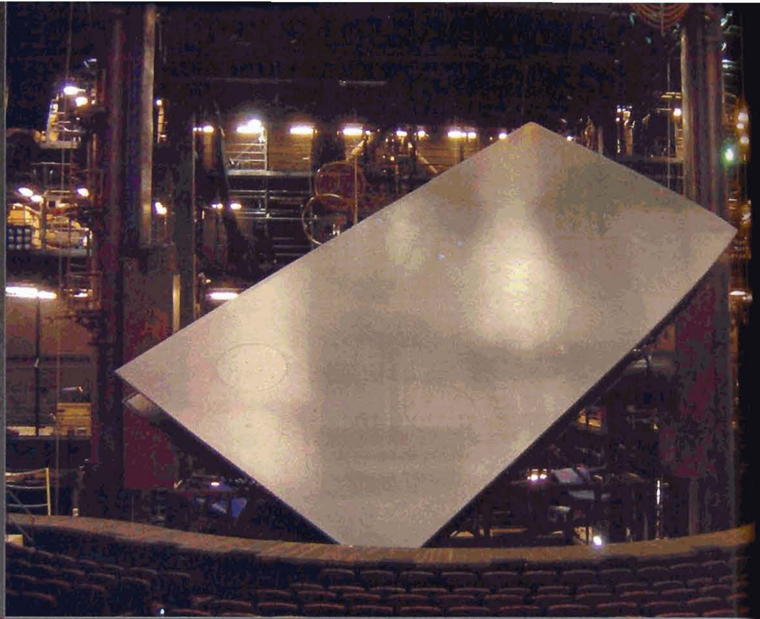
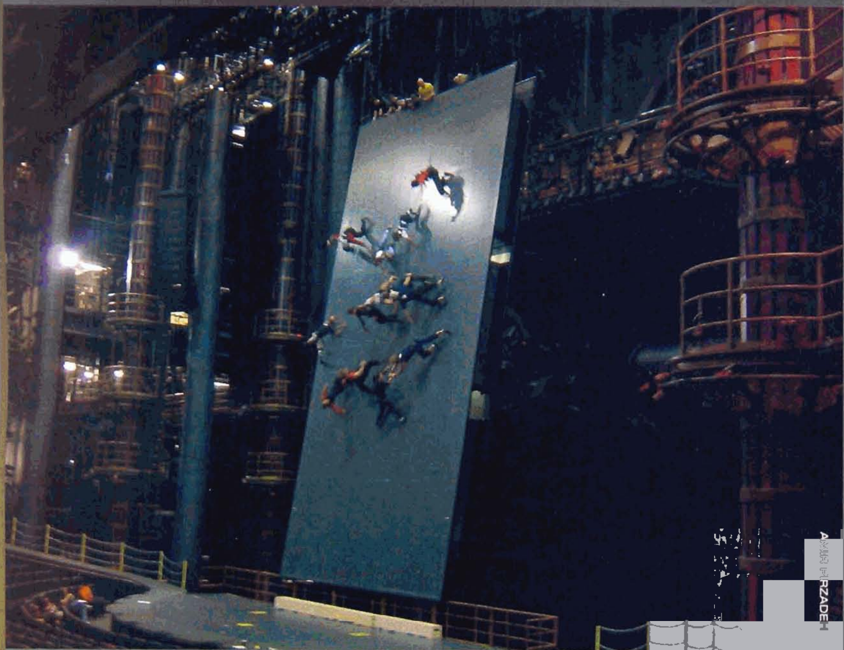




Above: performers rehearsing one of the vertical battle scenes under work light on the Sand Cliff deck. Above right: The Sand Cliff deck rotated to a different position.

# HOW DID

## A look at the scenic automatio

By John Huntington

After 20 years in the business, it's rare that I see a live show and say, "Wow—how did they do that?" But when I saw *KÀ*, I was so amazed that I felt compelled to write a behind-the-scenes detail piece, something I haven't done in many years.

