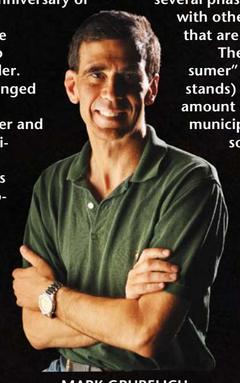
The art & science of Fireworks

Fireworks fascination: Sandian explains the science behind Fourth of July displays

Story by Julie Hall

It's one of the most American of traditions: trekking to a stadium or park — or sometimes to a well-positioned hill or your own backyard — to watch the annual display of fireworks in celebration of Independence Day, usually after a day of barbeques and maybe a holiday parade.

In fact, fireworks have been associated with the Fourth of July holiday since the first anniversary of the adoption of the Declaration of Independence in 1777. Fireworks were invented by the Chinese, who are also believed to have invented black powder.



MARK GRUBELICH

Photo by Randy Montoya

"The technology really hasn't changed much in a thousand years," says Mark Grubelich (700), a mechanical engineer and pyrotechnics expert who became fascinated with rockets and fireworks as a young boy growing up in New Jersey's Hudson River Valley. The basic components of a fireworks shell — "stars," a bursting charge, a fuse, and a container — have remained fairly constant over the centuries, although the ability to manipulate and control them to produce new colors, shapes, and even sounds has advanced, he says.

The basic ingredients

In commercial fireworks, the container is a shell casing made of plastic, paper, or an easily ruptured material. Inside are stars (pyrotechnic pellets) and a bursting charge. The stars, consisting of a fuel and an oxidizer, are doped with various chemicals to produce the desired colors and effects when ignited. Hundreds of stars may go into a single fireworks shell. The stars are produced by using a seed particle on which pyrotechnic material is applied. The seed particle typically consists of an actual seed (harkening back to the days of the Chinese inventors). The pyrotechnic materials are applied inside a rotating drum, much like layers are built up on a candy jawbreaker.

Shells are typically launched from a tube known as a mortar. A major fireworks display might involve hundreds of mortars. Once ignited, either manually by lighting a fuse or electrically with an electric match or squib, the lift charge in the tube propels the shell out of the tube. Time-delay fuses enable the shell to reach appropriate altitudes prior to ignition. The burst charge ignites the stars and ruptures the shell casing, scattering the stars into carefully designed directions and patterns. The patterns (geometric shapes and figures are a fairly recent development) created in the sky depend on the precise arrangement of stars inside the shell.

More complicated "multibreak" shells burst in several phases. They may consist of a shell filled with other shells or may have multiple sections that are designed to ignite sequentially.

The principal difference between "consumer" fireworks (the ones sold at fireworks stands) and commercial versions is the size and amount of energetic material, Mark says. Many municipalities have banned the sale and use of some consumer fireworks within their boundaries. In addition, the US Department of Transportation and the Bureau of Alcohol, Tobacco and Firearms have regulations governing transportation and storage of commercial fireworks.

Creating colors, sounds

Creating and controlling the colors in fireworks is a complex endeavor — part art, part science. At the most basic level, the colors of fireworks come from one of two mechanisms: incandescence or luminescence.

Incandescence is light generated from heat (think sparkler or your standard incandescent light bulb). Heat applied to a substance causes it to glow — first red, orange, yellow, and finally white at high temperatures. Luminescence is produced when energy is absorbed by an electron, causing it to become excited and unstable. When the electron drops back to a lower energy state it emits a photon (unit of light).

Manufacturers use these phenomena, coupled with the addition of certain chemicals, to control the colors of fireworks. "You see a lot of reds because they're real easy to do with strontium compounds," Mark says. Yellow is created with sodium compounds, blues with copper compounds, and greens with barium compounds.

"Occasionally you'll see pastels. Those are very difficult to do because you have to pick very specific chemicals and be careful about the formulation," he says.

If impurities enter into the manufacturing process, desired colors can be overpowered by other colors, or by smoke.

"The goal is very intense and pure colors," Mark says.

The sounds that accompany fireworks are also the result of chemical reactions that rapidly produce large quantities of gas. The sounds, which range from gut-felt booms to whistles (produced by oscillating, unstable combustion phenomena), are produced and controlled by using various fuel and oxidizer blends.

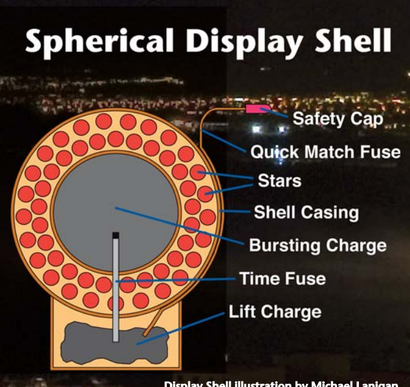
But let's get something straight: The loud "thumps" you hear (and often feel) technically are not the result of detonations. Fireworks don't detonate — they deflagrate, or burn at very high rates. High explosives, which detonate, are banned from fireworks.

The grand finales frequently employ spherical or cylindrical shells filled with flash powder, a mixture of potassium perchlorate and aluminum powder. The composition rapidly deflagrates in a confined space, producing an explosion and intense flash of light. This is the same mechanism behind the Mk141 diversionary device (aka flash-bang grenade) developed at Sandia by Paul Cooper and Ed Graeber (ret.). Several years ago, Mark developed another type of diversionary device that uses an explosive source that fans out as an airborne combustible powder before it ignites, making it less dangerous to the user.

Future fireworks

Despite the strong resemblance of today's fireworks to their ancient cousins, the increasing infiltration of technology is inevitable. In particular, computer hardware and software are increasingly playing a role in the development of the pyrotechnics and in designing and controlling displays. Multimedia simulation software allows pyrotechnicians to preview and adjust their displays on their computer screens without lighting a single match. Other software allows them to synchronize the firing of thousands of fireworks from a single control panel.

Perhaps on one Fourth of July in the future, a Red Storm-like computer will be used to develop and coordinate a fireworks display unlike any other humankind has ever seen. And the response from the audience? The same "oohs" and "aahs" you hear today.



Display Shell Illustration by Michael Lanigan

BACKGROUND PHOTO — Aerial shell explodes above ships from many nations involved in the Rim of the Pacific 2006 exercise during the 4th of July celebration held at Pearl Harbor, Hawaii.
(Photo courtesy of Dept. of Defense)