Daniel and Glenn Birket

In the theme park industry, "boring" means safety and profit.

Building "Boring" Rides and Shows

Theme-park engineering can be viewed from many perspectives. Ask a friend about their favorite theme-park ride, and you'll likely hear an animated recollection of how high, how fast, and how scared they were—and how many times they rode it again. Read a theme park's brochure, and you'll see adjectives like "exciting," "thrilling," and even "death defying." Ask a high school physics student to name the branch of engineering he would like to work in and you'll often hear "designing roller coasters." However, if you ask an entertainment industry engineer about his work, you'll learn that their *real* goal is to design attractions that look exciting but are actually boring.

This kind of "boring" is good because it is safe, reliable, and profitable. Years of operation without an injury are boring for the paramedic staff. Weeks on end without a challenging equipment breakdown are boring for the maintenance staff. And while the endless flow of smiling, paying guests day after day may be boring for the operations staff, it's a successful attraction when the only people who get excited are the guests and the stockholders.

The reality behind the eye-catching facades is that the people designing, maintaining, and operating theme-park attractions are very conservative. They're cautious because these attractions attract a lot more than smiling guests. A theme park is a lightning rod for a wide variety of unwanted attention ranging from disappointed guests demanding a rain check, to lawyers fishing for a lucrative out-of-court settle-

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ment, to media and politicians hoping for publicity. Knowing that on a slow news day a stranded roller coaster will soon have helicopters buzzing overhead has made the entire industry, in the words of one park executive, "risk adverse."

This industry-wide defensive posture governs the creation of a new ride or show. While artists still give their imaginations nearly free rein with an attraction's appearance, engineers and managers focus on eliminating threats to safety, reliability, and efficiency. Designs tend to be limited to proven technologies, trusted equipment, and timeworn techniques. While the design requirements are frequently bizarre and problems may be unusual compared to other industries, the engineering applications that satisfy the designs are as simple and mundane as possible.

An example of simple solutions to strange requirements is at a popular stunt show in a major Japanese theme park. The show features a battle on, under, and around an artificial lagoon in the center of the stage. At one point the script calls for a stricken, smoking seaplane to crash through a wall of the set, splash down into the stage's lagoon, explode in flames, and shower the audience with water—in complete safety—eight shows a day, for ten years—without costing a lot.

No problem.

The team of engineers assembled to bring this artistic vision to life started with a significant advantage: they had literally done it all before. Not only was the show the second of its name (the first one having opened years earlier in Southern California), but many of the vendors and engineers who created the original award-winning attraction were back for an encore. The project planners knew that hindsight of what worked and what didn't would be a powerful tool to mitigate risk.

Among the design tenets of safety, reliability, and efficiency, safety is supreme in this environment by a wide margin. For this stunt, safety includes not dropping the free-falling seaplane onto a stuntman, crashing it into the set, or throwing it into the audience. The safety solutions employed are simple and typical of the entertainment industry. An engineer working in another industry might think they are unusually cautious until he considered the entertainment environment. In some industries, safety focuses on stopping the machine when someone gets too close; but in the entertainment industry (among others), the machines must be safe while people are *in* them or interacting closely with them.

Safety is ultimately the responsibility of people, not machines, and the architecture of an attraction's safety system embraces that premise. Experienced crewmembers vigilantly watch the set from multiple vantage points to ensure that cast, crew, and audience are all well clear of each stunt's hazards. Surveillance cameras reveal any hidden areas and the vantage points shift as the action moves around the set. The set design provides open sight lines to critical areas. Not only does the audience have a clear view of the action, but also the spotting crew has a clear view of the entire audience.