Under the brilliant creative leadership of Robert Lepage and the Cirque team, the technology in *KÀ* is completely at the service of the art. While *KÀ* certainly could be called a spectacle, it certainly is not a case where the technology trumps the art, like one of those depressing high-concept special-effects action movies. In many ways, *KÀ* is an example of the kind of show I've been hoping would exist—and have been advocating for—for many years, because the performers are often in control of the technology, rather than the other way around, and the technology is integral to the performance, not a gimmick. In *KÀ*, the technology allows the show to connect with and reach the audience, extending the performance; it doesn't get in the way.

### Scenic Automation

There is no stage in *KÀ*. There is simply a huge pit, from which enormous performance spaces rise, descend, track, tilt, and swivel. The scenic elements were conceptualized by Mark Fisher; the Tatami Deck and the Gantry were designed by the entertainment team at the McLaren Engineering Group in West Nyack, New York, starting in late 2002; McLaren also engineered the

Sand Cliff deck, which was designed by Tomcat. (The other scenic pieces were done in-house at Cirque du Soleil, with the company also handling the integration of the pieces.) "Mark is a very clever man," says McLaren Engineering president Malcolm McLaren. "He thinks motion through, and he has a very good understanding of the mechanics that it takes to drive these things. So when he gives us his thoughts on

# THEY DO THAT?

## projection, and show control systems in *KÀ*

how something could be actuated, he respects the laws of physics."

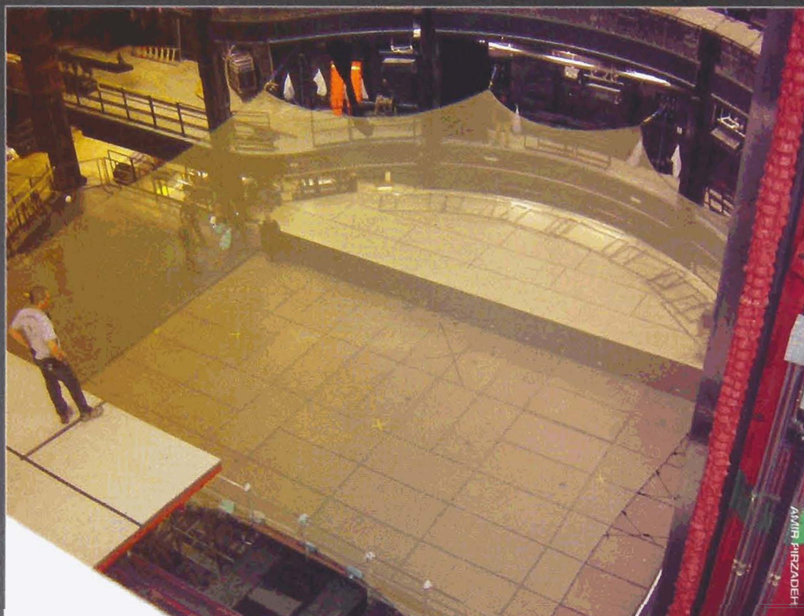
### The Gantry Lift

The enormous 50'x25' Sand Cliff Deck is actuated by the Gantry Lift, the largest and most incredible element of the scenic automation system—a mechanism you'd be more likely to see in an aluminum smelting plant than a theatre. The Gantry Lift mechanism can rotate the Sand Cliff Deck 360° at 2RPM (which is 12° per second) tilt it from flat up 100° (beyond vertical), and track the whole thing up and down vertically nearly 70' at 2' per second. Determining the maximum speeds of the Gantry Lift mechanism was a critical part of the design process, since a faster move meant more horsepower was needed. To make these horsepower calculations, McLaren made extensive use of sophisticated MSC Nastran design simulation software. However, Nastran "was designed for mechanics and assembly lines and so forth," explains McLaren's Murphy Gigliotti, "so we actually had to write a cue automation front end for Nastran in Excel."

The smallest amount of power needed to make the gantry lift work as desired was "just less than a locomotive," says McLaren. After calculating all the trade-offs and determining the maximum move velocities, the resulting *KÀ* hydraulic power plant was designed for 1,250 HP continuous from electric pumps, and, according to McLaren, about 6,000HP stored as hydraulic pressure in giant accumulators for peak usage during high-power cues. "The hydraulic power plant," explains James Tomlinson, the head of automation for *KÀ*, "will fully pressurize the accumulators (approximately 1,700 gallons) in about five minutes. The accumulator bank is reminiscent of the missile tube scene from [the 1990 film] *The Hunt for Red October*."

