By Tom Austin, IBA Chief Technical Advisor

Long-Distance Riding in Hot Weather

HOT WEATHER BECOMES a significant risk to long-distance motorcycle riders when the temperature climbs above the typical human skin temperature of about 93°F. Three of the four mechanisms by which riders normally stay cool while riding no longer work when the air temperature exceeds human skin temperature. The danger of heat exhaustion and/or heat stroke skyrockets.

It is possible to ride safely, and even comfortably, in triple digit temperatures, but you have to be aware of how things change when the air temperature exceeds your skin temperature. Conventional wisdom is that mesh riding suits are best suited for such conditions because they maximize airflow over the skin. However, for the reasons explained below, maximum air flow is not what you need under these conditions.

To understand what gear works best in hot weather, it helps to know how thermal regulation of the human body works.

Temperature Regulation of the Human Body

Being warm-blooded, humans must maintain a core temperature within a few degrees of our 97-99°F normal temperature. If we get just 5° hotter or colder, we are seriously impaired; 10° hotter or colder, we die.

With the right gear, we can ride safely and comfortably at temperatures below freezing. With adequate insulation and wind protection, the heat our basic metabolism is creating (about 100 watts when we are sitting at rest and 140 watts with light activity) is sufficient to maintain our core temperature. However, it is much more difficult to maintain a safe and comfortable temperature when the ambient temperature exceeds our skin temperature. Insulation doesn't work because we become overheated from within when the heat generated by our metabolism has no place to go.

To avoid becoming over-heated by our metabolic heat release, we need to be in contact with or surrounded by something cooler than our core temperature. That's why the maximum comfortable room temperature is typically 80°F or lower. In still air, we get uncomfortably warm and experience an increased rate of perspiration when the temperature is higher.

Human bodies exchange heat with their surroundings through convection, conduction, radiation, and evaporation.

Conduction involves the transport of energy by means of direct physical contact in the absence of relative motion. Conductive heat transfer can be very significant for a body immersed in water, but air is such a poor conductor, that conduction plays a fairly minor role.

Convection involves the transport of energy by the means of the motion of air surrounding the body. Heat transfer occurs when air at one temperature comes into contact with the skin at a different temperature. Convection allows the heat transfer to continue by bringing a fresh supply of air to the skin surface. At zero wind speed, there is a minor amount of convective heat transfer associated with the motion caused by the temperature differential between the skin and the air. At non-zero wind speeds, convection becomes significant if the air is at a different temperature than the skin.

Radiation is the form of heat transfer that does not depend on direct physical contact with the surroundings, only on the temperature differential. Heat radiates from a hotter surface to the colder surroundings. In still air, radiation is the primary cooling mechanism for the human body when the air temperature is significantly lower than the skin temperature.

Evaporation is the cooling mechanism associated with perspiration (which is about 99% water). It is an insignificant factor when the air temperature is significantly lower than the skin temperature, but it becomes the dominant cooling mechanism as air temperature rises. More importantly, it becomes the *only* cooling mechanism when the air temperature exceeds the skin temperature. Achieving effective evaporative cooling is therefore critical to surviving when the temperature is 93˚F or higher.

How Evaporative Cooling Works

Conduction, convection, and radiation are easier to understand than evaporative cooling because they involve the flow of heat from a surface that is warm to a surrounding medium that is colder. Evaporation is more complicated.

Evaporation of water occurs whenever the air in contact with the water isn't already saturated with water vapor. When the air is dry, it causes water to evaporate until the air becomes saturated; at that point, evaporation stops. The "relative humidity" of the air is then at 100%, meaning that it can't hold any more water. At 86˚F, each cubic meter (35 cubic feet) of air can hold 30 grams of water vapor, which is about one ounce. That may not sound like a lot, but when the air temperature is 86˚F or higher, the air seldom becomes saturated, even when there is a nearby ocean. (As warm air rises and cools, water is eventually removed by cloud formation and rain.)

Evaporative cooling works because of something called the *latent heat of vaporization.* "Latent heat" is the quantity of heat absorbed or released when substance undergoes a change of state, e.g., from a liquid to a vapor. As water vaporizes, it absorbs heat from the surrounding environment, which cools anything the vaporizing water is in contact with. Each gram (about 1 milliliter) of vaporizing water draws approximately 580 "calories" of heat from the surroundings. (A calorie is the amount of heat required to raise the temperature of 1 gram of water by 1˚C.)

