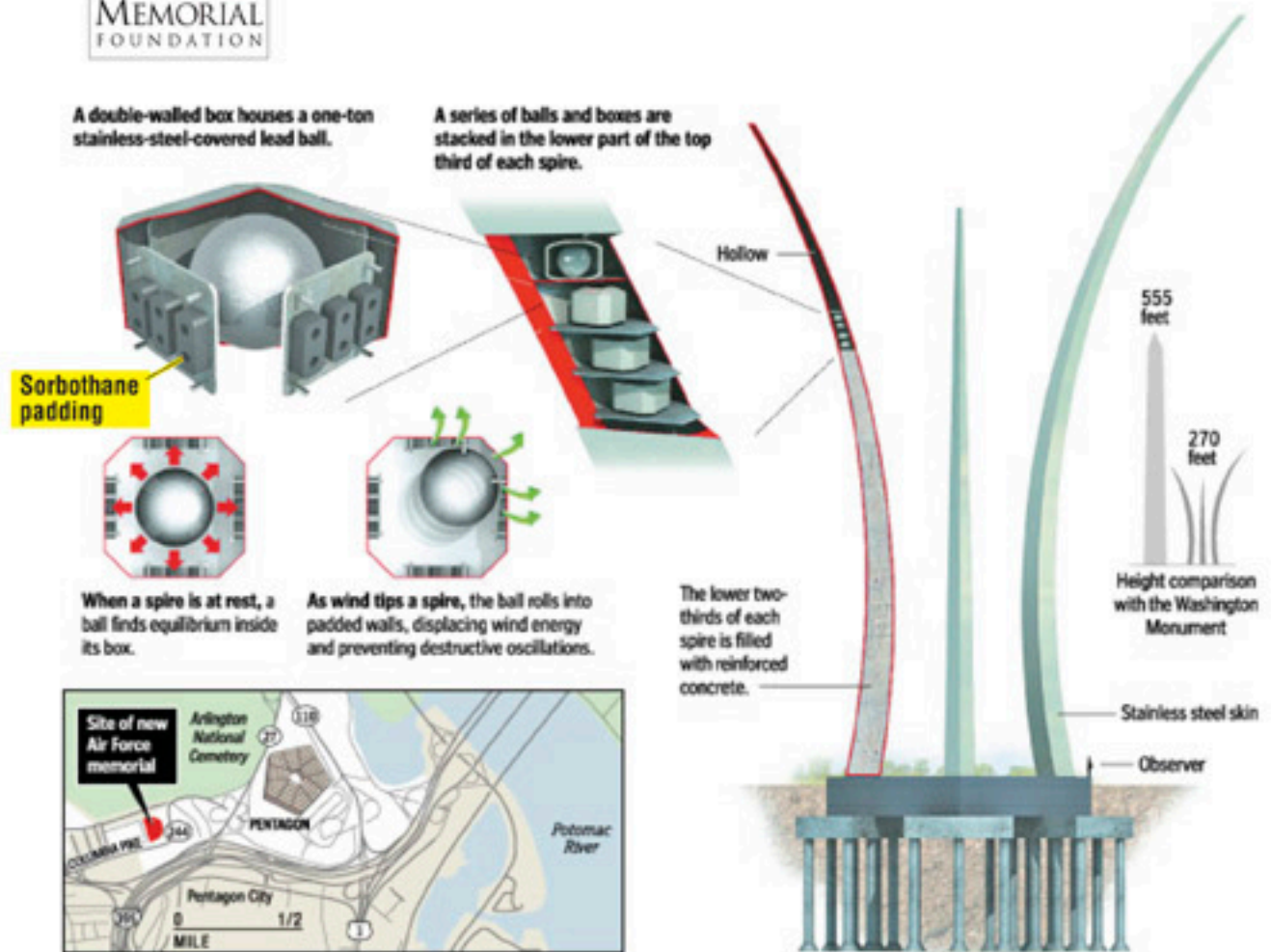


A Memorial's Moving Parts



Engineers have devised a series of colossal "ball-in-box dampers" designed to dissipate wind energy in the new Air Force memorial, which was dedicated October 14, 2006.



Air Force Memorial a Tribute to Flight and Engineering

By Rick Weiss Washington Post Staff Writer Monday, July 17, 2006; A08

When architect James Ingo Freed set to conceive a memorial for the Air Force, he faced a problem of weight and wisp: How to design a monumental structure that evokes that most structureless of mediums, the air itself?

Inspiration came while Freed was watching television. He happened upon footage of a team of Air Force jets performing the dramatic bomb-burst formation, in which several planes shoot skyward in unison and then peel off from each other, creating high-rising vapor trails that curl over at their tops.

Three years and more than \$30 million later, stainless-steel versions of those tapering trails are rising on a promontory just west of the Pentagon. When the project is completed in September, three towering tendrils — the tallest reaching almost 300 feet in the air — will arc with spectacular grace into the wild blue yonder.

