how it works

GO BEHIND THE SCENES AND SEE HOW ENGINEERS ARE RISING TO THE CHALLENGE OF ROLLER-COASTER SAFETY.

Safe at any speed

By Karen Auguston Field

"THE ENGINEERS ARE HERE—it's going to be a wait," Emmett Peter, Director of Ride & Show Project Development at the Walt Disney World Resort tells me, pointing to a group of men in a huddle near the track as the message is broadcast. While waiting in line to ride Disney/MGM's newest roller coaster, the Rock 'n' Roller, I learned from Emmett that it starts out with a 1.3G catapult-style launch, followed by an immediate double loop, a series of banked turns, and a barrel roll. Gulp. With the ride seemingly down for the count, I'm trying hard not to act visibly relieved. But Disney's new Chief of Safety, Greg Hale, and the amusement-park industry are working to ensure that amusement-park rides are safe. What's interesting is that the engineers who design these rides face a basic dichotomy: Their whole goal is to make you feel like your life is in danger yet have a design that is absolutely safe.

After my ride, Peter took me behind the scenes to learn more about the earlier technical difficulty. Engineer Bill Whitley explained that the problem involved a 1-sec disagreement between two positioning sensors that make sure the 10-ton train properly engages with a linear synchronous motor-powered pusher cart. He was able to determine this issue by analyzing real-time data from the ride's PLCs, linear logic devices, and sensors.

Safety has always been a hallmark of Disney. In fact, Hale, a 14-year veteran of the company, previously was responsible for operational safety. What's different about his new role is that he will oversee and facilitate the exchange of safety-related information and make sure that consistent standards are implemented across Disney parks worldwide. By sharing information, Disney hopes to institutionalize best safety practices at all properties.

What Hale does is sure to influence the rest of the industry, through his involvement with the American Society for Testing and Materials (ASTM). For the past decade and a half, he has been a member of the ASTM Committee F24, an independent standards-writing body that is responsible for developing amusement-ride safety standards. Essentially a consensus process, it involves balancing different and often opposing interests among theme-park operators, ride manufacturers, regulatory agencies, consumer advocates, and other interested parties.

Nothing polarizes people more than safety. Which means that Hale has his work cut out for him in a challenging job.

NEW STANDARDS RAISE BAR

Early this year, the ASTM F24 World Standards Task Force expects to issue a new standard, known as the Standard Practice for the Design of Amusement Rides and Devices, or Z9591Z. The result of discussion and debate among technical experts from around the world, the 80-pg document contains extremely detailed data on the design and manufacture of amusement-park rides.

"In my opinion, we've really kicked things up a few notches in areas such as patron restraint," says Mike Withers, chairman of the task force and vice president of ShowRide Engineering for Walt Disney Imagineering. "The standard now provides parameters that will help a ride designer determine the appropriate type of restraint based on the specific G-force loading."

The new standard is also addressing for the first time the controversial issue of G-force limits. There has been much debate in the research community on whether some high-G-force roller coasters produce sufficient "head rotational acceleration" to cause brain injuries (see **sidebar**, "Rotational acceleration"). (The most recent development has been the release of a National Institute of Health-sponsored study by the University of Pennsylvania that determined that the peak accelerations produced by some

high-thrill coasters—including the Rock 'n' Roller Coaster—were below the threshold required to produce brain injuries.) (See **sidebar**, "Going down!—carefully.") The standard will include upper limits (that vary by exposure time) for three axes (xyz) of G force. This standard will be more comprehensive than the Euro Norm CEN standards for amusement-park-ride design, which themselves have been in development for more than 12 years.

Mandated by law, the Euro standard served as an important reference for the F24 task force. "Our goal in developing this standard was to incorporate the best input from around the world. After studying the Euro standard, we realized it represented a good framework that we could use to create elements of our standard in areas like the G-force limits," says Withers, who also represents the United States at CEN meetings in Europe as an unofficial member.

