***Photo 1:** This never should have happened. The Superdome's roof membrane is missing after Hurricane Katrina in 2005.*

How Not to Build Roofs

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Hundreds of bullet holes were found when the roof of the Superdome was replaced after Hurricane Katrina. Over the years, the large, white Superdome roof that dominated the New Orleans skyline apparently proved to be an irresistible target for folks with weapons.

Now, I am a simple kind of guy. I bet that a roof with hundreds of bullet holes probably leaked. I wonder what those holes did to the Superdome's roof?

I remind everyone that the roof of the Superdome experienced one of the more spectacular failures in enclosure history. It was ripped off during Katrina in less than catastrophic wind conditions (*Photo 1*). Let's toy with this memorable failure a little. Hypothetically, because there is litigation ongoing.*

It is quite something when a roof blows off. To have one blow off during a national disaster with the world watching, puts it into a class by itself. However, the roof blowing off the Superdome is not an isolated incident. We seem to be experiencing more uplift problems with roofs lately. Why?

We seem to have forgotten how to build roofs. Back in the day, compact roofs required multiple layers. One of the most important was the air barrier (*Figure 1*). Air barriers were originally an artifact of cold climate construction and often misnamed as vapor barriers. In Canada, where there are only two seasons, this winter and last winter, architects and engineers learned about the importance of air barriers in controlling roof assembly moisture-induced deterioration from interior sources. However, early on, one of the most important lessons of using air barriers was the huge improvement in uplift performance. The air barrier helped to transfer the wind load to the structural deck. And, this proved to be important in all climates besides those dominated by hockey players.

When mechanically attached membranes became common—a bad idea in my humble opinion, the lack of an air barrier lead to fluttering of membranes (*Figure 2*), some interesting failures (*Photo 2*) and some interesting solutions (*Photo 3*).

Fluttering, besides stressing the membrane, leads to the pumping transfer of airborne moisture from the interior into the roof assembly. This has typically been a cold climate phenomenon but the problems are migrating south as membranes become white,

*There is always litigation. I am not involved, and I don't know any of the parties. I have not talked to anyone involved. However, I am bemused and curious, which allows me to explore avenues closed to well-mannered folk in polite society. I can speculate, a dirty word for physicists, but an honorable one for engineers. All of the information presented comes from the Internet or my own observations and experience. No one leaked information. The only thing that leaked was the roof.

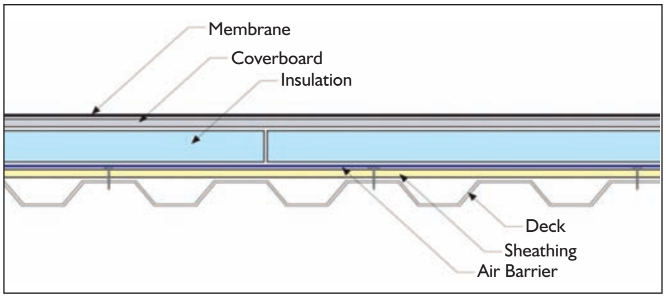


***Figure 1:** Multiple layer compact roof. Mechanically attached sheathing supports fully adhered air barrier. Fully adhered insulation boards have the best performance when split into two layers with joints staggered to further limit three dimensional airflow paths. Fully adhered coverboard protects insulation and facilitates lateral migration of water vapor and other off-gassing products to control blisters. It is becoming increasingly common to mechanically attach the insulation layers and membrane while also omitting the coverboard, which is an unfortunate development. Some insurance policies require mechanically attached layers because they don't trust the workmanship necessary for full adhesion of layers. Old-timers roll their eyes at this. Crotchety old-timers do both. They fully adhere the layers to get the performance and add the mechanical attachment to shut the insurance folks up.*

rather than black. Dark membranes become hot, and the heat drives the moisture back down into the building. In the south, mechanically attached dark membranes roofs typically dodged the moisture bullet because the moisture that was pumped up was driven back down by the huge temperature gradient. However, that all began to change with energy conservation and light-colored membranes. Many roofs no longer get hot enough to drive flutter-driven moisture back down into the building. Failures that were limited to cold climates now happen in Georgia.

Air barriers make fluttering go away and make the world safe for mechanically attached light colored membranes. The fluttering is controlled since any attempt by the membrane to lift off the insulation layer is resisted by suction. Air from the interior is not able to enter the roof assembly due to the presence of the air barrier. The lack of an air barrier and a leaky deck will allow replacement air to enter the roof assembly from the interior and the suction resistance is lost.