That these 17,000-ton fingers of glistening metal seem impervious to gravity is a tribute to Freed, who also designed Washington's Holocaust Museum. (He died in December.) But it is equally a tribute to a battalion of engineers who worked with the architect and his colleagues at Pei Cobb Freed & Partners to overcome not only gravity but also the treacherous forces of wind and vibration.

Early in the design process, it turns out, wind-tunnel tests revealed that those forces could send the silver spires into a series of oscillations that could lead to catastrophic failure. The solution involved an exotic trick of physics.

Hidden high inside those elegant metallic spires are 13 steel boxes — a stack of six in the tallest spire, four in the next and three in the last, which, although it is the shortest, still rises 201 feet above the ground. The boxes are about 2 1/2 feet on each side, and each contains a single, free-rolling, metal ball that is 20 inches in diameter and weighs nearly a ton.

Those balls in boxes provide a unique energy-damping system that, although invisible to visitors, promises to keep the monument's swaying within tolerable limits well into the 22nd century. Even seasoned construction workers say they are in awe of the novel design. "Ain't nobody ever worked on anything like this before," one sweaty worker recently exclaimed to a visitor with an apparent mix of exasperation and pride at the bustling site.

The memorial honors those who served in the Air Force and its predecessor services dating back to the U.S. Army Air Corps of the early 1900s,

and it aims to inspire visitors by creating the illusion of escape from Earth's bonds.

That required keeping the trio of arching, hollow, triangular spires as narrow as possible. The largest starts as a triangle just 13 feet wide on each side at its base and tapers to two feet per side at its cantilevered tip, 270 feet in the air.

Adding to the sense of weightlessness, and in defiance of architectural convention, the spires are not weight-bearing skeletons clad in metallic skin. Each is just skin — albeit three-quarter-inch-thick stainless-steel skin — almost two-thirds filled with reinforced concrete.

Although the three stainless contrails bend radically outward, like bananas curving away from one another, each is in perfect equilibrium — when there is no wind.

But wind happens. So while the spires are anchored firmly to a buried concrete pedestal, their upper portions are sure to sway. Getting that elasticity just right was a big part of Freed's challenge.

That challenge was in part aesthetic. Although some motion was inevitable, "we didn't want it to look like tall reeds in the wind," said Michael D. Flynn of Pei Cobb.

But of equal concern was the monument's structural integrity. Wind can transfer large amounts of energy to a structure, explained Peter A. Irwin, president of Rowan Williams Davies and Irwin Inc. of Guelph, Ontario, the consulting firm that put a one-fortieth-scale model of the memorial through its paces in a six-foot-tall wind tunnel.

"Lightweight steel structures have very little ability to dissipate that energy," Irwin said. Over time, that can make a structure oscillate.

"It's rather like pushing a child on a swing," Irwin said. "Oscillation will just grow."

Grow, that is, until the structure finally gallops beyond its elastic capacity and crashes to the ground — or into the waters of Puget Sound, as famously happened to an undulating, imperfectly engineered Tacoma Narrows Bridge in Washington state on a windy day in November 1940.

This is where the art and science of "damping" comes in — the process of intentionally dissipating the energy in a structure.

High-rise buildings often have specialized damping mechanisms, said Leo Argiris, a principal in the New York office of the design engineering firm Arup and project director for the Air Force memorial.

Some buildings use the sway of huge pendulums to scatter accumulated energy. But a pendulum

cannot hang in a banana-shaped structure.

Other structures sport roughened outer surfaces, indentations or clipped corners that, in effect, "confuse the wind," Argiris said. But that approach would have seriously compromised the appearance of the spires, which have been specially blasted with glass beads to get a velvety metallic finish reminiscent of aircraft skin.

Balls in boxes offered a solution. The approach is rarely considered in larger structures — enormous spheres would be needed to stabilize an entire building — but for the spires, they were perfect.

Each steel box is double-walled, and the two-inch space between those walls is filled with Sorbothane, an elastic energy-absorbing polymer commonly found in the insoles of shoes. The balls are lead, with an outer coating of stainless steel. When wind sets the mid- and upper reaches of the spires swaying, the balls roll about, banging into the walls of their padded cells.

Computer simulations predict that those random impacts will redistribute enough of the energy imparted by the wind to prevent worrisome oscillations from building up — ultimately dissipating that energy as imperceptible wavelets of heat.

One box assembly was road-tested on a large "shaker table" designed to simulate earthquakes. That is when it became clear that metal balls in metal boxes do not give up all their energy as heat. Some of it merges as clanging.

No one knows whether the rattling of those 13 balls in their cages will be perceptible to the public in a stiff breeze. Given all the muffling concrete and the noise of traffic on nearby Interstate 395, it seems unlikely, said retired Maj. Gen. Ed Grillo, president of the Air Force Memorial Foundation, which has ushered the project through more than a decade of planning.

But for those who are aware of the stealthy stabilizers, the fact that they are in there, out of public view yet preserving and protecting, may seem apt.

"This memorial will mean many things to many people," Grillo said. "I certainly hope it will serve as an inspiration to future generations to serve their country."

If not in the Air Force, then perhaps as architects and engineers.

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