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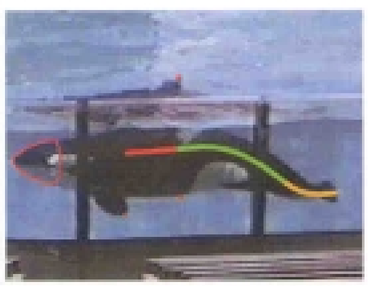
A whale of a tale

Animatronics blurs the line between reality and illusion.

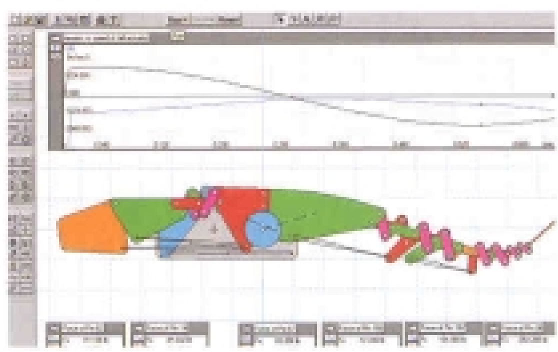
Lawrence Kren
Senior Editor

Is it live or is it animatronic?

The signature black and white figure slips by the underwater viewing window with a graceful, almost hypnotic rhythm. All eyes rivet on the 16-ft-long Orca as it surfaces for an explosive breath.



A digitally reworked video loop outlines the basic motion. This helped form the basis for both the ½-scale and full-size mechanisms.



The program Working Model from MSC Software, Santa Ana, Calif., simulates the animatronic whale's motion and joint forces.

Killer whale shows never fail to impress audiences, but the whale in this case isn't real or in the water. Rather, it is a convincing illusion made possible by Hollywood-style "smoke and mirrors" and some clever engineering from Mannetron Inc., Battle Creek, Mich. Mannetron's animatronic Orca is so lifelike that leading Japanese whale authorities signed off on its authenticity, a prerequisite for delivery to the Nogoya Port Public Aquarium in Japan.

Getting to the signoff, however, took nearly two years. The first step: compress the results of millions of years of whale evolution into images lasting mere seconds. For help, Mannetron tapped renowned whale expert Frank E. Fish of Westchester University in Pennsylvania.

Caught on video

Professor Fish's video footage of a killer whale swimming in a glass-windowed pool shows both the nature and extent of the motions. Mannetron engineer Peter Jungen selected ten separate sequences from the video. These were digitized at a 30-frame/sec rate with a 320 × 240 resolution. Each sequence was stored as a separate AVI file then processed with a program called AVI Constructor which turned each sequence into a bitmap file representing individual frames.

To better track whale motion, Jungen wrote a program in Visual Basic that crops out a segment of each frame and produces a new bitmap set. These were reassembled into a video in which the whale stands still and the water moves over it. A particular point in the frame sequence served as a start of a continuous loop. Several reference points and shapes added to each frame (with Adobe Photoshop) produced a clearer picture of the swimming motion. Finally, the frames were assembled into an AVI file.

The digitally reworked video reveals that a killer whale swims by moving its tail, fluke, neck, head, and body center. The whole body pivots about a point more or less at the center. "All five motions work together to produce a graceful, flowing, wavelike progression," explains Jungen. This agrees with Dr. Fish's formulas that model killer-whale swimming as a series of sine waves. In reality, swimming whales also move up and down slightly. But lack of this motion, it was determined, would not detract from the illusion so it was left out.

A worker checks the whale skeleton model. Images from the model and from computer-generated graphics of internal organs, project on an angled, partially silvered mirror in front of the whale. Audiences see a ghostly cutaway appear and disappear.

Jungen then extracted three of the Photoshop frames showing key positions of each motion. These provided overall measurements and formed the basis for a generalized mechanism: The tail section consists of six linked segments. The fluke moves independently with a three-segment mechanism. A three-segment neck lets the head move up and down, and a rigid center spine pivots though a hinge point.

A graphics program let Jungen superimpose a CAD model (DXF file) of the mechanism onto the three video reference frames. Fitting the mechanism to the frames provided a range of motion expressed as angles relative to the spine segments: tail 173 to 183°, fluke 170 to 190°, neck 175 to 182°, tail 185 to 195°, and an overall body motion of about 6° total range.

Start small

Rather than tackle the full-scale behemoth straight-away, Mannetron opted to first build a ½-scale model based on scanned illustrations of lateral and dorsal views. These scanned images were outlined with the CAD program Cadkey. The previously developed mechanism was then imported into this outline to scale the moving parts.

The next step selected actuators to move the mechanism. A linear actuator with a 2-in. stroke and a load rating of 50 lb at 3 ips moves the tail, head, neck and body. A 12-lb force, 3-ips linear actuator propels the fluke, and a conventional servomotor opens and closes the mouth. Further massaging in a modeling program

The whale skin emerges from the mold halves.

The quarter and full-scale Orcas under construction.

helped integrate the actuators and refine the 3D CAD model. The CAD model produced both engineering drawings and DXF files for NC machining of the various parts.

Sculpting a clay model paralleled the mechanical design work. The model became the mold form for the whale's outer skin. The scanned illustrations used to size the mechanism also served as a reference for the sculptor. Further details for the shape came from video, countless photographs, even going in a tank with and touching live Orcas.

Assembly presented additional challenges. For instance, the mechanism near the fluke would not fit inside the skin. It was based only on front and top views and did not account for the tail's oval cross section. Redesigning three tail sections nearest the fluke let the skeleton fit properly within the skin. But the overall shape was compromised somewhat to make the assembly physically possible without changing actuators.