The effectiveness of evaporative cooling depends on the humidity level. Sweat evaporates faster in dry, desert-like conditions. The effect of humidity on evaporation can be measured with a "wet bulb" thermometer, which is a thermometer with the bulb end covered by a wick soaked with water. Water evaporating from the wick causes the temperature to be reduced, just like a wet T-shirt against your skin makes you cooler as water evaporates from the shirt.

The cooling effect of evaporation can be dramatic with low, desert-like humidity. For example, at noon on July 26, 2009, the air temperature in Death Valley, California was 100˚F with a relative humidity of 13%. The wet bulb temperature was only 66˚F. Under these conditions, a wet shirt against your skin feels downright cold. In contrast, on the same day it also 100˚F in Houston, Texas, but the relative humidity was 42%. The wet bulb temperature was 80˚F. Under these conditions, a wet shirt still has a cooling effect, but not nearly as great as under desert-like conditions.

The evaporative cooling effect is why humans that are heavily perspiring can survive desert conditions. There is not enough perspiration to bring the skin temperature to the wet bulb thermometer reading, but a normal 93˚ skin temperature can be achieved.

Direct radiation from the sun can also be a factor, but when we are shaded from the sun or wearing reflective clothing, something in between the wet bulb and dry bulb temperature is the best indication of how hot it will feel at or above 93˚F. It will obviously feel cooler in Death Valley than in Houston at the same air temperature.

Examples of Heat Flow to and From the Body

With "light" activity, such as riding a motorcycle on paved roads, our basic metabolism produces about 140 watts of heat that has to be removed. To avoid a rise in core temperature, 140 watts must flow from the body to its surroundings.

Using published literature, primarily on the work of Dr. Rod Nave of Georgia State University and Zhang, et al. from De Montfort University in the UK, I've compiled a series of models and related heat transfer coefficients that produce reasonable estimates of the temperature levels at which people are comfortable. The models indicate that, without noticeably perspiring, the combination of conduction, convection, radiation, and evaporative cooling will allow us to remain comfortable in an indoor environment at an air temperature of 80˚F if we are wearing only very light clothing. The heat balance is illustrated in Figure 1. Most of the cooling is provided by radiation. It takes less than 1 ounce of perspiration per hour to provide the required 14 watts of evaporative cooling.

Figure 2 illustrates what happens when the room temperature rises to 93˚F. Heat flow from conduction, convection, and radiation stops because there is no difference between skin temperature and the air temperature. Evaporative cooling is the only available pathway and we must perspire enough to achieve 140 watts of cooling from the evaporation of sweat. To achieve 140 watts of evaporative cooling, about 7 ounces of water must evaporate from our skin every hour. To the extent

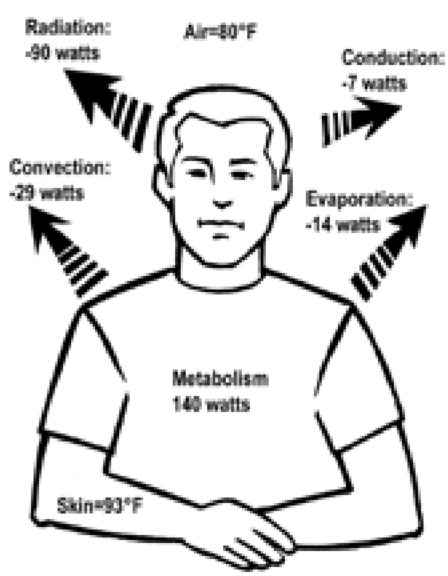

Figure 1
Heat Balance in Calm Air With 80°F Air Temperature
Required Evaporation: <1 oz. per hour

