A SYSTEM FOR THE EVALUATION OF ON-WATER STROKE FORCE DEVELOPMENT DURING CANOE AND KAYAK EVENTS

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Sport practitioners, including coaches and athletes of a wide variety of sport disciplines, are becoming more and more aware of the value of recording and analysing the real time data correlates of the force output of the athlete under competitive conditions. In no other comparable on-water sport is the relationship between absolute force development and the manner of its production and application more critical to the final outcome of the event than in flatwater canoe and kayak, particularly in multiple athlete events (Plagenhoef, 1979; Mann and Kearney, 1980).

While some insight into forces and their application can be gained from cinematographical analysis, there is no substitute for direct measurement of these data during competitive performances. This has therefore led to our design and construction of the following technology and methodology for on-line collection of force and acceleration data during paddling performance. This approach has taken the form of instrumenting the shafts of canoe and kayak paddles with strain gauges whose output is transmitted as a frequency modulated signal to a land based demodulator/digitizer system for CRT review and storage on computer disk for subsequent analysis.

The design, and development of the instrumented paddle system must conform, within very narrow tolerances, to stringent design specifications. In general terms this means that the experimental conditions must mimic, to the highest degree possible, those conditions encountered during international competition (Ishiko, 1968; Vos et al, 1974; Marhold and Herrmann, 1983). These include: (1) the force transducers must demonstrate high response fidelity and reliability, while remaining unaffected by severe mechanical shock; (2) the force transducers must be relatively unaffected by fluctuating ambient humidity and temperature conditions; (3) the paddles must duplicate the length, blade pitch, blade surface, weight, and balance requirements of each individual athlete tested; (4) the paddles must be unencumbered to allow free, "normal" use; (5) the athlete must be in no way restricted by the use of the paddle system; (6) the weight of the instrumented paddle system must not significantly increase (+3% or roughly 2 - 3Kg) the combined weight of the paddle, paddler, and boat beyond that normally encountered by the athlete; (7) the signals produced during force transduction must be recorded and stored with a high degree of fidelity and reliability; (8) the reproduction and subsequent analysis must represent exactly in real time the frequency and pattern of force production of

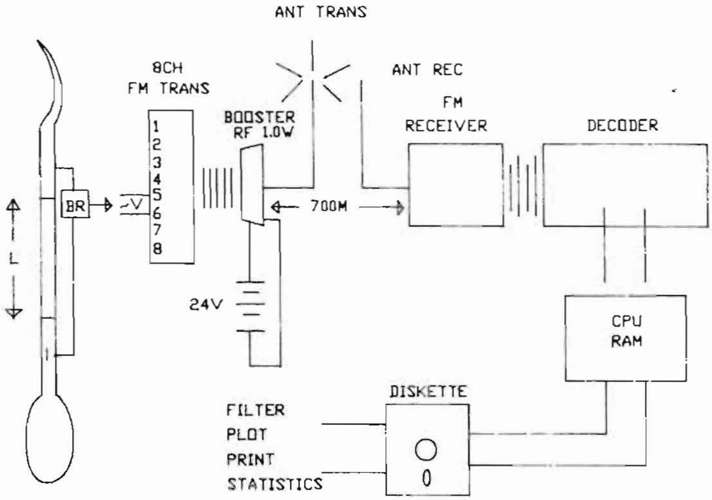

Figure 1. Stroke force measurement system schematic

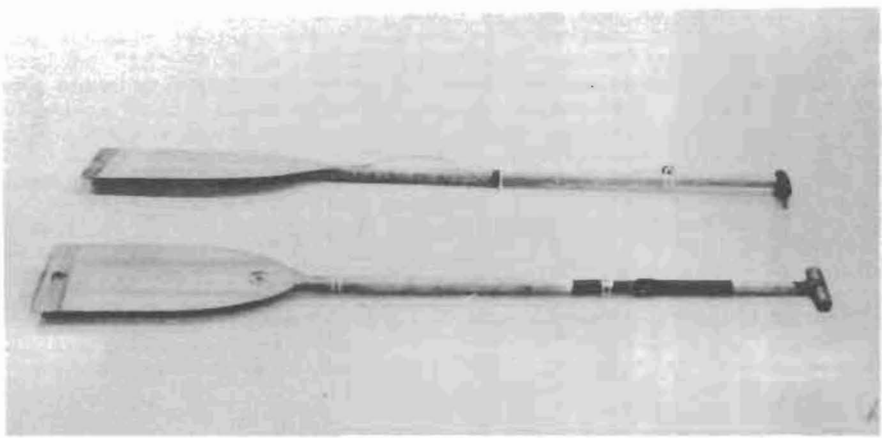

Figure 2. Canoe paddles: top - solid wood; bottom - wood adjustable.

the athlete during the paddling stroke; (9) the instrumented paddle and recording system must be portable; (10) the system must be suited for use under severe "extra-laboratory" conditions at several different Canadian and international sites; and, (11) the system must accommodate a minimum of two kayak athletes paddling simultanesouly (4 data channels).

The purpose of this project was therefore to design and develop an instrumented paddle system that meets all of the above specifications.