Scale up

Despite the setbacks, the smaller whale model let Mannetron test the basic concept before scaling up. Probably the easiest part to scale was the outer skin. Here, a 3D laser scanner precisely recorded the shape of the 4-ft-long whale model. The 3D image was scaled by a factor of four and turned into NC toolpaths so a large vertical-milling machine could cut the structural-foam mold form.

Designing the full-scale aluminum skeleton posed a new set of problems. The overall mechanism size scales linearly but component cross sections and power requirements don't. Mannetron first considered hydraulics to move the hefty hulk. But leaking hydraulic oil can ruin molded skin and paint. "That happened to one of the robotic dinosaurs when filming *Jurassic Park*," says Mannetron CEO Mike Clark. "They had to scramble Learjets to an off-island location to mold a replacement skin."

Heat and noise were other concerns with hydraulics because the large whale consumes about 15 kW during operation. The hydraulic power unit required to run it would have been housed in a separate air-conditioned, sound-proof room along with refrigerated oil coolers, all of which were unacceptable.

A little research located a suitable replacement — brushless servomotor-powered linear actuators from Exlar Corp., Chanhassen, Minn. Five of the three-phase actuators move the tail and one controls the mouth. The actuators eliminated the support equipment and equally important, the noise. Making the whale run silent was one of Mannetron's key goals.

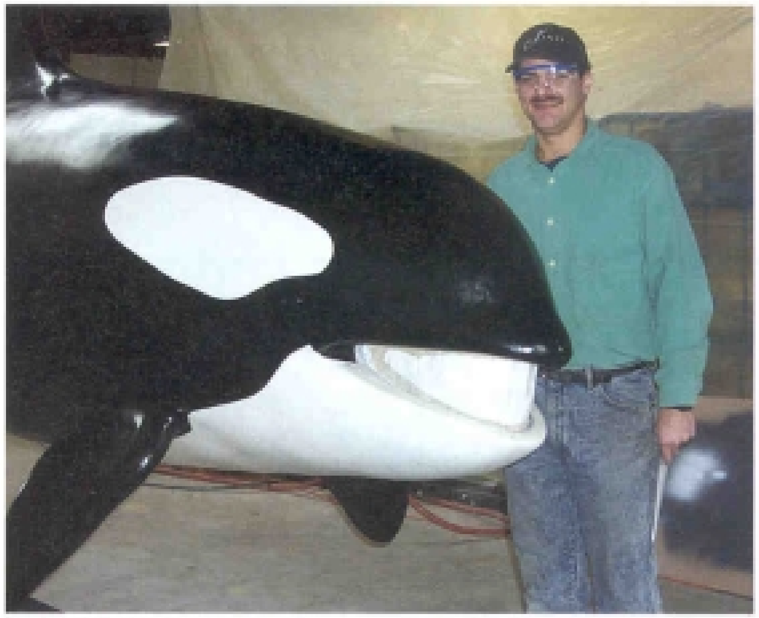
Swimming with fishes

Probably more challenging than building the animatronic whale was producing with it convincingly realistic swimming motion within the context of water, surface waves, fish, and other killer whales.

To start, Jungen programmed the whale's actuators to replicate Dr. Fish's motion models. A computer with real-time control of phase and amplitude runs the actuators in a sequence of sine waves. Jungen adjusts these parameters so the mechanical whale's moves match those of the real thing (on video). Mannetron developed a special control box to further help tweak the motion and eliminate gain-induced vibration. The box uses digital pots to control phase and digital gains, a more intuitive method than plugging in numbers, says Clark.

The next trick is placing the fake Orca in what appears to be water. Here's where the smoke and mirrors come in. Inside the whale "tank" are seven rear-screen computer projectors, some displaying real swimming whales. Images from three of the projectors overlap to give continuous floor-to-ceiling coverage. The images help make the animatronic whale appear to swim in place as the water images moves over it. A special Whale Input Device developed by Mannetron synchronizes the whale and water speeds in real time. It uses a weighted hand crank to control tail flopping rate (proportional to crank speed) over a range of several Hertz. The tail typically runs at about 1.5 Hz or 3 flops/sec.

Adding another dimension to the illusion is an old magic trick called Pepper's Ghost. The trick dates back to the 1860's magic lantern shows in London where it was used to make ghostly images appear on stage. The same effect also makes possible heads-up displays in modern jet-fighter cockpits.



Sculptor Chris Young scopes his handiwork on the 16-ft-long whale skin.

On the whale set, a partially silvered mirror, placed at an angle to the viewing window, periodically projects high-resolution images of the whale's internal organs. Superimposed on these are reflected images off of a skeleton model suspended above. The audience sees a ghostly cutaway magically appear and disappear.

Keeping the projected images and the whale in lockstep is the Society of Motion Picture and Television Engineers (SMPTE) time code synchronization protocol. SMPTE was originally developed for use in the television and motion picture industries to deal with the inherent slipping and stretching of videotape. It places a frame number and time stamp on each 1/30-sec video frame.

This comes in handy, especially when the animatronic whale surfaces to "breathe." Unfortunately, Fish's formulas don't cover surfacing, so Jungen wrote a program to bend the whale's tail, come up for the blow, then morph back to the Frank-Fish motion. Images projected on a separate screen, and on the partially silvered mirror in front of the whale, simulate the blow-hole spray in 3D as well as sunlight filtering through the water surface.

Like any convincing illusion, however, all these technical details are transparent to the audience. They see only a graceful act of "water" ballet put on by a magnificent, albeit animatronic, killer whale. About the only thing missing from the experience is a wet seat. ■

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