International Journal of Industrial Ergonomics 68 (2018) 186–198

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Computational and subjective assessment of ventilated helmet with venturi effect and backvent

Bhagwat Singh Shishodia*, Sanjeev Sanghi, Puneet Mahajan

Applied Mechanics Department, Indian Institute of Technology Delhi, New Delhi, India

ARTICLE INFO

Keywords:
Helmet ventilation
Venturi effect
Backvent
Subjective trials

ABSTRACT

The effectiveness of providing venturi effect and backvent in full face ventilated motorcycle helmets to provide thermal comfort to a rider is investigated using Computational fluid dynamics (CFD) simulations of air flow and human thermoregulation system in the microclimate of the helmet. Thermal comfort of a motorcycle rider is then predicted using heat indices. The effect of increase in ambient air temperature on the thermal comfort of a rider wearing a modified ventilated helmet, with venturi effect and backvent on the air flow, and temperature distribution in the region above the head is studied. The results are then compared with the conditions when the rider is wearing a full-face, conventional non-ventilated helmet, ventilated helmet with three vents in front and a helmet with only venturi effect. Results are also compared for the conditions when the rider is not wearing any helmet.

It is observed that the venturi effect in a ventilated helmet increases the local air velocities in the air gap as compared to a ventilated helmet with three vents in the front of the helmets. Further, it is observed that backvent in venturi helmet augments the thermal comfort of the rider if the ambient air temperature is less than normal body temperature. When air temperatures are higher than the body temperature (36 °C), it is found that the trends are reversed and ventilated helmets are no longer able to provide thermal comfort to the motorcycle rider.

For better understanding of effect of newly designed ventilated helmets on the cognitive performance and the willingness of a rider to wear helmets, subjective evaluation of the prototype of venturi helmet is done. Each set of trials required riders to ride with different types of helmets. Based on the results of numerical simulations of ventilation in helmets and responses from subjective human trials, a set of fluid dynamics and design guidelines is also proposed for the helmet manufacturing industries.

1. Introduction

In tropical climates, high temperatures and dripping sweat from the rider's head creates a microclimate inside a helmet which is very uncomfortable for a rider. For this reason, riders generally prefer not to wear helmets, especially on hot summer days in tropical countries. Riders are thus at great risk of severe head injuries during a collision. Design modifications for a full-face helmet should take these considerations into account and attempt to enhance ventilation, rate of sweat evaporation and heat removal from the rider's head, so a rider's willingness to wear a helmet can be increased.

Fonesca (Fonseca, 1973) investigated sweat evaporation from the head of a person wearing a helmet. He recommended an air gap of at least 6 mm in a helmet to facilitate the air flow and sweat evaporation. He also suggested physical contact of helmet with the head should be kept to a minimum, because the head surface in contact with the helmet will not contribute to the evaporative heat transfer. This may increase the local skin temperature of the head. Edward and Burton (Edwards and Burton, 1960) reported the head has almost no vasoconstriction mechanism, so there will be continuous heat loss from the head. Additionally, sweat generation from the head will occur continuously because there is no physiological mechanism for controlling the sweat generation from the head. If this sweat has not evaporated from the rider's head, the dripping of sweat on face, neck, ears and back of the head will cause itching sensation and thermal discomfort to the rider. Mithun et al. (2013) and Raju et al. (2009) suggested the use of air vents, an exhaust fan and backvent in the helmet to improving ventilation and maintain the freshness of air flowing in the helmet air gap. From the above discussion, it is obvious that proper ventilation and freshness of air inside the helmet air gap is of utmost importance for the thermal comfort of a rider.

To the best of author's knowledge, a numerical investigation to

* Corresponding author.
E-mail addresses: bhagwat.shishodia@jietjodhpur.ac.in (B.S. Shishodia), sanghi@am.iitd.ac.in (S. Sanghi), mahajan@am.iitd.ac.in (P. Mahajan).

https://doi.org/10.1016/j.ergon.2018.07.009
Received 4 May 2018; Received in revised form 24 July 2018; Accepted 31 July 2018

redesign the internal ventilation system of a helmet using coupled computational fluid dynamics (CFD) and numerical model of human thermoregulation system is probably the first of its kind. All previous studies to redesign air ventilation systems in helmets, focus only on numerical simulations of air flow in the air gap, as investigated by Haider (2008) and Pinnoji et al. (2008). They did not consider human thermoregulation and sweat evaporation from a rider's head in their numerical investigations. Shishodia et al. (2017) performed the air flow and human thermoregulation simulations to investigate the effect of increase in ambient temperature and relative humidity (RH) on the thermal comfort of a rider wearing ventilated and non ventilated helmets. In their studies they considered the effect of sweat evaporation from the rider's head on the thermal comfort of the rider. They found that ventilated helmets provide thermal comfort to riders only up to 36 °C.

The present work intends to propose a new and improved design of full face, ventilated motorcycle helmets, so a rider's thermal comfort can be increased. In the present study, the air flow and heat transfer in the air gap along with the sweat evaporation from the rider's head while wearing different designs of a full face motorcycle helmet is numerically investigated. Numerical simulations are also performed for the human thermoregulation system of a rider to understand the effect of design changes in the helmet on the thermal comfort of a rider.