Uplift resistance is increased with the presence of an air barrier by the transfer of a significant amount of the load from the membrane to the air barrier and deck. A little algebra illustrates the principle. The total wind pressure is taken by all of the roof elements acting together. The total wind pressure resisted by the roof assembly is equal to the sum of the individual pressures taken by each element. In general, the tighter the element, the greater the pressure taken by the element. A simple series pressure relationship is a pretty reasonable approximation of what actually occurs.

$$P_t = P_m + P_i + P_d$$

where

P_t = total wind pressure
P_m = membrane pressure
P_i = insulation pressure
P_d = deck pressure

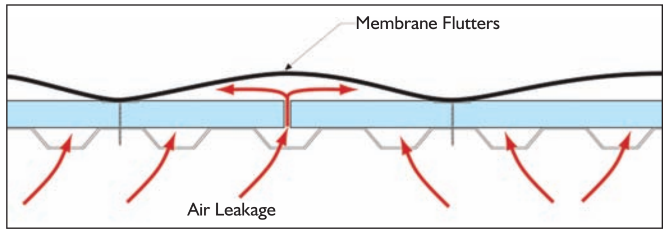


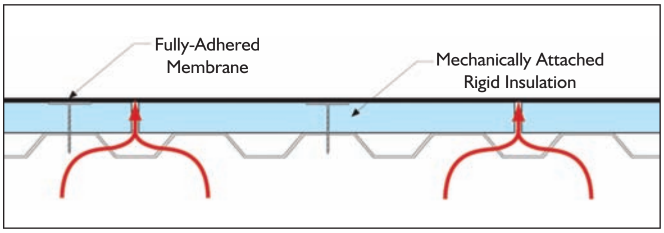
***Figure 2:** Fluttering membrane. Mechanically attached membrane flutters due to air leakage from interior when air barrier is omitted.*

***Photo 2:** Fluttering membrane. No air barrier at deck leads to an idea for a Disney World ride.*

***Photo 3:** Fluttering membrane fix. "I'll fix that darn moving membrane. Get me some pavers and blocks."*

Here is a trick question: what is the tightest element of a roof? That would be the element without any holes, which is the membrane since it can't have holes. Otherwise, it leaks. So, if I have a tight membrane, rigid insulation installed in boards/sheets with gaps over a fluted steel deck with seams and holes, the majority of the wind load is taken by the membrane. That was the case in the Superdome roof (*Figure 3*). How do we know that? Well, the membrane is gone, and the insulation was left behind (*Photo 4*).

With an air barrier, a significant portion of the wind pressure is transferred to the air barrier and its attachment to the deck. The tighter the air barrier, the greater the load transfer. The greater the load transfer to the air barrier, the less stress



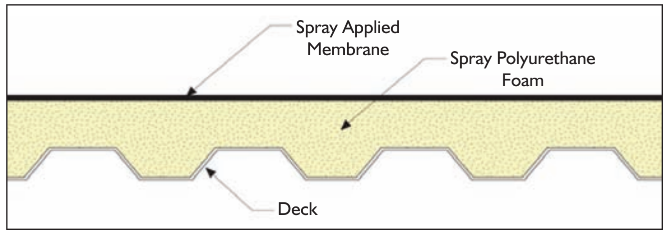


Figure 3 (left): Failed Superdome roof section. Mechanically attached rigid insulation boards on fluted metal deck with fully adhered membrane. Note absence of an air barrier. Membrane takes full wind load. Figure 4 (right): New Superdome roof section. Fully adhered spray-applied membrane over fully adhered spray polyurethane foam insulation layer and integral air barrier.

Photo 4: Superdome roof damage. Missing membrane and exposed rigid sheet insulation. Note the mechanical connectors. The membrane was adhered to the top of the sheet insulation boards and to the mechanical connectors. Also, note the metal deck and the flutes that allowed lateral airflow and lateral water migration.

Photo 5: Spray foam application. New fully adhered roof insulation and integral air barrier.

on the membrane. *Figure 1* rocks, *Figure 3* sucks (literally, wind suction).

The Superdome roof did not have an air barrier. At least the replacement roof installed in 2002 didn't have one, which is the roof that failed during Katrina. It was reported that the smoke dampers at the top of the roof were sucked off during Katrina and that allowed the wind to enter, exacerbating building pressurization and stressing the roof assembly. The membrane took the majority of the load, unzipped and traveled to a neighboring parish.

