Proceedings of the
International Conference on Mechanical Engineering 2005
(ICME2005) 28 - 30 December 2005, Dhaka, Bangladesh

ICME05-TH-32

AERODYNAMIC EFFICIENCY AND THERMAL COMFORT OF BICYCLE HELMETS

Firoz Alam, Simon Watkins and Aleksandar Subic

School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University
264 Plenty Road, Bundoora, Melbourne, VIC 3083, Australia

ABSTRACT

Bicycle helmets are mandatory for recreational or professional bicycle riders in many countries including Australia. Although the primary objective of a helmet is to provide head protection during fall or accident, thermal comfort and aerodynamic efficiency are becoming important design criteria. Helmet increases the frontal area of a rider’s head that induces higher aerodynamic resistance (drag). Therefore, helmet must have a good aerodynamic shape to minimise the frontal area in order to produce less aerodynamic drag. Most bicycle helmets are made of foam that holds up heat, generated by the rider’s head during cycling. Humidity and high ambient temperature make the situation worse as trapped heat causes significant discomfort (sweating, stickiness etc). Helmets with venting can minimise this problem. However, venting generally increases aerodynamic drag. Therefore, an optimal design for helmet is very important in order to satisfy both aerodynamic and thermal efficiency. The primary objective of this work is to study the aerodynamic efficiency and thermal comfort of a series of current production helmets available in Australia Aerodynamic drag and thermal comfort was measured under a range wind speeds, yaw and pitch angles. All helmets were ranked according to their aerodynamic efficiency and thermal comfort.

Keywords: Bicycle helmet, Aerodynamic drag, Thermal comfort, Wind tunnel

1. INTRODUCTION

Bicycle helmets are mandatory for recreational or professional bicycle riders in many countries including Australia. Although the primary objective of a helmet is to provide head protection during fall or accident, thermal comfort and aerodynamic efficiency are becoming important design criteria, [1], [2], [3] and [4]. Helmet increases the frontal area of a rider’s head that induces higher aerodynamic drag. Therefore, helmet must have a good aerodynamic shape to minimise the frontal area in order to produce less aerodynamic drag. Most bicycle helmets are made of foam that holds up heat, generated by the rider’s head during cycling. Humidity and high ambient temperature make the situation worse as trapped heat causes significant discomfort (sweating, stickiness etc). Helmets with venting can minimise this problem. However, venting generally increases aerodynamic drag. Therefore, an optimal design for helmet is very important in order to satisfy both aerodynamic and thermal efficiency. The primary objective of this work is to study the aerodynamic efficiency and thermal comfort of a series of current production helmets available in Australia. Each helmet was tested for their aerodynamic efficiency and heat dissipation characteristics under a range wind speeds, yaw and pitch angles in the RMIT University Industrial Wind Tunnel. Descriptions about RMIT Industrial Wind Tunnel and other equipment are given in Section 2. Helmets were ranked according to their aerodynamic efficiency and thermal comfort.

2. EQUIPMENT, TEST PROCEDURE AND HELMET DESCRIPTION

The aerodynamic efficiency in terms of drag and heat dissipation characteristics for five helmets were experimentally measured in the RMIT Industrial Wind Tunnel under a range of speeds (20, 30, 40, 50 and 60 km/h wind speeds), yaw angles (0, ±30º, ±60º and ±90º) and pitch angles (90, 60, 30 and 0 from horizontal axis). The aerodynamic drag was measured using a six component force sensor. The thermal efficiency in terms of heat dissipation (temperature drop) was measured using a heat pad on the dummy head. Seven thermo couples were attached with the heat pad located around the head under the helmet. An instrumented dummy head with the heat pad, thermo couples and helmet is shown in Figure 3. All five helmets are different in terms of venting holes and structural geometry. All five helmets were new and manufactured by Rosebank Australia (a subsidiary of Dunlop Pacific Australia). These helmets are: Blast, Mamba, Nitro, Summit and Vert (see Figure 1). As mentioned earlier, tests were conducted in the RMIT Industrial Wind Tunnel. This tunnel is a closed return circuit with a turn table to yaw a suitable model to simulate the crosswind effects. The dimension of the test section is 9 m long, 3 m wide and 2 m high with a maximum air speed of 150 km/h. A mounting device for the dummy head was manufactured so that it can be mounted on the six-component force sensor. Figure 2 shows the dummy head with mounting device in the test section of the wind tunnel.