METHODOLOGY

The proposed system design was separated into three functional stages in keeping with the specifications outlined above. They are: (A) The paddle force transduction stage; (B) The signal transmission and reception stage; and, (C) The signal conditioning, recording, and storage stage.

(A) The paddle force transduction stage

The original instrumented paddle design consisted of a standard wood laminate paddle to which was applied two 350 ohm foil strain gauges. In original prototypes of the instrumented paddle, pressure transducers, mounted on the blade surface, were used as the force sensing devices. However, this method was discarded because the hardware and software required to resolve the effects of varying hydrostatic pressure as the paddle enters and exits the water, were far too extensive. The final method of choice, and the most simple, was to employ shaft mounted, foil strain gauges. These strain gauges were glued 4 cm distal to the lower hand hold on diametrically opposed surfaces of the paddle shaft in the plane of maximal normal force application. In this configuration, when the gauges were connected as the active elements of a full Wheatstone Bridge, the opposition of gauges served to compensate for variant changes in temperature. The excitation voltage was supplied by two 1.5V "AA" batteries attached, with the bridge, to the shaft at a point midway between the upper and lower hand holds. Changes in gauge resistance resulting from strain on the paddle shaft, gave rise to linear changes in voltage output of the bridge within the anticipated load range. The connecting cables were strapped to the surface of the paddle in a fashion that did not obstruct the paddler. Thus, in order to accomodate individual paddle specifications (weight, length, blade pitch, balance, etc.), the paddle of each athlete was instrumented. This approach complied fairly closely with specifications 1 through 5 above. From an experimental point of view, however, there were a number of drawbacks to this design, not the least of which was the wide variation in the elasticity of different paddles, and even between ends of the same paddle. This necessitated a recalibration and reset of the amplifier for every different set of gauges and encumbered practicality of the system considerably.

The second generation instrumented paddle was similar in design to its predecessor except to the incorporation of an adjustable, locking, aluminum telescopic joint in the shaft. This joint, while allowing all combinations of blade pitch and overall length, did not significantly change (< 1%) the weight or balance of the paddle. Two such kayak paddles (one female, one male) and one canoe paddle were fabricated.

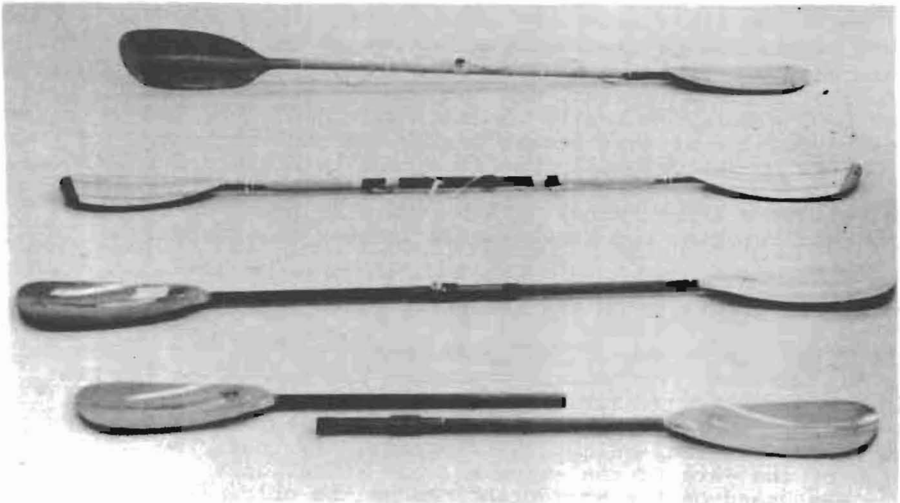

Figure 3. Instrumented kayak paddles: top - solid wood; second - wood adjustable; third and bottom - carbon fiber, adjustable, hollow core.

Figure 4. Strain-gauge location - kayak paddle.

The third prototype kayak paddle, the design currently in use, incorporates the same strain gauge technology and telescopic joint as former models. The major differences are in the structure of the paddle itself. The latest paddle design incorporates the wiring and electronics inside hollow carbon fiber tubes which have come into popular use as paddle shafts. The blades, of a common design, are composed of fiberglass. The paddle is connected by a single, centrally located, shielded cable to the transmitter. Instrumented paddles of this latest design are thought to conform to a much greater degree to the original specifications than did previous models. Further, in using two electronically stable paddles (one for males and one for females) for a large number of athletes, the need for repeated, time consuming recalibration and resetting is largely eliminated.

(B) The signal transmission and reception stage

In the first prototypes of the instrumented paddle, the bridge amplifier was directly wired to recording instruments transported in the boat. At this time the recording instruments consisted of a small pre-amplifier and a multi-channel, portable FM data cassette recorder. This total system was found to exceed original weight restrictions. Further, the subsequent reproduction of the data in real-time was not as reliable as hoped. The next prototype was based on the same principle as the original model in that the data was recorded directly on tape. The system was modified however to accommodate a much smaller, commercially available, stereo micro-cassette recorder (Sony M-1000). In order to match the frequency response of the recorder to the system, a voltage to frequency converter was introduced between the bridge and the recorder. There was considerable difficulty in adjusting the sensitivity of the system to accommodate the force production of different paddlers without reverting back to the idea of instrumenting the paddles of each athlete. Frequently the dynamic response range of the recorder was exceeded, particularly during the initial acceleration phases of the 500 M time trial.