Could it be that the lack of an air barrier caused the Superdome roof to fail in wind conditions that were pretty minor as far as hurricanes go? I'm asking hypothetically. And, how was the Superdome replacement roof that was installed in 2002 allowed to be constructed without an air barrier when the original roof that was installed in the 1980s had one? Where were the adults?

Let's return to the bullet holes. It may be surprising to folks that people shoot at domed stadium roofs in many areas, regardless of team affiliations. So, specifically, what about the bullet holes at the Superdome? Well, the steel decking was so corroded it had to be replaced after the Katrina blow-off. The steel decking was fine in 2002 during the re-roof. It wasn't fine in 2005. The water came from somewhere. Could it be that hundreds of bullet holes could be a factor? I'm asking hypothetically.

The good news is that the post-Katrina repair is bulletproof† and has an air barrier. The new roof is similar to the original roof. It is a spray polyurethane insulation system applied directly to the roof deck (*Figure 4* and *Photo 5*). A spray applied fully adhered membrane is installed over the top of the insulation (*Photo 6*). The spray polyurethane insulation also acts as the air barrier.

So, how are bullets handled in the new roof? The bullet goes right through the roof system providing a straight-through-the-assembly water path. The spray foam does not allow the lateral migration of water that occurred in the 2002 roof (*Figure 5*). So, the roof isn't really bulletproof, but bullets don't cause anything besides a minor annoyance. The bullet holes are easy to fix—the hole and the leak are coincident—and corrosion is limited and controlled.

Photo 6: Better than before. Welcome back Saints.

†I would have given anything to have been a fly on the wall when the engineer or architect of record was told that not only did the post-Katrina Superdome replacement roof need to resist uplift but that it also had to deal with bullets. I do not know who the engineers or architects were on the repair and replacement project, but I salute them. They succeeded on both fronts. Well done. Very well done indeed.

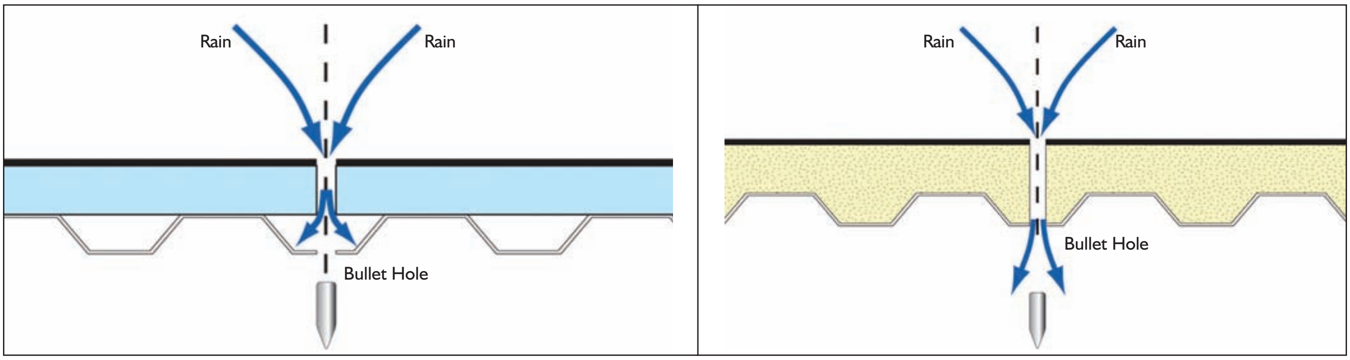


Figure 5: Bulletproof. Bullet holes in the left-hand roof section allow for lateral migration of rainwater due to the gaps in the roof system layers and the channels provided by the fluted steel deck. In the right-hand roof section bullet holes result in a straight-through-the assembly flow path for water, thereby limiting damage to the hole only.

Would there have been any difference in the Superdome roof blow-off if there were no bullet holes and no corrosion of the underlying deck? Probably not. The only thing that might have changed on the repair side would have been the deck replacement. However, the argument has been made that the deck needed upgrading regardless to handle even greater wind loads.

Can we learn any lessons from all of this? Lots of roofs today are being constructed without air barriers or have been constructed without air barriers. I predict many uplifting moments in our future unless air barriers become common (to say nothing of the problems of fluttering membranes and light colored roofs).

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