In order to understand the effects of no venting, the Vert helmet was modified and tested twice as standard configuration with the venting and modified configuration without the venting (venting blanked off), see Figure 1f.

a) Nitro Helmet

b) Mamba helmet

c) Summit helmet

d) Vert helmet

e) Blast

f) Vert helmet modified (simply blanked off)

Fig 1. A bird's eye view of all helmets

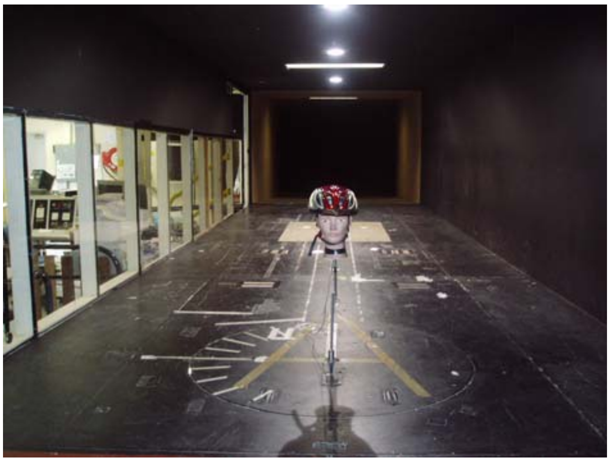

Fig 2. Experimental setup in the test section with a dummy head

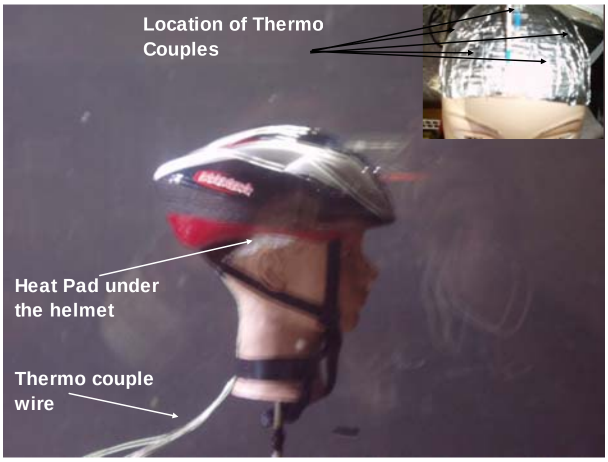

Fig 3. Experimental setup for thermal testing (dummy head, heat pad and helmet)

3. RESULTS AND DISCUSSION

Each helmet was tested with and without the head assembly (dummy head and mounting device) for all speeds, yaw angles and pitch angles. The aerodynamic forces due to helmets were determined by subtracting the forces with head and helmet from the forces with head only. All three forces (drag, side and lift) and their corresponding moments were converted to non dimensional parameters. Only drag force coefficient (Cd) is presented in this work. As mentioned earlier, the drag forces were measured under a range of speeds (20 to 60 km/h with an increment of 10 km/h), yaw angles and pitch angles.

Thermal efficiency was measured by heating up the heat pad at 60ºC which was selected arbitrarily. A thermostat was used to keep the temperature constant on the heat pad. Seven thermocouples were attached on the heat pad under the helmet to monitor the temperature drop around the head. Two thermocouples were attached at the front of the head, two on each side (left & right), two on the rear of the head and one thermocouple at the centre of the head in order to obtain a comprehensive temperature distribution (see Figure 3). The temperature drop was monitored for 5 minutes at all wind speeds. The readings from all seven thermocouples were averaged and presented in this paper. As mentioned earlier, all helmets were tested under a range of wind speeds, yaw and pitch angles. However, the results for zero yaw angles are presented here. The drag coefficient as a function of Reynolds numbers (varied by speed) and pitch angles for all helmets are shown in Figures 5 to 8. Similarly, the average temperature drop as a function of Reynolds numbers and pitch angles for all helmets is shown in Figures 11 to 15. The heat dissipation was documented by a Thermal Imaging Camera. Typical heat dissipation through the Vert helmet is shown in Figure 10. The results for other helmets are not shown in this work. The drag coefficient (Cd) is relatively independent of Reynolds numbers for all helmets at 90º and 60º pitch angles except at very low speeds. However, minor Reynolds number dependency for all helmets was noted at other pitch angles (30º and 0º). The pitch angle was measured from the horizontal. The zero pitch angle means that the dummy head is absolutely horizontal and the helmet is vertical whereas at 90º pitch angle, the dummy head is absolutely vertical and the helmet is horizontal. The airflow at 30º pitch angles becomes complex due to the interaction of the flow separation from the local venting and fitting strips. The highest aerodynamic drag was found at 0º pitch angles for all helmets except the Vert helmet with and without venting. With an increase of pitch angles, the projected frontal area of the helmet reduces. Additionally, the airflow becomes more streamlined and produces less aerodynamic drag. The Vert helmet has minimum venting. Therefore, it is expected that the Vert helmet will produce relatively lower aerodynamic drag compared to other helmets. No significant variation in drag coefficient of the unmodified and modified Vert helmets was noted. Although it was expected to have less drag coefficient for the modified helmet compared to unmodified helmet as it is more streamlined. The Vert helmet generates the lowest drag at over 30 km/h and 90º pitch angles. On the other hand, the Nitro and Summit helmets produce higher drag at the same speeds and pitch angles. The pitch angle has virtually no impact on the drag coefficient for the Vert helmet (see Figure 8).