At this point the system was upgraded to include an FM radio link to transmit the bridge output signal (+6 mV or -6 mV) to a distant receiving station. The transmitter system used was commercially available (Conestoga Medical Electronics, Waterloo, Ontario) and consisted of an 8-channel multiplexor, a 0.1 Watt transmitter, a receiver, and a decoder. The broadcast frequency was set in the commercial range at 98.6 MHz. This system was limited by the power of the transmitter such that the range of transmission was not sufficient even for 500M events. Further, the transmitter broadcast frequency required constant readjustment when testing was carried out in different geographic regions. These problems were partially overcome by modifying the system to include a 1 Watt, broadband, RF booster amplifier, and tuned, matching antennae servicing a crystal controlled receiver. While there are still problems with the range of the transmitter for 1000 M events when operating in areas with many FM signals and the frequency setting must still be adjusted to accommodate the testing site, the system proves to function extremely well under most conditions. The total weight of the paddle, transmitter/multiplexor, and battery pack is less than 3 kg, and falls within the range of the original specifications.

(C) Signal conditioning, recording and storage

Originally, the signals recorded directly on cassette tape were played back through an ultra violet strip chart recorder for permanent record. Subsequent analysis of the data was carried out manually. Although this part of the system complied with the original specifications, analysis of the data proved to be arduous and time consuming. This stage was completely redesigned such that the original decoder was replaced by a new demodulator and A-D signal conversion step. Thus the received signals were decoded and digitized at the same level and subsequently filtered and entered into the expanded RAM of an Apple IIe microcomputer. The software was written such that the decoded data stream sampling rate was 150 Hz per channel. A 10 MHz clock integrated with the decoding system, and peak to peak modulation of ±6mV, allowed a maximum descrimination interval of 240 gms. There are three options for data storage: on floppy diskette; on hard disk;or by downloading to a mainframe computer. Subsequent analysis includes various parameters of timing and force development including df/dt, absolute force, time-to-peak force, duration, impulse, and stroke/recovery time ratios. Modifications currently being made include the addition of a fifth channel for transmission and analysis of an accelerometer mounted on the boat.

CONCLUSION

A system has been designed and developed that meets the original specifications. That is, a light weight, familiar, adjustable, easy-to-handle system, capable of measuring and recording real-time changes in force production during canoe and kayak paddling, has been developed and is functioning. The system has proven to be a reliable and accurate force transduction instrument.

Although the intrumented paddle/telemetry system complies with the rigid specifications of elite canoe and kayak athlete testing, the system is not perfect and must continue to be developed to take full advantage of evolving technology. Proportionally greater amounts of time have been spent in the development of the instrumented paddle and the decoding and digitizing stage, than have been spent on the radio link itself. Thus, much work remains to be done to increase the capacity of the system to record data reliably at distances consistent with 1000M time trials conducted in geographically difficult and radio-frequency polluted areas. By the same token efforts must be oriented towards the collection of data during multiple athlete events. Other parameters, such as boat velocity and single plane acceleration data are also required in order to yield a more complete picture of the kinematics and kinetics of canoe and kayak paddling.

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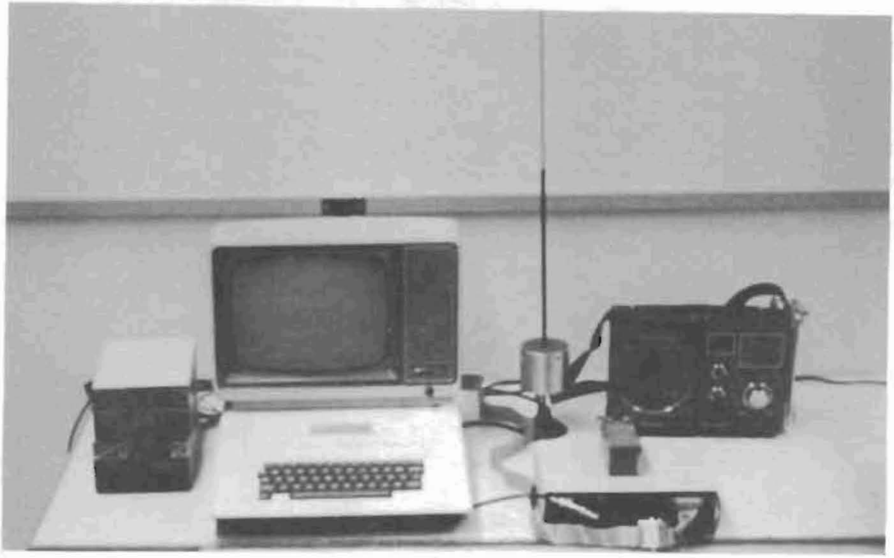

Figure 5. Signal reception, conditioning and recording instrumentation; clockwise from centre - receiving antenna, FM receiver, decoder, and microprocessor.

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