The Gantry Lift mechanism itself tracks on two enormous 4' diameter steel tubes that run from the lowest floor of the building to the roof, made, along with the rest of the "static" steel, by Fabriweld, of Salt Lake City, Utah, a company whose primary business is roller coasters and other enormous structures. McLaren Engineering was initially told that these tubes could be connected to the massive existing structure of the MGM's roof, but, partway through the design process, compliance with seismic regulations resulted in a new answer of no. Therefore, the team had to come up with an enormous bracing structure for the tubes, creating a sort of freestanding 75' tall "building within the building," according to Stephen Sywak of McLaren. Many details were considered; the enormous vertical tubes are even fitted with acoustical dampers to keep them from acting like "pipe organ tubes."

A massive 6' diameter cross tube, called the "torque tube, connects the two 'hammerheads,'" says Tomlinson, "which are guided by 75- and 150-ton capacity Hilman rollers traveling on steel wear plates on the columns." The rollers, made by the Hilman company of Marlboro, New Jersey, are generally used to move massive loads, like oil rigs components, entire buildings, and bridges. Perpendicularly attached to the center of the torque tube is an arm which goes out, towards the audience, to a pivot joint called the "wrist," which, according to Tomlinson, "includes a 10' diameter Rotek bearing typically used in tower cranes," and connects




A view into the pit at one of the safety nets.

to the Sand Cliff Deck itself. The moving parts of the Gantry Lift were made by Timberland Industries from Woodstock, Canada, a company whose primary business is offshore and timber harvesting equipment, giant winches and other huge mechanisms. The whole torque tube assembly and arm gets lifted, says McLaren, "by what we understand to be the longest cylinders ever produced in North America—a 70' stroke. When they are fully extended, the cylinders are 145' long." The cylinders are so massive that they must only ever be in tension—if put under a compressive load, they might buckle.The cylinders were made by Parker, of Cleveland, Ohio and supplied (with the rest of the hydraulic system) by Atlantic Industrial Technologies, of Islandia, New York, working in conjunction with GS-Hydro U.S. Inc., of League City, Texas. Even getting the cylinders to the site proved a challenge. "We had to get special trusses fabricated," says McLaren's integration project manager, Jay Reichgott, "just to support the 75' hydraulic cylinders during transit."

"No one wanted to be the one to flip the switch the first time. The system was so expensive and massive that there was no room for error."

**The Sand Cliff Deck**

The 80,000lb. Sand Cliff Deck was manufactured by Tomcat USA in Midland, Texas. Longue Vue Scenique of Montreal, according to Tomlinson, "supervised the artistic treatment of the playing surface by Tomcat staff." The deck is over 6' thick, and, according to William Gorlin, McLaren Engineering VP, consists of, "a steel primary truss structure that bolts to the slew ring. Mounted to that steel structure is an aluminum outer structure and deck system; it's configured so that you can have technicians inside to service all the pieces."

During one part of the show, adds Tomlinson, "an 8 x 16' 'refuge' platform flies in from the grid and attaches to one end of the vertical Sand Cliff Deck, then moves with the Sand Cliff Deck as it rotates, tilts, and descends to the basement. It has a trap door for access to and from the Sand Cliff catwalk system."

In addition to lifts and other features of the deck, there are 80 pegs, each roughly 2' long, manufactured by Microtrol of Montreal, that can shoot out at 8' per second. At that velocity, the pegs appear to the audience in a quarter second, which is surprisingly fast since they are run by electric linear actuators. These pegs were designed so that performers can slide, swing between, and catch them when the Sand Cliff Deck is vertical. Many performers slide more than 60' from this platform to their "deaths," where they land on an enormous, hydraulically tensioned safety net in the pit, out of sight of the audience. Some falls are so extreme that air bags are placed on top of safety nets to break the performer's fall.