The temperature drop is evident for all helmets with the increase of Reynolds number (see Figures 11 to 15). The pitch angle has negligible effects on temperature drops for the Blast, Mamba, Nitro and modified Vert helmets. However, a significant variation in temperature drops due to pitch angles is noted for the unmodified Vert helmet. Additionally, a small variation in temperature drops was noted between 90º and other pitch angles for the Summit helmet. The lowest temperature drop was noted for the modified helmet as expected due to no venting (see Figure 15). The highest temperature drop was evident for the Mamba helmet (see Figure 12). The second highest temperature drop was measured for the Summit helmet. Although the Vert helmet was aerodynamically more efficient, it is the worst performer in terms of thermal efficiency. On the other hand, the Nitro and Summit had relatively higher aerodynamic drag at 90º pitch angle and generate significant temperature drops. However, the Mamba helmet is the optimal helmet for its aerodynamic and thermal efficiency as it produces the highest temperature drops at all pitch angles and low aerodynamic drag (second lowest drag). The number of venting, venting geometry and venting location play an important role in temperature drops. However, they also can generate more aerodynamic drag. Figure 10 shows the heat dissipation through the venting of the Vert helmet. It is interesting to see the mechanism of heat dissipation using Thermal Imaging as it shows the heat signature well. As mentioned earlier, the heat dissipation characteristics were recorded for all helmets as part of the larger study. However, the results of other helmets are not presented in this work. Figure 10 also shows the trails of heat towards the back (rear) of the helmet by the wind.

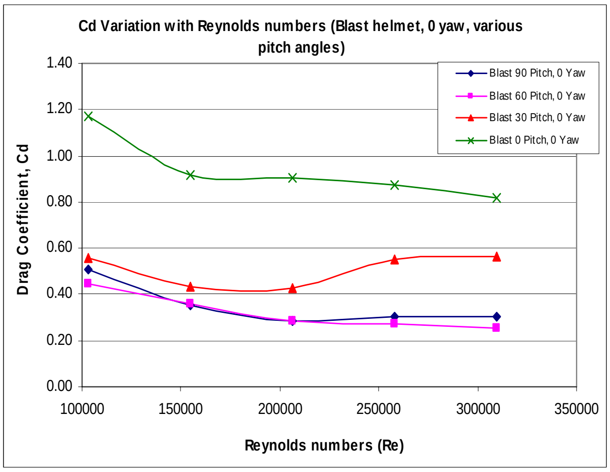

Fig 4. Drag coefficient as a function of Reynolds number and pitch angles (Blast helmet, 0º Yaw)

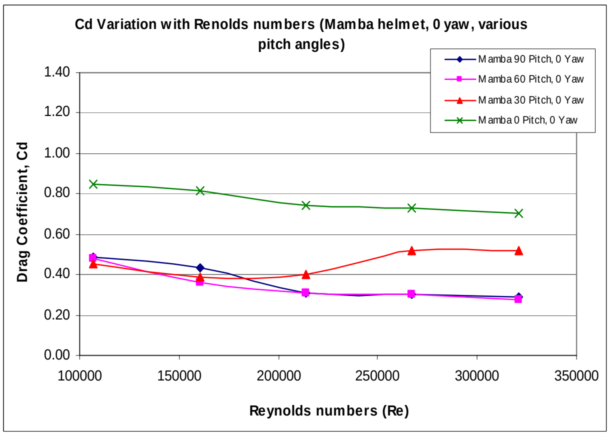

Fig 5. Drag coefficient as a function of Reynolds number and pitch angles (Mamba helmet, 0º Yaw)