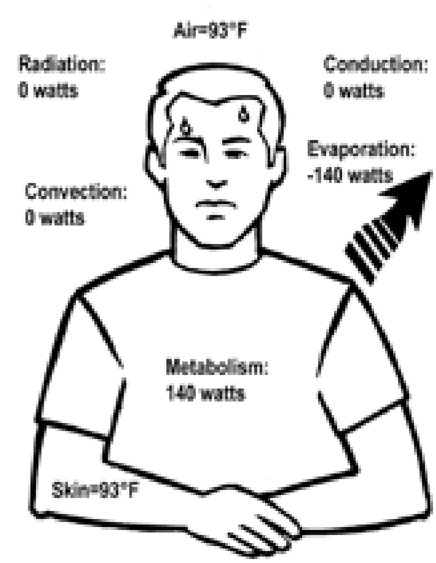

Figure 2
Heat Balance in Calm Air With 93°F Air Temperature
Required Evaporation: 7 oz. per hour

that some of the sweat drips off before evaporating, the required level of sweat production increases correspondingly. Considering that other bodily needs for water are about 3 ounces per hour, we would need to drink a minimum of 10 ounces of water every hour to avoid dehydration.

Above 93°F, the required perspiration level increases because the air temperature is then transferring heat into the body. Figure 3 shows what happens at 103°F. In addition to the 140 watts being generated by our metabolism, 99 watts of heat are transferred into the body by the combined effects of conduction, radiation, and convection. To supply the required 239 watts of evaporative cooling, the amount of sweat we have to evaporate increases to 12 ounces per hour.

Now consider what happens when we move from indoors to a motorcycle. Assume that we are riding a motorcycle with no fairing and wearing light clothing or a mesh riding suit that doesn't block the wind, the front surface of our body (about one square meter) is exposed to the full effect of the wind. Because convective heat transfer is a function of the velocity of the air over the surface of the skin, the heat transferred into the body increases significantly. At 103°F air temperature, the convective heat transfer increases from just 22 watts under calm

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conditions to 550 watts at freeway speeds. This is the opposite of “wind chill;” a light breeze can still enhance evaporative cooling but above 93°F a strong wind is heating the body.

As illustrated in Figure 4, the increase in convective heat transfer when the skin is exposed to high wind speeds at 103°F increases the required level of evaporative cooling to 767 watts. That requires 39 ounces of perspiration per hour. Riding four hours between fuel stops under these conditions causes more than 1.2 gallons of water loss in the form of perspiration. This is close to the maximum sustainable perspiration rate for the average adult.

At 113°F, the minimum required evaporation rate increases to 70 ounces per hour when your body is exposed to a strong wind. Unless you are acclimated to working in tropical environments, you can't sweat that much, regardless of how much water you are drinking. Keep riding under these conditions and you will faint from heat stroke.

The secret to avoiding heat stroke when riding in extremely hot weather is to cut down the convective heat transfer by blocking most of the wind. This can be accomplished by using a fairing and windscreen and/or by wearing a helmet and riding suit that blocks the wind and has vents to allow a lower velocity of air to pass over your skin. By knocking the air velocity down to about 10 mph, the convective heat transfer is reduced by 70% and there is still plenty of air flow for efficient evaporative cooling.

The effect of reducing the wind speed to 10 mph at an ambient temperature of 103°F is illustrated in Figure 5. Compared to the heat balance with the skin exposed to high wind speed, convective heating is reduced from 550 watts to 165 watts and the evaporative cooling required drops from 767 watts to a more manageable 382 watts. The required perspiration rate drops by about 50% to a more manageable 19 ounces per hour. At 113°F the required perspiration rate drops from 70 ounces per hour to 32 ounces per hour.

Minimum Water Requirements

Replacing a quart of water loss per hour under extreme desert conditions (e.g., 113°F) is manageable, but only if

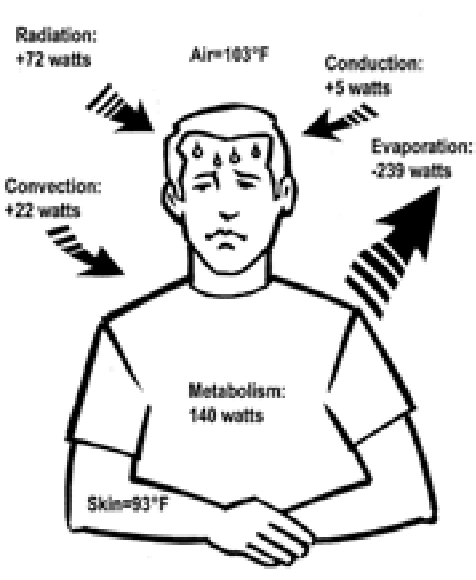

Figure 3
Heat Balance in Calm Air With 103°F Air Temperature
Required Evaporation: 12 oz. per hour