In one stunning scene, the Sand Cliff Deck is covered with "sand;" then the deck is raised before our eyes and the sand pours off. Real sand was originally considered but abandoned, due to weight and dust issues. The team considered walnut shells and Santoprene, but eventually chose cork. The material is contained on the edges of the deck by 3" "flippers," run by 18 electrical actuators, which are retracted when the material is

**The Tatami Deck**

The 30 x 30', 75,000lb. Tatami deck is

an amazing feat of engineering and construction, but it's actually the "small" piece on the show. The deck was named, according to Tomlinson, "because the opening scene with Tatami mats was to play there," but that scene was later moved to the Sand Cliff Deck. The Tatami deck is supported by a giant, 65' long, two-stage "drawer slide" mechanism, which is tilted at a 4° rake towards the audience from its anchorage upstage, with 45'-6" of cantilever. The Tatami deck and mechanism is actuated by 75 and 150 HP electric motors, and was built by Show-Canada in Montreal, with scenic treatment again by Longue Vue Scenique.

**Scenic Automation Control**

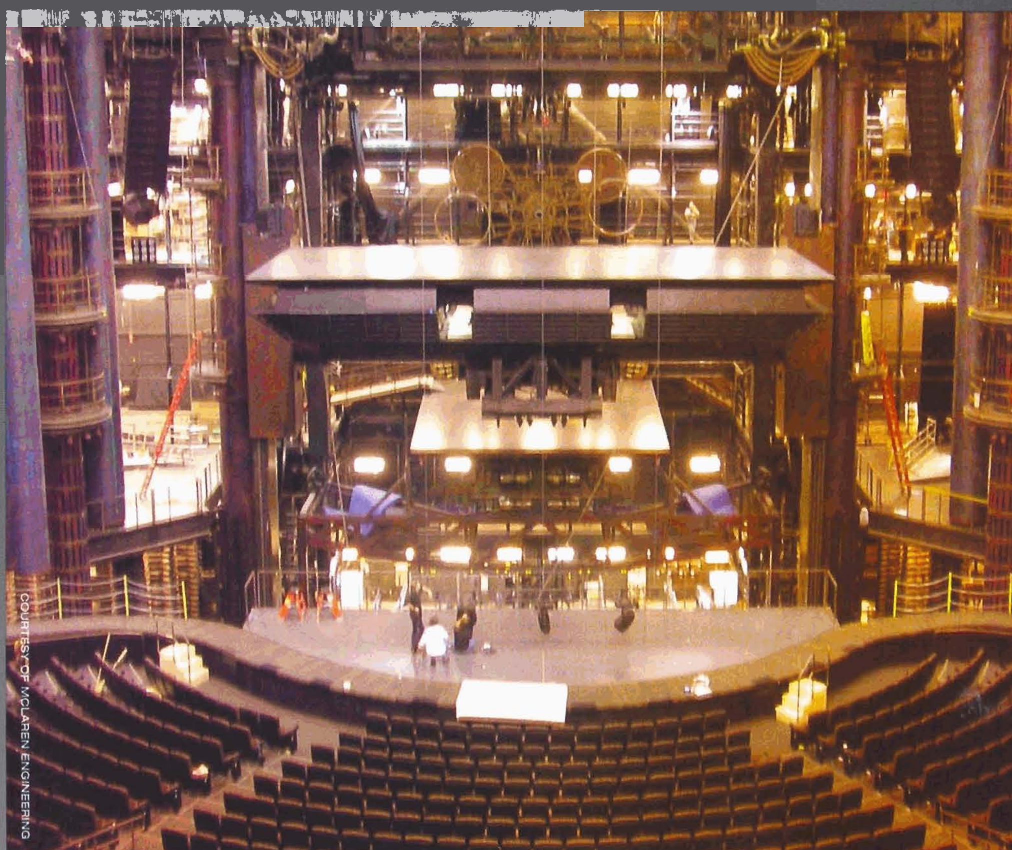
Controlling all this scenic automation equipment was the daunting challenge taken up by Stage Technologies, which has offices in London and Las Vegas. The company's Nomad system for *KÀ* controls over 40 arbor winches; 16 high-speed winches for the performers in the battle scenes, each axis with individual radio control; five lifts controlled by 26 motors; a giant bird flown over the audience, controlled via five 2,200lb winches with wings flapped by performers; the 80 pegs in the Sand Cliff deck; three small pod lifts [called "sand traps," according to Tomlinson]; 12 winches for the forest scene; 18 hydraulic safety net winches in the pit; and 16 actuators for the Sand Cliff deck's edges.