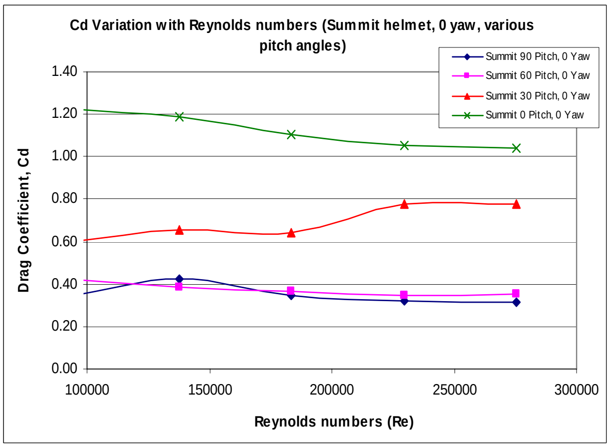

Fig 6. Drag coefficient as a function of Reynolds number and pitch angles (Summit helmet, 0º Yaw)

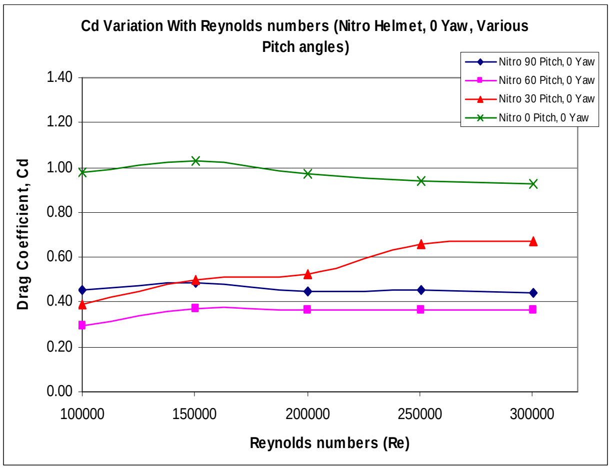

Fig 7. Drag coefficient as a function of Reynolds number and pitch angles (Nitro helmet, 0º Yaw)

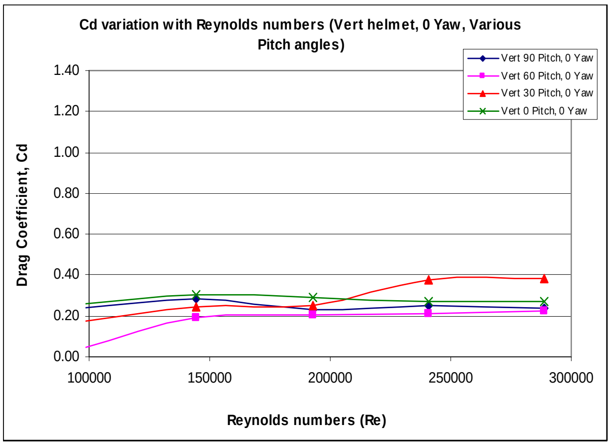

Fig 8. Drag coefficient as a function of Reynolds number and pitch angles (Vert helmet, 0º Yaw)

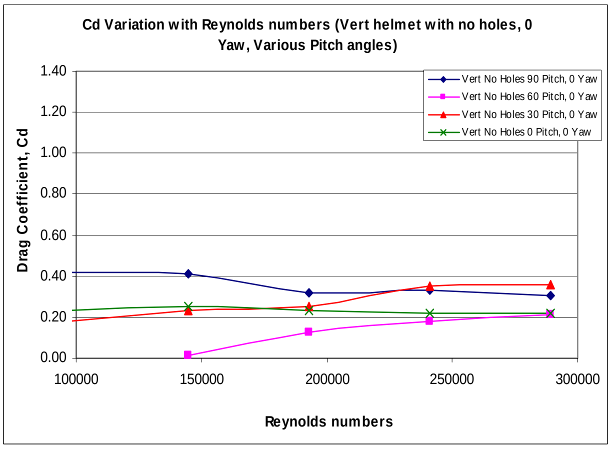

Fig 9. Drag coefficient as a function of Reynolds number and pitch angles (Vert helmet with no venting, 0º Yaw)