As you would expect, every vantage point and every control panel is equipped with an emergency-stop (E-Stop) push-button. What isn't obvious is that they all do exactly the same thing. The backstage area of a stunt show with a hundred effects managed by two dozen control subsystems is a maze of electrical conduits, hydraulic and pneumatic lines, and control boxes. To eliminate the problem of finding the "right" E-Stop button in an emergency, every subsystem in the venue is required to participate in an attraction-wide E-Stop architecture. An entertainment industry interface specification detailing the interconnection of E-Stop buttons in cabinets from different vendors and a fail-safe hierarchical E-Stop power bus

Technical Standards for the Themed Entertainment Industry

In addition to the familiar technology-specific IEC, UL, IEEE, ISA, and NFPA standards, control systems engineers working in the themed entertainment industry have available dozens of industry-specific standards. The three below are particularly focused on safety.

ASTM F-2291-03: Standard Practice for Design of Amusement Rides and Devices

This extensively revised standard was released in June 2003. It is the result of a five-year effort by the 400-plus members of the ASTM F-24 committee. It is a far-reaching, global revision of the original standard that provides guidelines to ride manufacturers on the design of rides.

The two NFPA standards below address distinctly different types of effects, although the distinction is often lost on the audience. Pyrotechnics are chemical mixtures, often ignited by an electric match, that contain their own oxidizer. Flame effects result from the controlled release of propane or natural gas onto a proven pilot flame in a unique application of boiler or burner control technology.

NFPA 1126: Standard for the Use of Pyrotechnics Before a Proximate Audience, 2001 Edition

This standard applies to the use of pyrotechnics in conjunction with theatrical, musical, or similar productions before a proximate audience, performers, or support personnel.

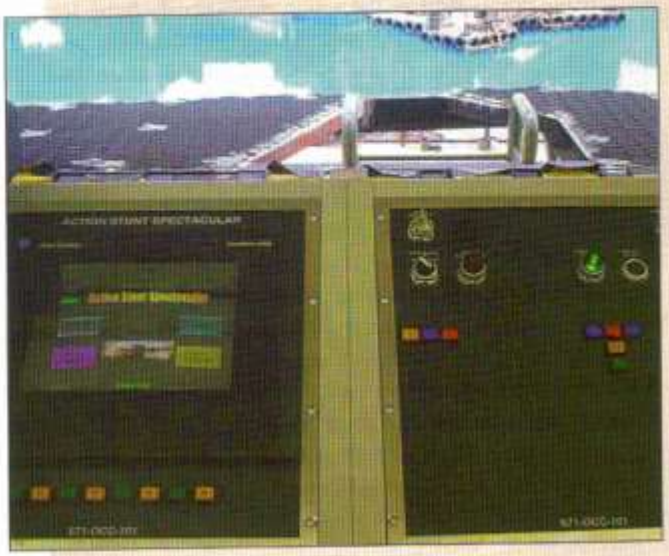
NFPA 160: Standard for the Use of Flame Effects Before an Audience, 1998 Edition

This standard provides guidelines on the use of indoor and outdoor fire special effects in the areas of design, installation, testing, operation, maintenance, and approval.

—Glenn Birket

The seaplane launchers' console outside the secure area backstage. Like the main console, it subscribes to a standard labeling, appearance, and placement of operator controls. Status and diagnostics from this subsystem are forwarded to the attraction's main control system.

The "Pig" makes its first flight on the newly constructed set in Japan. Notice the tip of the launcher track visible through the cutaway section of wall. The hole will later be filled with breakaway foam sections. The permanent, themed crane arm on the left is used to reset the seaplane between shows.



The main show console behind the audience overlooking the pool/stage. The primary effect-enable buttons for pyrotechnics, mechanical, and flame effects are duplicated beneath the technical director's left and right hands. The T-shaped arrangement of buttons controls the progress of the technical script that synchronizes the sound, lighting, effects, and other elements of the show. The touch-screen on the left displays current status as the show plays and is used between shows for manual operation and reset of equipment.

structure ensures that when a crewmember hits the closest big red button, everything will stop, regardless of who built it.