Famous for being secretive, especially about an issue as sensitive as safety, Disney has assumed an unlikely leadership role in the development of standards. The company opened its books to the ASTM organization, sharing the techniques and processes it uses to ensure that rides are designed to the highest standards. And several high-ranking engineers from Disney, including Greg Hale and Mike Withers, have spent hundreds of hours sharing their technical expertise with the task force. And that openness is likely to continue: For example, Disney engineers plan to take to the industry what they learn about different safety-restraint systems they are currently testing.

Who would seem to benefit the most from Disney's sharing of information are the smaller companies and mom-and-pop-type parks that do not have the large engineering teams and expertise that bigger organizations bring to the table. Hale, however, stresses that everyone benefits. "What I think is important here is that we all came together in a noncompetitive arena at ASTM and were able to share our best practices about things that we learned internally and to help ensure that those practices

ROTATIONAL ACCELERATION

By Larry Zirkle

There's been much debate about the possible hazards of high-G-force amusement-park rides and the issue of head rotational acceleration.

We commonly think in terms of G forces applied to the whole body. Body components that are free to have relative motion, such as blood, resist the change in speed. The resulting relative motion of body components causes stretching of tissue, pooling of the blood in the lower body, downward pressure on spinal fluid and the spinal column, and numerous other effects. We experience these motions every day but normally not at levels that cause physiological trauma.

Sufficiently large accelerations (forces) can cause the tearing of tissue and blood vessels, reduced cardiac output, the fracture of vertebrae, or other physiological effects. The body is more tolerant of linear accelerations in certain directions than in others, which is why astronauts lie prone with respect to the principle direction of the engine thrust.

In addition to whole-body linear-acceleration effects, a physical entity called "jerk" is important in determining whether injury occurs to a body in motion. Jerk is the time rate of change of acceleration, or the third derivative of position with respect to time. For a given change in acceleration (force), a large value for jerk means that the change occurs rapidly.

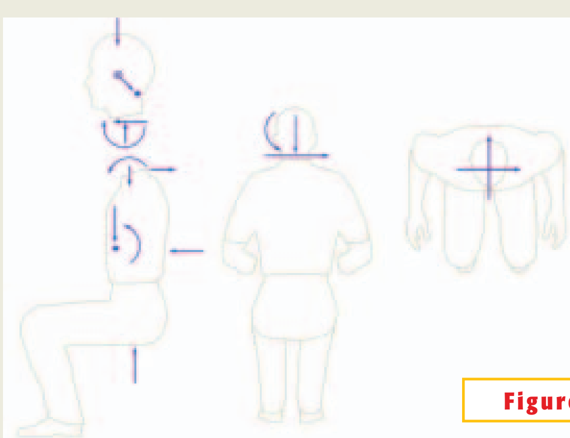

Figure A

You need to investigate the acceleration modes of the trunk for complete analysis.

The unrestrained head is a component that normally moves relative to the trunk when the whole body experiences acceleration. In **Figure A**, acceleration of the trunk results in forces (as well as moments) being transferred to the head by the top of the neck. Because the center of mass (CM) of the head is normally out of alignment with the forces, moments are created about the CM, resulting in angular acceleration (rotation) of the head in addition to linear acceleration of the CM. The magnitude and direction of the angular acceleration depends on the relative magnitudes of the applied forces and the radial distance from the base of the head to the CM. Like linear acceleration, angular acceleration can also cause relative motion between the components of the head, causing brain damage, tearing of vascular and other tissues, and other types of trauma if the acceleration is large enough. Anticipation of the motion by tensing up can affect the resulting acceleration of the head.

Analysis of the motion response of the head to linear whole-body acceleration is fairly complex for the most general situation. If considered to be a rigid body, the head is a six-degree-of-freedom system with three components of linear motion and three components of angular motion with constraints. However, by considering the various modes of acceleration one at a time, you can simplify the problem and perform an analysis using traditional methods from mechanics.

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would be consistent across the industry."

"I think that the standards are more effective than anything else out there in their ability to influence good design," says forensic engineer Walter Laird. A specialist in amusement-park-ride-accident investigation, Laird says that the ASTM standards are becoming better known and more widely accepted.