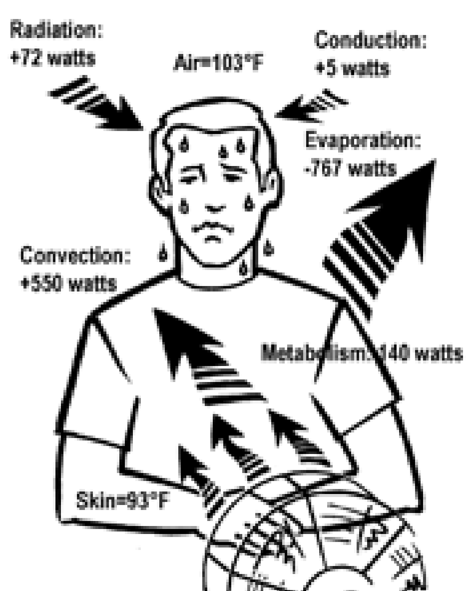

Figure 4
Heat Balance Exposed to High Wind Speed With 103°F Air Temperature
Required Evaporation: 39 oz. per hour!

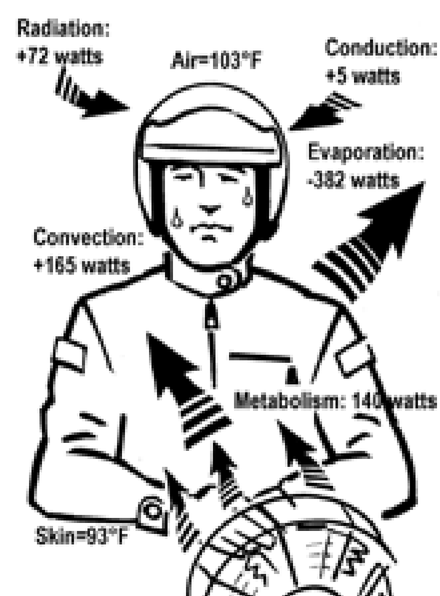

Figure 5
Heat Balance Wearing a Vented-Windproof Suit With 103°F Air Temperature
Required Evaporation: 19 oz. per hour

Table 1: ***Minimum* Water Consumption With Low Wind Speed Over Skin**

Temperature	Required for Evaporative Cooling	Total Water Required	Water Needed Every 4 Hours
80°F	< 1 oz./hour	3 oz./hour	12 ounces
93°F	7 oz./hour	10 oz./hour	40 oz. (1.3 quarts)
103°F	19 oz./hour	22 oz./hour	88 oz. (2.8 quarts)
113°F	32 oz./hour	35 oz./hour	140 oz. (1.1 gal.)

Note: The values shown reflect ideal conditions with no heat being absorbed from the motorcycle.

you are carrying about a gallon of water on-board your motorcycle and drinking frequently between fuel stops. You can't wait to drink during a fuel stop, especially if you are only stopping every four hours. As shown in Figure 6, a drinking tube with a "bite valve" connected to an insulated jug or cooler is the ideal setup. Table 1 summarizes water requirements for a range of temperature conditions.

Although perspiration is about 99% water, there are also trace amounts of sodium chloride and other electrolytes that are lost through perspiration. Notwithstanding the marketing hype used to sell "sports drinks," typical diets are sufficient to replace the electrolytes lost through perspiration without the need for sodium chloride or glucose supplements. According to the American College of Sports Medicine, "There is little physiological basis for the presence of sodium in an oral rehydration solution for enhancing intestinal water absorption as long as sodium is sufficiently available from the previous meal." However, the available sports medicine literature does suggest that sodium chloride supplements are beneficial when conditions result in high rates of perspiration for more than 4-5 hours. For such extreme conditions, sports drinks like Gatorade are a better alternative than pure water unless the salt loss is being replaced with the consumption of salty snack foods. The glucose content of sports drinks is less important for long-distance motorcycle riding because a high level of work is not being done.

