QUANTIFYING LIFT AND DRAG FORCES IN FLATWATER KAYAKING

Ross H. Sanders and Selina J.

Kendal School of Physical Education, University of Otago, New Zealand

INTRODUCTION

In recent years there has been considerable modification of the flatwater kayak paddle blade in an attempt to enhance performance. The most recent designs use a wing shaped blade in order to generate lift forces. To gain the benefit of lift forces the wing blade is moved in a more lateral direction than the standard blade (Issourin, 1989; Sanders, 1992).

For analysis of swimming technique Schleihauf (1979) has determined the lift and drag coefficients of a hand for varying orientations to the water flow (sweepback angle) and for varying angles of the hand plane to the flow (pitch). Using these lift and drag coefficients in conjunction with three dimensional hand velocity and orientation data the efficiency of the force (the magnitude of the force component in the desired direction of travel as a proportion of the total force) may be assessed.

Collection of data in an open water environment for analysis of flatwater kayaking technique requires modification of the methods employed for analysis of swimming technique. As yet methods of determining lift and drag forces produced by the flatwater wing kayak blade using data digitised from film or video have not been developed. In this paper an approach to the task of determining lift and drag forces produced by the wing blade in flatwater kayaking is described.

METHOD

This method involves six operations described below (a full paper including a detailed mathematical model may be obtained from the first author). To date, the first three of these have been tested with actual data:

1. Record by two cameras on film or videotape known positions of points on a three dimensional calibration frame, two reference points on the kayak, and two reference points on the shaft of the paddle and a point on an attachment to the shaft. A floating 3 dimensional calibration frame 13m long by 6.5m by 2m high was constructed. Ten 3m uprights of 15mm tubular aluminium articulated freely with a submerged 13m by 6.5m frame that consisted of seven 15mm galvanised steel pipes triangulated with wire rope (no. 8). Cell foam floats attached to the uprights supported the frame and ensured that the uprights were vertical when the structure was floated. To avoid distortion of the underwater framework, the positions of the floats on the uprights were adjusted so that the frame was level at 1m below the surface. Florescent red-pink markers were attached to the uprights at known positions. The structure was floated in a sheltered section of a freshwater lake and filmed at 100 Hz by two synchronised Photosonics cine cameras each fitted with an121200 Angenieux zoom lens. The cameras were positioned on the bank of the lake at approximately 30m from the centre of the calibration frame with the lens axes at 45 degrees and 135 degrees respectively to the long axis of the calibration frame.

Eight elite kayak paddlers were filmed performing four trials at race pace through the calibrated space and in the direction of its long axis. Markers were placed on the camera side of the kayak 2m apart and at known positions with respect to the centre of the kayak and kayak cockpit. Two markers were placed on the paddle shaft and one marker was placed perpendicular to the

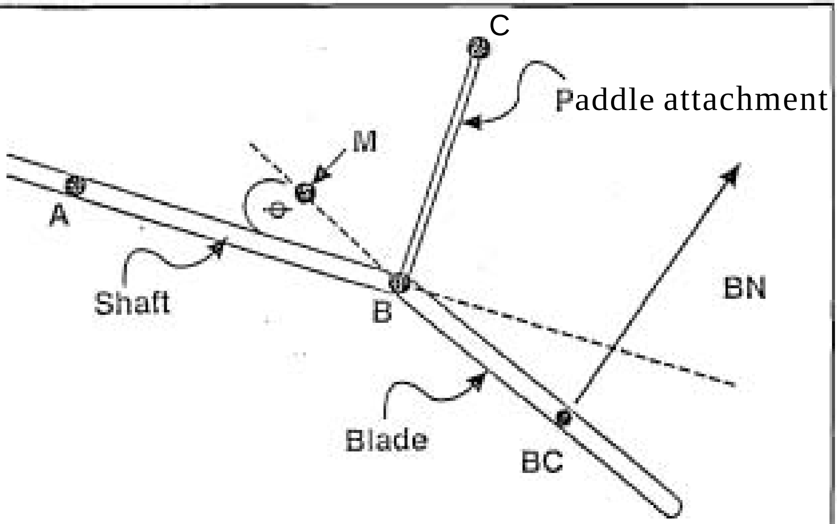

Fig.1. Schematic diagram of points used to determine the blade center (BC) and normal to the blade plane (BN)