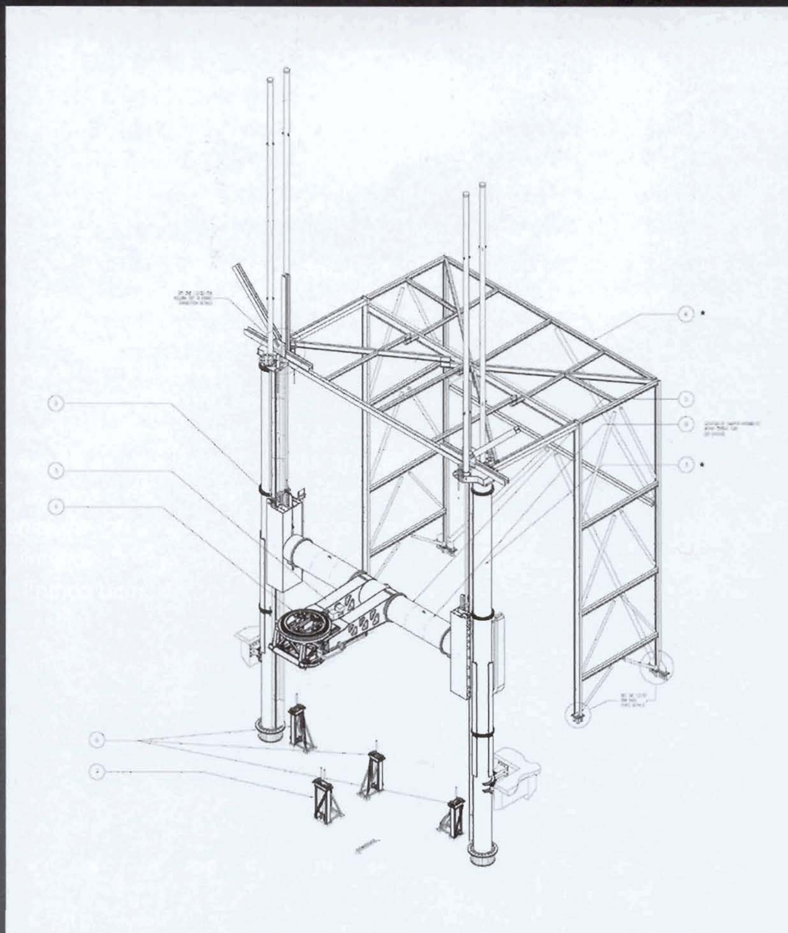
Control is highly distributed throughout the system. "We have 17 nodes in the theatre, each controlling up to 40 axes," explains Kevin Taylor, Stage Technologies' director of electrical engineering. "The desk sends commands to the nodes, and the nodes do the housekeeping, whilst the axes deal with actual position control. There are the Delta Tau [hydraulic control] nodes, 12 Siemens S7_400 PLCs, and the entire safety Estop [emergency stop] system is done using a Siemens safety PLC. In addition, we have two extra processors, one for the interlock system and the other to run the 3D flying of the bird. The consoles are connected over the primary command network, which is Ethernet, and the MaxisID internally positioning drives connect to the node PLCs over ProfiBus. A separate high-speed deterministic network is used for synchronization. The crew uses four desks during the show, with a fifth backup in the event of a failure, and, happily, we have had no desk failures to date. In addition, we provide a local backup network with a completely independent path for controlling axes via a hand held HMI in a crisis. In the worst case, during the climb scene using the pegs, we could be running 90 axes at once. The majority of the time, we are running 20-25 axes at once. In the event of a motor failure, we can continue to run the lifts right down until only two are left. The lifts are the show, so there is a huge amount of redundancy there."

**Hydraulic Control**

While the Stage Technologies system provides overall control of the scenery, the hydraulics control is handled by Tisfoon Ulterior Systems, of Raleigh, North Carolina, using a Delta Tau motion-control system as a basis. "We provided Tisfoon with a spec at the beginning of the project," explains Taylor, "to enable us to make it mimic standard axes [in the Nomad control

In this work light shot, the massive Sand Cliff deck is at about mid-height, with the Tatami deck retracted upstage.