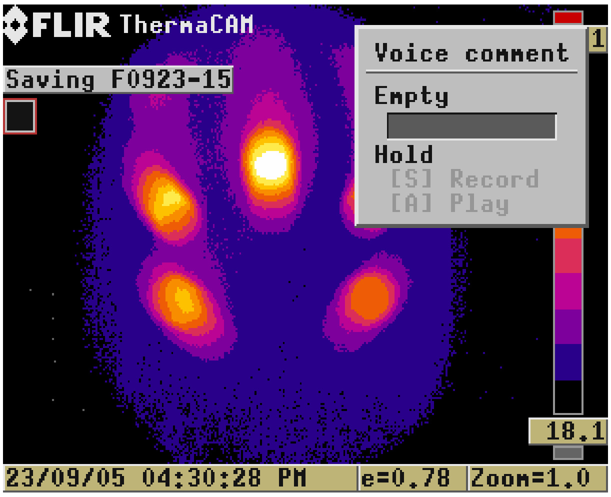

Fig 10. Typical Heat Dissipation through the venting hole

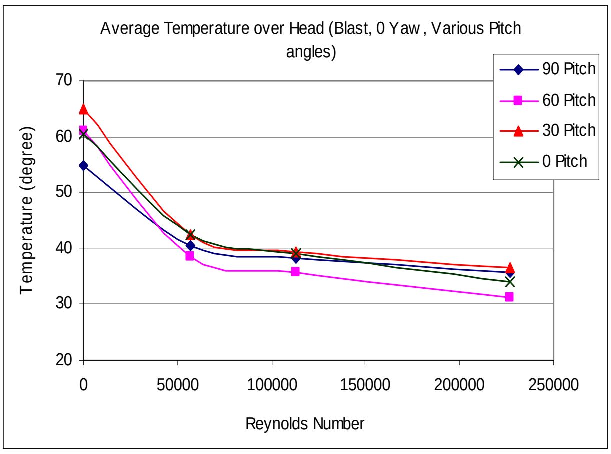

Fig 11. Temperature variation with Reynolds numbers as a function of pitch angles (0º yaw), Blast helmet

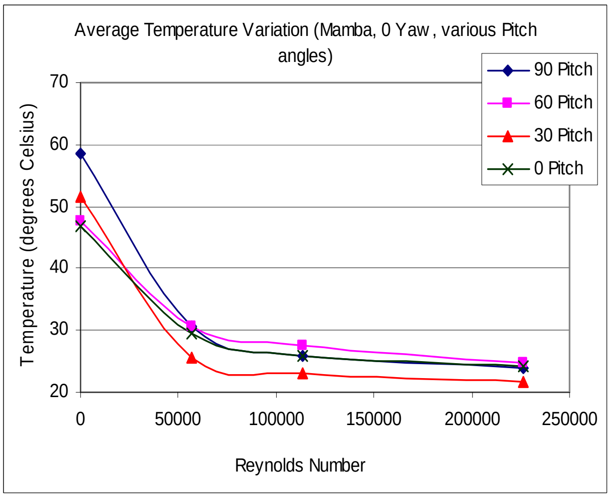

Fig 12. Temperature variation with Reynolds numbers as a function of pitch angles (0º yaw), Mamba helmet

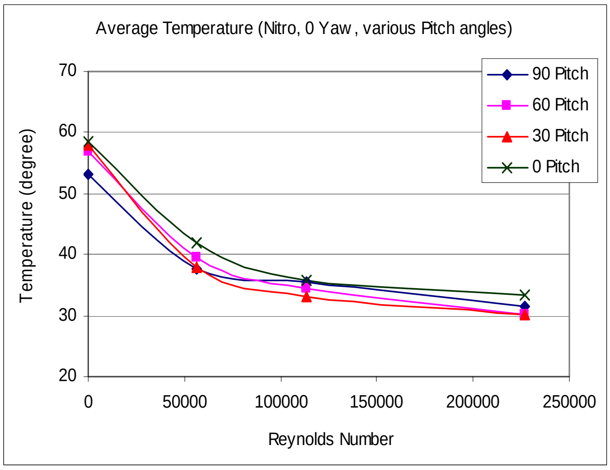

Fig 13. Temperature variation with Reynolds numbers as a function of pitch angles (0° yaw), Nitro helmet

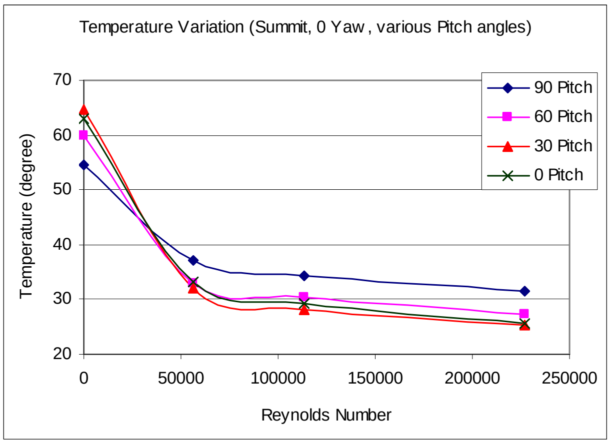

Fig 14. Temperature variation with Reynolds numbers as a function of pitch angles (0° yaw), Summit helmet