Wicking Undergarments

The calculated amounts of water for evaporative cooling described above are based on the assumption that no perspiration is dripping from the body or being blown off of the body before it evaporates. To minimize the loss of any perspiration before it evaporates, it is necessary to wear undergarments that stay in contact with your skin and serve as a wick, just like the wick on a wet bulb thermometer. Garments made by LD Comfort (www.ldcomfort.com) and UnderArmour (available at sporting good retailers) are ideal for this purpose.

Figure 7 shows the LD Comfort helmet liner and turtleneck shirt. The helmet liner is especially important because of the relatively high surface area of the head and the large about of perspiration from the head that can be wasted if it is not captured by a wicking material. Riding shorts or tights made of the same wicking material are also critical for minimizing the dreaded "monkey butt" caused by hours in the saddle sitting on damp, non-wicking material.

Other Sources of Heat

Some motorcycles are better suited for riding in hot weather than others. The need for water described above assumes the motorcycle itself isn't contributing to the thermal load on the rider. Unfortunately, that's a bad assumption for some models.

If engine heat is noticeable at temperature below 93°F, it is likely to be a significant problem at higher ambient temperatures. Water-cooled engines won't necessarily run hotter in hot weather because a thermostat controls the temperature of the coolant. But waste heat absorbed by the coolant has to be transferred to the air passing through the radiator. The higher the temperature of the air entering the radiator, the higher the temperature of the air leaving the radiator will be.

At 93°F, the radiator air discharge might be 140°F and perhaps be reduced to 110°F before it contacts your leg. It feels very warm, but it won't burn you. If

Figure 6
1-Gallon Insulated Cooler With Drinking

Figure 7
Wicking Undergarments like LD Comfort For More Efficient Evaporative Cooling

the ambient temperature is 10˚F higher, your leg might be exposed to 120˚F. That's hot enough to actually burn you in a few minutes if your leg isn't insulated from the radiator discharge.

According to data from the National Burn Center, the combination of temperature and time to cause a second degree burn is 113˚F for 1.7 hours, 122˚F for 2 minutes; 131˚F for 11 seconds, and 140˚F for 2 seconds. (The only thing protecting you from being burned when your bare skin is exposed to ambient temperature of 113˚F or higher is evaporative cooling and the cooling of the skin surface by blood flow.) To be protected from radiator discharge temperatures in excess of 113˚F, you need insulation between your skin and the hot air stream. Your riding suit may not be sufficient. LD Comfort tights will help.

Other Sources of Cooling

Evaporative and "phase change" cooling vests are two options for supplementing the evaporative cooling available from perspiration. They work, but not for very long. Although manufacturers often claim such vests keep you cool for "up to 3 hours" or even longer, two hours of noticeable benefit is more typical. That's less than the time between fuel stops for a typical long distance rider. For a short-term break from the heat without the hassle of a separate cooling vest, you can pour some water on an LD Comfort top during a gas stop — or even while riding — and experience increased evaporative cooling until it dries out.

Evaporative cooling vests can be "recharged" fairly quickly by just soaking them in water, but the phase change vests require 20 minutes in ice water (or longer in a refrigerator) to recharge. Few long distance riders are going to be willing to take the time required.

As I write this, a company named "EntroSys" is advertising an actual air conditioning system that supposedly will provide cool air to a special vest. Although you can't buy the system yet, the company is offering 20% discounts from an undisclosed price for the first 500 individuals to "pre-order" the system. In theory, this could work without consuming an unreasonable amount of power, but it hard to believe many riders will be interested in carrying the hardware required for the limited amount of time the system would actually be used.

In Summary…

The magic number is 93. Below 93˚F, it's fairly easy to stay cool on a motorcycle as long as you are moving fast enough to get some wind against your skin for convective cooling. A mesh riding suit feels great.

Above 93˚F, it's a different world. The wind is no longer your friend.

For long distance riding in temperature higher than 93˚F, you need to (1) minimize your body's exposure to direct wind blast; (2) wear wicking undergarments, including a helmet liner; (3) carry an adequate supply of cool water and drink frequently; and (4) insulate any parts of your body exposed to engine heat or radiator discharge.

Dress right, drink right, and enjoy the ride.