In this study, a 3- dimensional ventilated helmet with three air vents in the front of a full face motorcycle helmet is designed, using computer aided design (CAD). The helmet is then raised above the rider's head by 6 mm using supports or spacers. A modified neck curtain (soft linear foam with gradually increasing thickness from top to bottom) is provided at the back of the helmet. This modified neck curtain, along with supports, is designed to let the passage for air flow (air gap) between the rider's head and the helmet decreases in cross section from front to the back of helmet, thus creating a venturi like air gap between the rider's head and the helmet. This "Venturi" air gap intends to create local acceleration of air flow in the helmet air gap, resulting in an increase of local air velocity over the rider's head. This will increase the rate of evaporation of sweat from a rider's head, resulting in an increase in thermal comfort to the rider. This increase in the rate of evaporation of sweat from a rider's head and subsequent cooling of the rider's head using venturi shaped air gap in helmets is known as "Venturi Effect". To further augment the ventilation in the helmet, a backvent has been placed at the back of a venturi helmet. This will result in increase of sweat evaporation from the rider's head. This backvent also ensures the early removal of hot and moisture-laden air from the helmet as well as permitting early entry of fresh air into the helmet air gap. *The results of CFD simulations are also compared with no helmet conditions, to use as a benchmark, to estimate the effectiveness of each helmet design in providing thermal comfort to the rider.*

Steadman (1984) reported that Dry Bulb Temperature (DBT) influences the Apparent Temperature (AT) and the thermal comfort of humans, more than relative humidity of air. Shishodia et al. (2017) also reported that with an increase in relative humidity of air, the moist air in the helmet air gap is unable to evaporate and carry all the sweat from the rider's head, causing thermal discomfort to the rider. So, in this work, to save the computational resources and time, the effect of an increase in relative humidity of air on the thermal comfort of a rider is not further investigated.

2. Mathematical formulation and validation of turbulence model

2.1. Equations for fluid flow, heat transfer and diffuse species

The governing equations for fluid flow and heat transfer in the computational domain are described by the continuity equations, Reynolds Averaged Navier-Stokes (RANS) equations and heat transfer equations. In addition to the above equations, the equation for diffuse species (Humidity) is also solved. For an incompressible flow these equations are as follows (ScTetra User Guide, 2011):

$$\text{Continuity Equation:} \frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

Reynolds Averaged Navier Stokes equations:

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial u_j \rho u_i}{\partial x_j} = \frac{-\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\mu\left[\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right] \tag{2}$$

where μ is Viscosity $(=\mu_l + \mu_t$: Molecular Viscosity + eddy Viscosity)

$$\text{Energy Conservation Equation:} \frac{\partial \rho C_p T}{\partial t} + \frac{\partial u_i \rho C_p T}{\partial x_j} = \frac{\partial}{\partial x_j}\kappa\frac{\partial T}{\partial x_j} + \dot{q} \tag{3}$$

$$\text{Equation for Diffuse Species (humidity):} \frac{\partial \rho C}{\partial t} + \frac{\partial u_j \rho C}{\partial x_j} = \frac{\partial}{\partial x_j}\rho D_m \frac{\partial C}{\partial x_j} + \rho \dot{d} \tag{4}$$

2.2. Validation for turbulence model

Shishodia et al. (2013) suggested that the Spalart Allmaras (S-A) turbulence model predicts the mean flow parameters in the helmet air gap better than $k-\varepsilon$ models. For validation of turbulence model, they compared their results of numerical simulations of air flow in the air gap of 3- dimensional hemispherical head-helmet arrangement to the experimental results of Yadav (2006) as (shown in Fig. 1(a)), comparing different turbulence models, to predict air velocity at 8 non-wall points on top of the rider's head. They found that S-A model predicted the velocity in the helmet gap better than $k-\varepsilon$ models. For this reason, in the present study, we have used Spalart Allmaras (S-A) turbulence model for estimating the mean flow parameters of air in the air gap of a helmet.

The Spalart Allmaras (S-A) turbulence model is one equation turbulence model for predicating mean flow properties (Spalart and Allmaras, 1994). It solves the Reynolds – averaged Navier-Stokes equations and a transport equation for turbulence model. The Reynolds stresses are given by

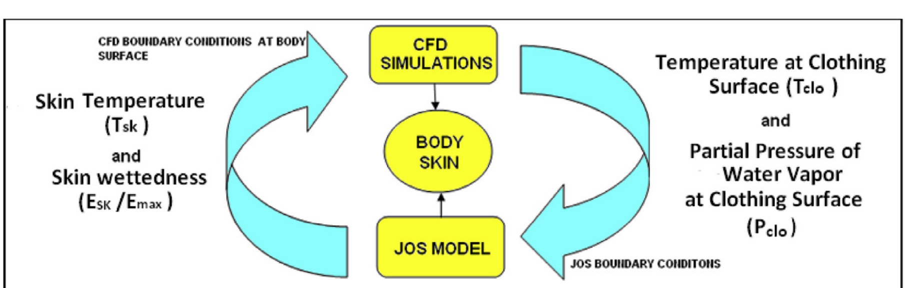

Fig. 1. Flow Chart of JOS- CFD calculation, Ando (Ando, 2009).