COURTESY OF MCLAREN ENGINEERING



COURTESY OF MCLAREN ENGINEERING

McLaren's schematic view of the Gantry Crane mechanism and bracing structure.

system]. The operator can instruct the axes to move to a different dead [target position] at a different speed for every cue as he so wishes." The Tisfoon system takes it from there, and also provides a local controller so that the hydraulic systems can be run independently of the Nomad. To protect the cylinders, the Tisfoon system provides "a closed loop 'charge-up' of the rod side of the cylinder before releasing the brakes," explains the company's president and chief software engineer Amir Pirzadeh. "This insures that the valves are operational and that there is oil in the rod side before the brakes are released. The load balancing is a closed-loop system on top of the regular positioning loop. This system uses the load cell information from the four cylinders to lead or lag an upstage axis (relative to downstage) for proper load balancing." The Tisfoon system incorporates a "VCR" feature, where all data related to the hydraulic systems is logged every 100ms continuously for 24 hours; if a problem develops, precise information is later available for troubleshooting. "No one wanted to be the one to flip the switch the first time," says Pirzadeh, only partly in jest. "The system was so expensive and massive that there was no room for error. I was not only the developer, but became the de-facto operator, as well."

**Performer Winches**

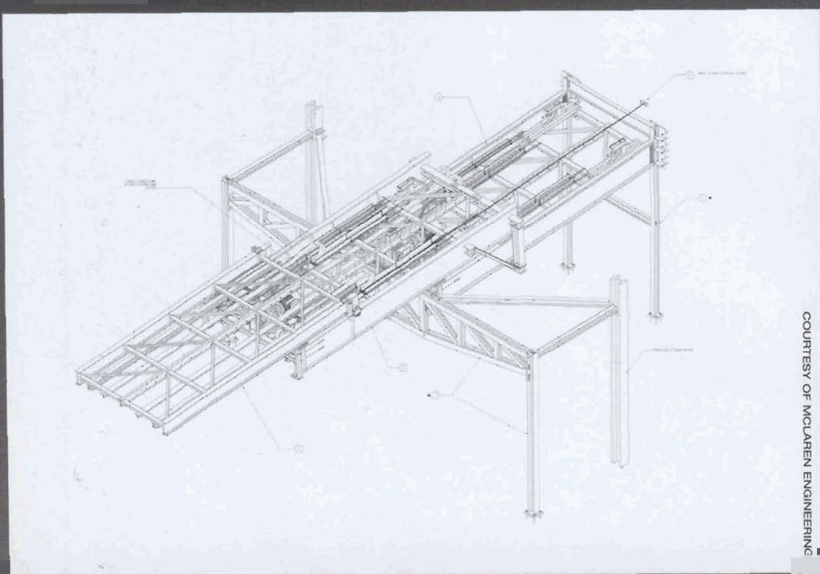
Some of the most incredible scenes in *KÀ* are the "vertical battles," where performers appear to defy gravity while battling on the Sand Cliff Deck in an almost vertical position. In fact, they are supported on high-speed winches supplied by Stage Technologies. Each of the 16 performers controls his own movement through a radio control, with the transmitter in his costume, using a handset controller. "The winches", explains Stage Technologies' Taylor, "are capable of running at up to 14' per second, and accelerating and decelerating in .75 seconds. The radio units are a standard component supplied from Germany, meet the very highest standards, and, in the event of [interference], shut down to prevent unauthorized movement."

Malcolm McLaren, summing up the team's experience on *KÀ*, says, "When the Ford Motor Company releases a new car, they design it, test it, crash it, run it around the track a few thousand times, tweak it, alter it, and value-engineer it. We have to build one prototype and it has to work, with time and budget constraints. It's not easy, and the tricks just keep getting bigger and bigger."

**Projections**

One of the most groundbreaking aspects of *KÀ* is Holger Förterer's interactive projection design. "I attempt to express poetry, emotion, and content in the language of mathematics and algorithms," he explains. "This is my artistic language, and the result on-stage is referred to 'augmented reality.' We do not use any real video footage in the imagery of the production—all images are generated on-the-fly by the projection computer in real time using physical or artificial simulation. Water, stone, clouds, air are all completely synthesized by the image computer—at the

McLaren: “When the Ford Motor Company releases a new car, they design it, test it, crash it, run it around the track a few thousand times, tweak it, alter it, and value-engineer it. We have to build one prototype and to work with time and budget constraints. It's not easy, and the tricks just keep getting bigger and bigger.”



