Heat: An Agent of Change

Heat Shields as Insulators

STUDENT TEXT

Imagine putting a radio into a cooler and launching it at 170,700 km/hr (106,000 mph) through a fiery caldron at 14000 °C (twice as hot as the surface of the Sun). Would you expect the radio to still work, or even still look like a radio? This is essentially the challenge engineers face when they design a spacecraft for entry into an atmosphere. The above conditions were present when the Galileo space probe entered Jupiter's atmosphere in December of 1995. This particular entry was the most difficult one to deal with to date. The huge mass of Jupiter caused the probe to accelerate to a very high entry velocity. This caused the probe to experience a buildup of heat, 30 times that experienced by the Apollo missions upon reentry into Earth's atmosphere.

(Figure 1)[i]

This is an artist's rendition of the entry of the Galileo probe. First the probe is released by the satellite. Then it burns through the upper atmosphere until it slows down enough to deploy a small chute that pulls out the larger chute. Finally, the probe is separated form the heat shield and descends through the Jovian atmosphere collecting data.

The challenges faced by the Genesis spacecraft engineers are similar to the ones faced by the Galileo engineers. They expect the leading edge of the returning spacecraft to reach a temperature of approximately 2000° C during reentry. Genesis engineers must design a heat shield that is lightweight, heat resistant, insulated and durable. The most common material for a heat shield is material called **carbon phenolic**.

Carbon phenolic is a substance made of layers of carbon fabric held together by a special plastic glue. It is a lot like taking ash from a charcoal grill and gluing it together in sheets. How hot do you think you would have to make charcoal grill ash before it melted into ash (carbon) liquid? Then, how much hotter would you have to make this liquid for it to vaporize into a gas? As you can see, this material is very resistant to high temperatures. The glue makes it strong enough to withstand the rigors of spaceflight.

Another interesting trait of this type of heat shield is its tendency to ablate. To **ablate** is to the fall apart at a constant rate. You may wonder why the engineers would want the heat shield to fall apart. Actually, they don't want it to fall apart completely. Rather, they want it to fall apart partially and gradually as the probe enters an atmosphere. This slow decay of the heat shield gets rid of really hot layers of the shied and exposes fresh layers that are more able to build up heat until they too fall away. Often this type of heat shield can lose more this half its thickness by ablation. For example, the Galileo probe went from 152 kilograms to 70 kilograms after entry into the Jovian atmosphere.

Heat shields are also used to slow down a spacecraft. When a spacecraft travels through space, it goes as fast as it can. But when it reaches its destination it must slow down for entry into the atmosphere. To accomplish this the spacecraft skips along the upper layers of an atmosphere on its heat shield. This is like jumping out of the back of a speeding truck on a plastic snow sled. Assuming you could hold on and not crash, you would eventually slow down. What would the temperature of the sled bottom be like? Would the sled have lost any mass?

Why is a heat shield needed?

The primary reason a spacecraft heats up so much while entering an atmosphere is friction between the craft and the air. Think of sticking your hand out of a car window on the highway. You would notice air friction. Would your hand get warmer or colder? If you thought it would get colder, you're right! This is because the air whipping by your hand evaporates moisture from the surface of your skin and conducts heat off the skin's surface. The air friction is not large enough to cause any significant heat buildup.

Now think of your hand sticking out of the window of a jet—not just any jet, but a military jet traveling faster than the speed of sound. Assuming your hand stayed attached to your arm, what would you feel? Your hand would quickly build up an intense amount of heat, so much so that it would burn. The front of the jet is made of materials that can stand up to this extreme friction, but your hand isn't. A spacecraft can travel more than 100 times faster than a military jet. This causes a huge buildup of heat from friction when the spacecraft encounters an atmosphere.

Friction is the change of mechanical energy into heat energy. It is caused by molecules rubbing together. The faster the rubbing, the more heat produced. In the case of the Genesis spacecraft, the solid molecules of the heat shield rub against the gaseous molecules in the air.

[i] *Image of Galileo Jupiter Probe, NASA,* www.jpl.nasa.gov/galileo/images/galprobe.gif