Not everyone, though, agrees that this community-based effort is enough. Representative Edward Markey of Massachusetts says that rides need more regulation; he has introduced a bill that would give the Consumer Products Safety Commission jurisdiction to conduct follow-up accident investigations at fixed-site amusement parks. It already does so at mobile (traveling) amusement parks.

Although the ASTM standards are voluntary and do not carry the same weight as a law, they routinely influence the regulatory environment. The standards for amusement-park-ride design are being adopted by an ever-increasing number of states, such as New Jersey, which in 2002 adopted G-force limits based on ASTM guidelines.

MANY FACETS OF SAFETY

On the question of whether the new design standards will help to reduce or even eliminate amusement-park-ride accidents, Hale says, "I think engineering standards are effective in helping to avoid design failures, but it's important to recognize that standards work hand-in-hand with good operation and maintenance practices, as well as guest education."

Ride operation and maintenance are top priorities at Disney. Cast members, for example, can operate rides only after undergoing attraction-specific training and have command of the ride's mechanics and operating procedures. To keep things running smoothly and avoid unplanned shutdowns, Disney routinely takes ride vehicles out of service for scheduled maintenance. Each night when the parks close, the maintenance team also inspects each attraction and will not authorize it for operation the next day if any maintenance issues need attention.

Guest safety is also a priority at Disney—and no wonder. According to a recent study by the Florida Department of Agriculture and Consumer Services, patron error accounted for approximately 76% of all amusement-park-ride accidents in Florida over the past three years. In the summer of 2002, Disney rolled out a major campaign to build public awareness about safety. More than 10,000 new signs with safety instructions have been installed throughout the parks, and gates or fencing that cordons off visitors from active ride areas have been standardized.

In the end, the question is whether the industry's community-based effort to develop safety systems will be successful. How to measure success may be relatively odd, though, given that the only way to know the industry is doing a good job is when nothing happens.□

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GOING DOWN!—CAREFULLY

Since the Tower of Terror at MGM opened in 1994, visitors have been experiencing their biggest nightmare: Captive in an elevator cab with a complicated motion profile (**Figure A**), they experience a series of lifts and drops, culminating in a seemingly out-of-control 123-ft plummet to the ground at 2680 ft per minute—12X faster than a typical elevator. "Although we want our guests to perceive the motion as unplanned and catastrophic, it is of course controlled, monitored, and safe," says engineer Emmett Peter.

Take the 123-ft "fall." The elevator cab is actually suspended from a drive drum by two cables. Beneath the cab, two more cables travel downward to a tensioning sheave in the pit, then upward to a counterweight that rides along the side of the shaft. From the counterweight, two additional cables travel up to the drum on the opposite side. The result is a closed cable system that pulls the cab upward and downward in the desired motion profile, unimpeded by the limitations of gravity. The twin cables throughout provide a level of safety redundancy, Peter explains. "Were both cables somehow to fail, the elevator cab is also equipped with standard elevator safety brakes," he says.

As a safety precaution, two velocity tachometers on the motor shaft and a tape encoder attached to the elevator cab monitor speed and measure velocity every 2 msec. If the measured velocity deviates from the commanded velocity, or there is a discrepancy between measurements, a system stop initiates. In all, more than 100 processors control the ride's operation, communicating to a supervisory system over an Ethernet link.

As if the ride weren't thrilling enough already, engineers will be introducing new motion profiles this year; one of four profiles will be randomly selected for each ride cycle.

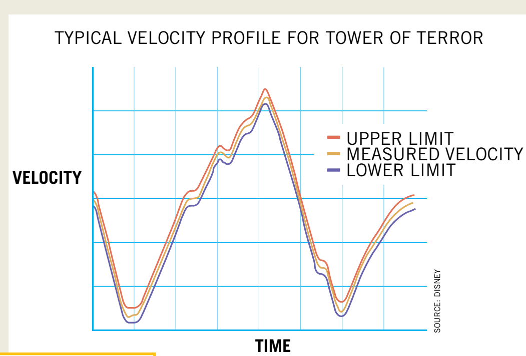

Figure A The velocity profile is a critical parameter; the system measures it against tight upper and lower limits.