COURTESY OF MCLAREN ENGINEERING

McLaren's schematic view of the enormous Tatami Deck "drawer slide" mechanism.

same instant they are shown—and react to the action on stage.” This is the hallmark of Förterer and his team's work on *KÀ*—the performers are actually controlling the imagery that surrounds them in a fully interactive and meaningful way. While, of course, there is a tight structure and some general predictability to the performers' motions for story and safety reasons, Förterer says, “We give the performers the freedom to improvise and follow the set wherever it moves.”

**Tracking the Performers**

The freedom to which Förterer refers is quite apparent when you see the show. In one example, a scene called “The Deep”—a giant ship full of performers is raised, and performers fall off and “drown,” descending almost the entire stage space, followed by a trail of bubbles. Förterer is tracking the performers, *creating the bubble images in real time and projecting them onto the scrim.* “Here, we are using camera tracking,” explains Förterer. “We are lighting the actors with invisible infrared LED light. The IR camera acquires their movement through a scrim onto which we project the bubbles. The use of infrared light is necessary to avoid feedback of the projected image into the camera and be able to light the scene brightly without the audience noticing anything. My tracker picks up movement in the scene and generates bubbles based on the size and motion of the objects causing it. This is one of the scenes where projection helps in telling the story.”

**Scenic Interactions**

In “The Climb”, “The Blizzard,” and—the most astonishing scene of the show—“The Battle,” Förterer not only tracks the performers themselves, but can sense how they are interacting with the scenery. For example, under the Taraflex performance surface of the Sand Cliff Deck, are sensing tiles manufactured by Les Ateliers Numériques of Montreal, which turn the entire deck into (to overly simplify for the purposes of explanation) a giant touchscreen. Förterer uses this information to create graphical waves and other images that radiate out from where the performers' feet contact the deck, or to create interactive falling “rocks” that they must dodge. “The system of sensors in the deck was specifically created for this show by the interface designer and inventor Philippe Jean from Montreal,” explains Förterer. “It works on a technology comparable to the musical instrument theremin, which allows musicians to control electronic instruments by moving their hands in

Förterer: "I attempt to express poetry, emotion, and content in the language of mathematics and algorithms. This is my artistic language, and the result on-stage is referred to 'augmented reality.'"

the air. The deck is literally able to 'sense' the proximity and presence of the artists to and on the surface. The maximum sensor depth is approximately 4". So it makes a difference if you are very close to the surface, tiptoeing, or sliding across it at a certain distance." JT Tomlinson, Cirque's head of automation, adds, "The sensing tiles system detects performer locations on a 6" grid pattern all across the deck and can simultaneously report every one of those coordinates, at 60Hz, via Ethernet."

With all that imagery created in real time, Förterer then projects it onto real, physical, three-dimensional, moving scenery, and the approach is so effective that many in the audience won't even realize they are looking at projections. To accomplish this, Förterer must track the movements of the scenery exactly. The projection system "listens to positions that multicast out through the Nomad system," explains Kevin Taylor, Stage Technologies director of electrical engineering. "The positions from this system are sent every 50msec, and because of the size of the pieces a lot of the data is sent in 1,000th or 10,000th of a degree resolution." To cope with the latency of the various systems, and potential encoder error, Förterer says, "We actually use an adaptive physical model that predicts the position of the stage into the future and smooths those values correctly to avoid both lag and jitter, so we're always on. I was surprised myself to see this work smoothly after punching in the maths for a month, but I think we mastered something you could never pre-cue or plan, since every show will not only be slightly different on the artistic, but also on the technical side."