Each spotter location also has one or more effect-enable buttons that must be held down continuously to allow effects to begin or continue. Additional buttons, photo eyes, or other sensors protect stuntmen involved in apparent narrow escapes. Anyone releasing a button or missing a sensor will cancel an effect before it begins or stop the action already in progress. If an actor fails to reach the safety of his "mark" within the scripted time, the seaplane won't fly, the explosions will abruptly stop, and the gas-fed flames will snuff out. Like the E-Stop system, the independent effect-enable matrix system operates in parallel with the attraction's control computers. The control system continually supervises the enable matrix and E-Stop logic in detail. A failure will cause the controller to shut down the affected area or the entire attraction as dictated by the safety analysis.

Behind the set, the seaplane's launcher is surrounded by a high fence and monitored by security sensors integral to the show's safety control system. After the stage crew reloads the launcher with its seaplane between shows, the stage manager checks the enclosure for stragglers, closes and locks the gate, and arms the security system. Any attempt to reenter the area, even for maintenance, will trip the alarm and abort a launch. The control system helps to enforce that maintenance and operation remain safely separate activities.

The fake seaplane was designed to be aerodynamically inert so that it follows its programmed trajectory reliably and exactly. Despite its appearance, this "seaplane" has more in common with a falling rock than a real aircraft. To prevent a sudden gust of wind from disturbing its "flight," five strategically located anemometers continually monitor wind strength and direction. Too strong or too erratic a wind will veto a launch. The same wind sensor system disables aerial pyrotechnics and snuffs flames, each according to their own safety parameters. The wind history along with a technical show log and detailed diagnostics are continuously recorded in a permanent log.

Long before the first launch of the seaplane on set in Japan, the launcher system underwent months of testing in

The crane crew resets the "Flying Pig" test vehicle during factory testing on San Francisco Bay. The six 55-gallon drums are weighted with concrete to match the final themed vehicle.

The "Flying Pig" test vehicle splashes down in the pool/stage.

The onboard RF pyrotechnic system hidden within the prop seaplane. The onboard pyrotechnic system is linked to the attraction's overall control system by an early implementation of the wireless Ethernet systems popular today.

Marcial Godoy of Birket Engineering, Inc. adjusts the RF pyrotechnic system inside the themed prop seaplane while it rests on its launcher backstage. Among the challenges of creating control systems for entertainment is hiding or disguising them in unusual places while preserving easy access.

San Francisco Bay to prove its safety and demonstrate its reliability over hundreds of launch cycles. Every component's failure modes and diagnostic messages were provoked and demonstrated to be fail-safe before the first show in front of an audience. During most of these exercises, the launcher was loaded with an ungainly and decidedly unaerodynamic construction of I-beams and concrete-filled 55-gallon drums christened the "Flying Pig."

As in any safety critical design, a failure analysis determines to what extent we can rely on any component of the system. In this case, the design does not rely on the computer to control the launcher during the critical moments of launch. To ensure that the seaplane is neither thrown too long nor too short (where it might fail to clear the wall), the launcher design resembles a large spring-powered crossbow. Once triggered, it is sure to complete a full-speed launch with a premeasured supply of energy.

A fixed-capacity hydraulic accumulator stores exactly the energy needed to accelerate the fixed-weight vehicle along its calculated trajectory. Because the launch is powered by the carefully controlled potential energy of a compressed nitrogen tank, a power failure or computer glitch in midlaunch can't cause a short launch. The control system monitors the process for any of several hundred anticipated and instrumented failures and then, providing everything is in the green, simply triggers the redundant launch valves to release the hydraulic "spring." As with the wind data, the launch control system writes detailed graphs of important process parameters and extensive diagnostic messages to a remote computer.

The launcher's framework is another proven technology in an unusual application. The launch carriage resembles the base of a roller-coaster car and rides on an aborted segment of steel-tube roller-coaster track. A hydraulic piston and pulley system like those used on some modern roller-coaster launch systems accelerates the carriage up its short track. The deceleration of the carriage at the top disengages the vehicle, which continues through the breakaway wall.

The seaplane never actually hits the breakaway wall, despite its appearance of crashing through and leaving burning rubble in its wake. A pair of large air cannons actually

Ride and Show Automation Equipment

Theme-park ride and show control systems are typically integrated from readily available devices designed for more general applications. A few products are unique to entertainment applications. Some commonly used components are the following.

