure 16

HEAD/NECK - SIDE RIGHT

--- SUBJECT 1
----- SUBJECT 2
----- SUBJECT 3

PERCENTAGE OF STROKE

DEGREE ANGLE OF LIMB
Appendix B

Figure 17

MEAN DEGREES/DIRECTIONS OF MOVEMENT VERSUS STROKE COMPLETION

Water Exit

Top Forearm

Bottom Forearm

Top Upperarm

Bottom Upperarm

Trunk

PERCENTAGE OF STROKE

Extension/# Degrees

Flexion/# Degrees