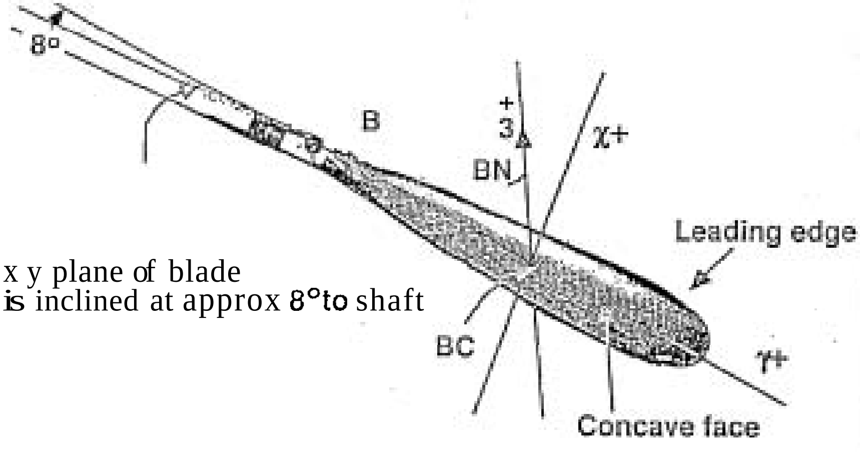

Fig.2. Blade axis System

paddle shaft (at a distance of 18cm) and perpendicular to the transverse axis of the left blade (Figure 1). The length of the blade from the point of shaft attachment to the tip and the angle between the long axis of the blade and the line projected along the shaft of the paddle were measured.

2. Obtain the three dimensional positions of the digitised markers using the Direct Linear Transformation (DLT) method (Abdel-Aziz, 1971). The known points of the calibration frame and the unknown points of the two kayak markers and three paddle markers were digitised and input to the DLT program (Marzan, 1975). The x (in the direction of desired travel of the kayak), y (perpendicular to the x axis in the horizontal plane), and z (vertical) coordinates of the five markers were output by the DLT program and used in the subsequent analysis.

3. Determine the path of the blade and its orientation with respect to the external reference frame. The known marker positions and the known angle between the shaft and long axis of the blade were used to calculate the centre of the blade over the period of a complete stroke cycle. The component velocities of the blade centre with respect to the external reference frame were then obtained by applying the central difference formula to the x, y, and z coordinate records for the period of the stroke cycle. The flow vector was then obtained by multiplying the blade centre velocity vector by -1.

To establish the orientation of the blade axis system the normal to the plane of the blade (BN) was determined as the cross product of the normal to the plane containing the points A, B, and C (N1) and the long axis of the blade (Figures 1 and 2):

$BN = (BC - B) \times N1$ where: $N1 = (A - B) \times (C - B)$

The blade axis system was then given by the unit vectors:

$x = BN \times (BC-B)$; $y = BC-B$; $z = BN$

4. Calculate the 'sweepback' and 'pitch' angles of the blade using the direction of the blade centre path as the reference. Using the method of Schleihauf (1979) the orientation of the blade in three dimensional space may be described in terms of two angles-sweepback angle, and pitch. These angles describe the orientation of the blade with respect to the flow or drag vector and are independent of the external reference frame. Sweepback angle is defined as the angle between the projection of the flow vector onto the xy plane (paddle plane) and the x axis (Figure **3).** The opposite sense of the flow vector is used. For example, when the flow is coming directly across the leading edge of the blade the sweepback angle is 0 degrees rather than 180 degrees. Pitch angle was defined as the angle between the projection of the flow vector and the original flow vector.

By measuring the forces acting in the x, y, and z directions of the blade axis system for known sweepback and pitch angles coefficients of lift and drag for given sweepback and pitch angle orientations may be determined. The magnitude of these coefficients is given by:

$Cd = 2D/(pF^2S)$; $Cl = 2L/(pF^2S)$

Where: Cd and Cl are the coefficients of lift and drag; D and L are the lift and drag forces respectively, p is the density of the water, F is the magnitude of the flow velocity vector and S is the surface area of the blade plane.

5. **Apply known lift and drag coefficients for each calculated sweepback and pitch angle combination to determine the magnitude of the lift and drag force vectors at each sampled instant. The flow direction vector in the external reference system is transformed to the blade coordinate system and the sweepback and pitch angles determined.** The magnitude of the drag vector and lift vectors are then obtained by looking up the drag andlift coefficients for that sweepback, pitch combination and applying the formulas:

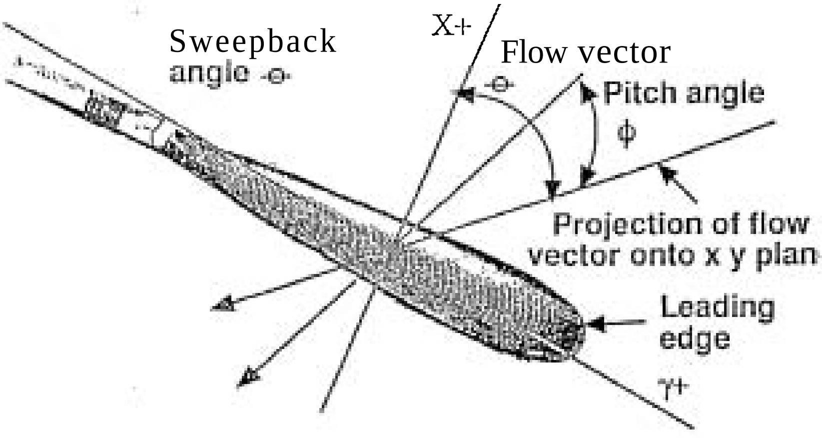

Fig.3. Sweepback and Pitch angles

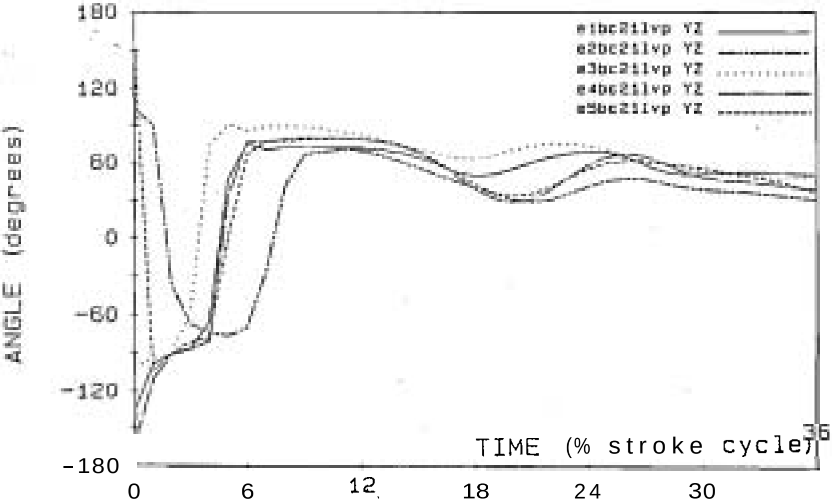

Fig.4. The angle of the lift vector onto the yz plane of the blade throughout the pull phase. Results of five repeat digitisations of one trial provide reliability of angular measures

$D = 1/2pl^2CdS$; $L = 1/2pl^2ClS$

To determine the direction of the lift vector the orientation of the lift vector to the blade axis system for the given blade orientation must be used.

6. **Determine the components of the lift and drag force vectors in the desired direction of travel and using these to calculate efficiency of the lift and drag vectors.** The drag and lift vectors in the blade reference system are transformed to the external reference system.

To calculate efficiency of the drag and lift vectors the component of the vector in the direction of the desired direction of travel (x axis) is expressed as a proportion of the magnitude of the drag and lift vectors:

$Ed = Dxk/|D|$; $El = Lxk/|L|$

Where: Ed and El are the efficiency measures for the drag and lift vectors respectively.

To calculate the efficiency of the resultant of the drag and lift vectors the sum of Dxk and Lxk is expressed as a proportion of the length of the resultant of the drag and lift vectors:

$Er = (Dxk + Lxk)/|D+L|$

RESULTS AND CONCLUSIONS

The differences in given positions of the points on the calibration frame and those computedby the DLT program were less than 0.02m in all cases. Repeated digitisation showed that the random error due to digitising was less than 0.03m. This error was less than 0.01m for the smaller markers on the paddle. It was concluded that the method of calibrating the three dimensional space showed potential but can be improved. Because the uprights were not constrained at the top there was a tendency for these to sway out of phase due to the action of waves. On the day of testing this problem was minimised by selecting a sheltered section of the lake. However, the utility of the method may be improved by joining the tops of the uprights with a light frame. Inclusion of known points within the borders of the calibration frame is also suggested.

Reliability studies performed on angular variables indicated that substantial improvement in filming and digitising is required before accurate measures can be obtained. There was a great deal of variahility in angular measures around the time of paddle entry. However, soon after paddle entry reliability improved considerably. Figure 4 shows the results obtained for five digitisations of one of the most error sensitive measures - the angle of the lift vector projected onto the yz plane of the blade. For most of the period of blade immersion the standard error of the angular measures were within 10 degrees. It is believed that reliability may be improved by:

i. Maximising image size by panning the cameras and using a moving DLT technique to determine the three dimensional coordinates of the digitised points.

ii. Extending the point (C) further from the paddle shaft to enhance the accuracy of defining the blade centre and blade plane.

iii. Making the attachment to point C more rigid so that the point has a smaller oscillation away from its known resting position relative to the paddle shaft and blade.

REFERENCES

- Abdel-Aziz, Y.I., & Karara, H.M. (1971). Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry. In ASPUI Symposium on Close-Range Photogrammetry. Falls, Church, Va: American Society of Photogrammetry. pp. 1-18.
- Issourin, V. (1989). Biomechanical aspects of kayak related to strength. In J. Vrijens, J. Verswtnyft & D. deClerq (Eds.), International Seminar on Kayak-Canoe Coaching and Sciences. Bu-

dapest, Hungary: International Canoe Federation. pp. 83-91.

- Marzan, G.T., & Karara, H.M. (1975). A computer program for direct linear transformation solution of the collinearity condition, and some applications of it. Symposium on Close Range Photogrammetric Systems. Falls Church, Va: American Society of Photogrammetry. pp. 420-476.
- Sanders, R.H., & Kendal, S.J. (1992). A description of Olympic flatwater kayak stroke technique. Australian Journal of Science and Medicine in Sport. June 1992 (In press).
- Schleihauf, R.E. (1979). A hydrodynamic analysis of swimming propulsion. In J. Terauds & E.W. Bedingfield (Eds.), Swimming III. Baltimore: University Park Press, pp.70-109.