Safety Controllers

The common industrial "PLC" controller is used to ensure the safety of rides and stunt shows because of its low risk. It is reliable, predictable, well documented, well supported, and readily available. Twenty-year-old "Ladder Logic" is the usual software language. Most U.S. theme parks have standardized on the Rockwell Automation (a.k.a. Allen-Bradley) line of controllers and related products (http://www.ab.com). Other suppliers of PLCs include: Siemens Simatic (http://www.siemens.com/automation/simatic-controller), Omron (http://oeiweb.omron.com/Products-PLC.shtm), and Mitsubishi (http://www.mitsubishi-plc.com/).

Show and Animation Controllers

Ride and show elements without strong safety considerations typically use show controllers for timing and synchronization. These devices speak a wide variety of multimedia and theatrical protocols including: USITT DMX512 (lighting), MIDI (multimedia), and SMPTE timecode. Suppliers of these controllers include: Alcorn-McBride (http://www.alcorn.com), Anitech Systems (http://www.anitech-systems.com), and Gilderfluke (http://www.gilderfluke.com). Theatrical lighting controllers are also often pressed into service as show controllers.

Pyrotechnic Controllers

The safe control of pyrotechnic devices requires a specialized pyro controller. These devices trigger their colorful explosive charges by energizing an electric match in each device exactly on cue. Suppliers include: Pyrodigital (http://www.infinityvisions.com/pd_FC.htm), Pyropak (http://www.pyropak.com/), and Birket Engineering, Inc. (http://www.birket.com).

You can read more about the technology behind entertainment control systems in *Control Systems for Live Entertainment*, second edition, 2000, by John Huntington (http://www.zircondesigns.com/), available from Focal Press (http://www.focalpress.com).

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knocks the painted foam wall down a few hundred milliseconds before the seaplane passes through the opening. A combination of pyrotechnics and a gas burner flame-effect system provides the scripted conflagration. The safety control system enforces that all the necessary elements play out as scripted or not at all. For example, a launch failure will prevent the flame system from toasting the still-intact flame-resistant foam wall.

The seaplane arcs though the air, trailing smoke from one damaged propeller. The other propeller is "still" spinning, actually driven simply by airflow. Showers of sparks erupt from the fuselage as it impacts the water. Its momentum carries the burning hulk downstage to its submerged landing platform close to the audience—where it unexpectedly produces a final, loud, and very wet explosion.

The smoke, sparks, and flames are all generated by pyrotechnic charges snapped into permanent holders on the fuselage sides and wing tops. The holders are shaped to direct their explosions in a safe direction. An onboard pyrotechnic system enabled by the attraction's safety control system via a wireless link triggers the charges. Any interruption of the link back to the spotter's enable-buttons will disable the onboard pyro system. The final wet explosion is produced by both onboard and shore-mounted pyrotechnics together with two shore-mounted air-powered water cannons. The "lagoon water" allowed to reach the audience is actually filtered drinking water.

All of these safety systems, distributed E-Stop interface, effect-enable matrix, wind monitoring, extensive fault detection, system self-checks, and more, are all biased to disable the effects if anything unusual happens. It is not enough that the system not notice anything wrong—it must confirm that everything is right before it will enable the effects. As difficult as it can be to meet all the strict safety requirements, the cast and crew consider it a victory when a show works perfectly. But the occasional missed effect also assures them that the safety features work. They know that they can blow up and burn down their workplace eight times a day and remain safe at their "boring" attraction.

Glenn Birket founded Birket Engineering, Inc., designer of ride and show systems for the world's most advanced theme parks and theaters, after leaving Disney's "WED" engineering division in 1984.

Daniel Birket escaped from his aerospace job in 1989 and joined the entertainment engineers at Birket Engineering. His experience in writing software for the military has helped to design safe control systems for some of the most explosive shows in the world.

Brothers Glenn and Daniel are both alumni of the University of Central Florida and members of the IEEE and the NFPA Technical Committee on Special Effects.