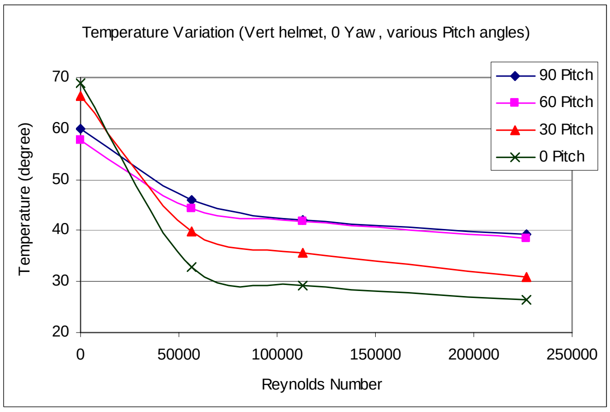

Fig 15. Temperature variation with Reynolds numbers as a function of pitch angles (0° yaw), Vert helmet

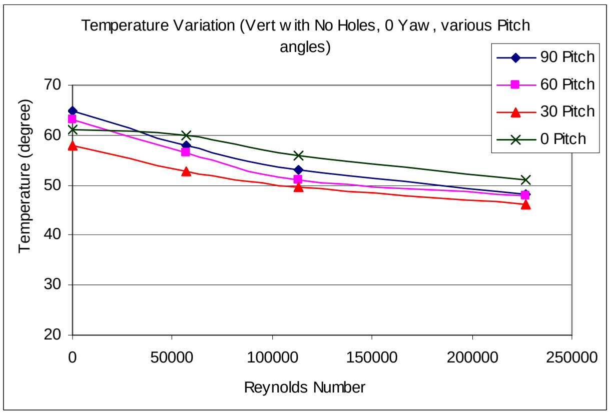

Fig 16. Temperature variation with Reynolds numbers as a function of pitch angles (0° yaw), Vert helmet with no holes

4. CONCLUSIONS

The following conclusions were made from the work presented here:

- The drag coefficient is relatively independent of Reynolds numbers at high speeds at 90° and 60° pitch angles for all helmets.
- The Vert helmet produces the lowest aerodynamic drag. However, it is the worst in terms of heat dissipation.
- The Nitro and Summit generate higher aerodynamic drag but perform well in heat dissipation.
- The pitch angles have significant effects on aerodynamic drag, however less effects on heat dissipation.
- The Mamba is the optimal helmet for its aerodynamic and thermal efficiency.
- The number of venting, venting geometry and venting location on the helmet play the key role for the thermal and aerodynamic efficiency.

5. ACKNOWLEDGMENT

The authors would like express their sincere thanks and gratitude to Mr Anthony Resta and Mr Rhys Solomons for their assistance with the testing and data analysis. Without their assistance, it was not possible to complete this paper on time.

The authors are also grateful to Rosebank Australia for providing the helmets.

6. REFERENCES

1. Reid, J. and Wang, E. L., 2000, "A system for quantifying the cooling effectiveness of bicycle helmets", *J Biomech Eng*. 122 (**4**): 475-460.
2. Wang, E. and Reid, J., 1999, "Designing Bicycle Helmets for Thermal Comfort", *ASME Summer Bioengineering Conference*, June 16-20, Big Sky, Montana, USA.
3. Bruhwiler, P. A., 2003, "Heated, perspiring manikin headform for the measurement of headgear ventilation characteristics", *Meas. Sci. Technol*. **14** 217-227.
4. *Consumer Product Safety Review*, 1999, Vol 4, No. 1 by the U.S. Consumer Product Safety Commission.

7. NOMENCLATURE

Symbol	Meaning	Unit
T	Temperature	(ºC)
F	Force	(N)
Cd	Drag coefficient	-

8. MAILING ADDRESS

Dr Firoz Alam
School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Bundoora East
Bundoora, Melbourne, VIC 3083
Australia
Phone: +61-3-99256103
Fax: +61-3-99256108
E-mail: firoz.alam@rmit.edu.au