**Projecting it All**

Three converged Barco Director R18 DLP projectors are used to give the required brightness and project from the back of the auditorium to create a canvas across a large part of the performance area. "Theoretically, we could project onto any moving surface within the show," explains Förterer. "We are using different convergence files [which call up different projector settings] to take care of the depth ranges. We are also using dousers in the drowning scene to avoid hard edges of video black resulting of the coupling, and to be able to kill all projection in an emergency." All projections on the main

Förterer's projections can be seen clearly in this photo, although to fully appreciate them you have to see them in motion.

moving stage use 3D modeling, "but we use a technique [similar to] the bubbles in the drowning scene to match the position of the actors one-by-one,"says Förterer. "A two-dimensional distort[ed] image would not have hit the main stage without causing warping on the close or far edge."

### Infrastructure

Förterer needed a lot of computer horsepower and I/O for this project, and also had to ensure that the system can be maintained and updated over the projected 10-year run of the show. "We are using dual-processor PCs," he explains, "to ensure fast calculations and display of all virtual simulation and imagery. We kept away from most proprietary packages. Windows-dependency was reduced to a minimum; we are using OpenGL, and we skipped using the Intel Performance Libraries, since I strived for minimum dependency on the platform or processors used. Not too many portions of the code would have to be rewritten if the [IT] market went berserk for whatever reason."

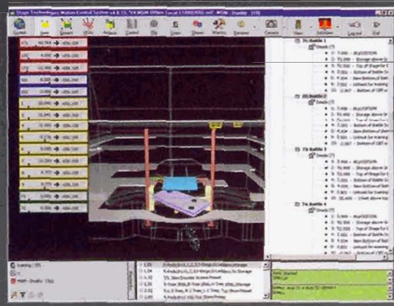
With projections so critical to the show, Förterer had to also ensure that there was sufficient redundancy in the system. "We have a backup PC for all vital systems," he explains. "Switching to backup systems is partly automated. On a crash of the main computer, the backup computer would automatically take over within a maximum of two seconds, causing the Barco projectors to smoothly fade into the new system's video output. This would be much faster than the operator could diagnose the problem and react by himself."

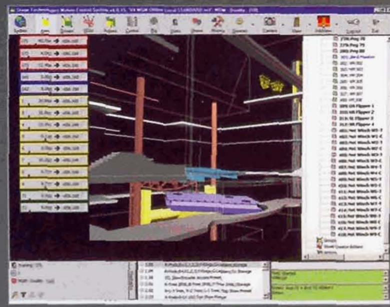
The front end for the system is actually a lighting desk, and, says Förterer, "we are not connected to the rest of lighting, to avoid both systems going down at the same time. Luc Lafortune prepared backup lighting if projections should fail—and if a certain part of lighting should, we are still ready to go."

### Show Control

As a show control guy who has seen and enjoyed almost every Cirque production since 1991, it has always bothered me that some of the cue timings across and between departments were not as tight as they could have been. This is not the case on *KÀ*, and this is partly because of the use of show control for certain aspects of the show. A widely misused and misunderstood term, *show control* simply means interconnecting more than one production element control system (scenery, projections, sound, etc.), and on *KÀ*, says Förterer, "our system is networked to quite a few systems in the theatre." The projection system receives positional data from the scenic automation systems as detailed above, and then also communicates via Ethernet to sound. "We get data from projections," explains sound designer Jonathan Deans, "and then convert it (via MAX MSP [software]) to MIDI to trigger our effects." In some scenes, this structure allows performers to not only generate imagery interactively, but trigger sound effects as well. Cirque has recently been implementing show control systems on its cruise ship projects. However, for the more traditional shows, *KÀ* is "the first attempt for two departments to link," according to Deans, who has worked on many Cirque productions for more than 10 years.

Rigid, time-based control is what most people think of when they think of show control, and this approach has become routine in many shows today. However, the distributed and interactive interconnection seen on *KÀ* and other recent projects is an even more interesting and powerful way forward, and is one that I hope we will see more of in the future from Cirque and others.





COURTESY OF STAGE TECHNOLOGIES

Two screen captures from the Stage Technologies Nomad scenic automation system showing some of the show's systems.

Everyone I know is tiring of me talking about this show, but I have to say that *KÀ* is now Mecca for anyone interested in the intersection of art and technology for live performance. You should make the pilgrimage yourself, and it's worth plopping down $150 for the ticket, as I did. *KÀ* sets a new standard in artistic use of technology, raising the bar so high I'm not sure who will have the imagination and resources to exceed it.

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