



I was an 18-foot robot

Strapped in place, the author was the steel giant's brain. His motions were duplicated by the robot, but with enormous power

By James R. Berry

MY FIRST TASK was to learn how to balance. Confidently, perched in the body of an 18-foot, two legged robot, I leaned forward. The platform I was standing on, sensitive to my slightest shift of weight, moved too. With a loud sigh of hydraulic valves the automaton I was commanding sprang to life.

Instantly, it mimicked my move. Before

I realized what had happened, it pitched forward out of control. Using my toes for leverage, I frantically tried to stop our headlong plunge by throwing myself backwards. The robot's reaction was as quick as it was violent. Accompanied by a piercing shriek of valves, the automaton shuddered to a halt, then swiftly heaved back. Before I could react, it had crashed down on its heels with a jolt that rattled every bolt in its body.

Able to Rock

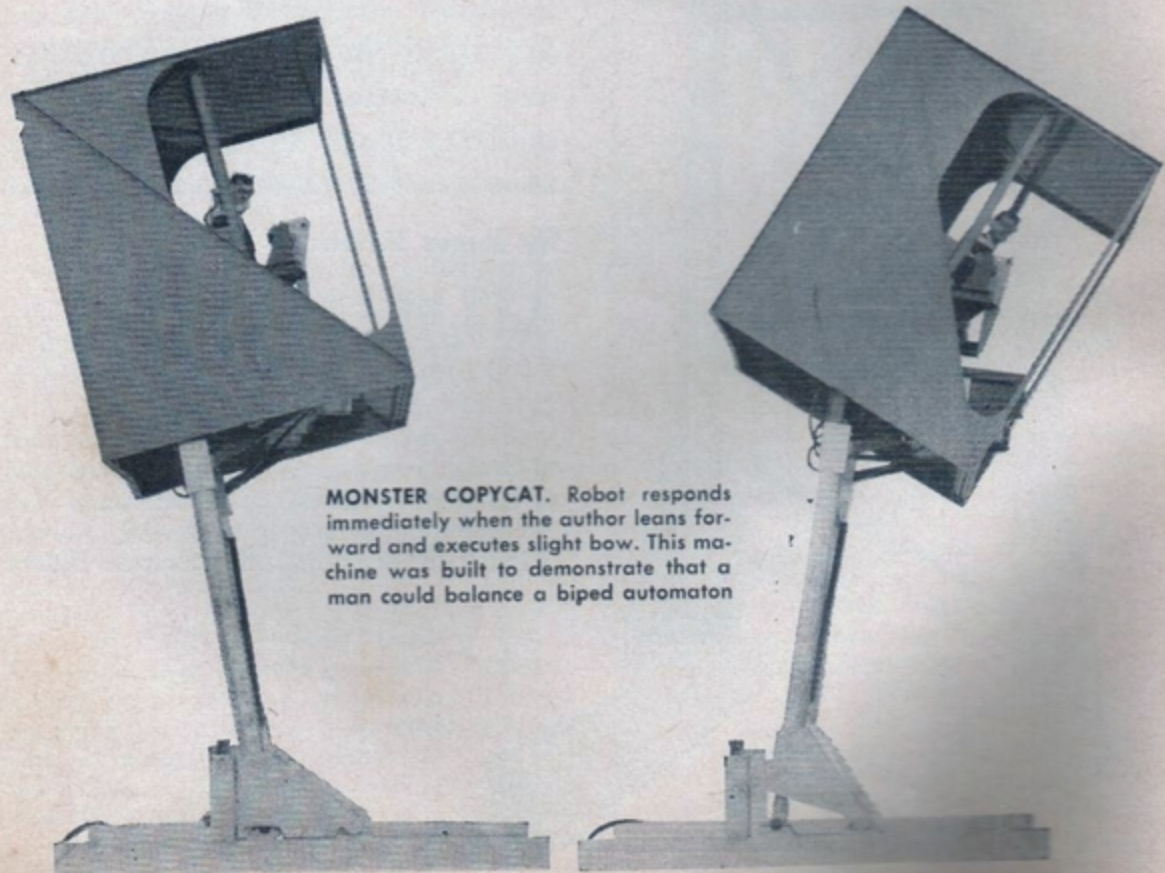
More warily now, I tried the maneuver again, this time successfully. After a few minutes of cautious trials, I was able to rock on my feet while the automaton, duplicating my moves, swung back and forth in slow, five-foot arcs. Soon, I could keep the machine where I wanted with a slight pressure of heel or toe.

Now, holding the robot in quivering equilibrium, I bent forward at the waist. The automaton's hips—controlled by a movable metal frame strapped to my back—moved and the machine dipped forward in a polite bow. I bent backwards and the

robot obediently did the same. Compared with balancing on my feet, this maneuver was a cinch. Inspired by my success, I raced through all the motions I had learned. The hydraulic system hissed, roared, and wailed as the automaton went through a series of movements as outlandish as the latest discotheque dance.

I was at General Electric's Advanced Technology Laboratories in Schenectady, N.Y., harnessed in the Pedipulator, one of an extraordinary new race of robots with the tongue twisting name of cybernetic anthropomorphic machines—CAMs, for short. This CAM, precursor of a generation of walking automatons, was built to demonstrate that a man can balance a bipod robot. Achieving balance is the first and most difficult part of walking. So, at the moment, the Pedipulator's feet are stationary and its arms, though developed, await being scaled up and bolted on.

What will the fully operating, walking robot actually be like? From the experience I'd just had and from what the GE engineers told me, I could easily imagine the robot at a building site or in a ship-



MONSTER COPYCAT. Robot responds immediately when the author leans forward and executes slight bow. This machine was built to demonstrate that a man could balance a biped automaton

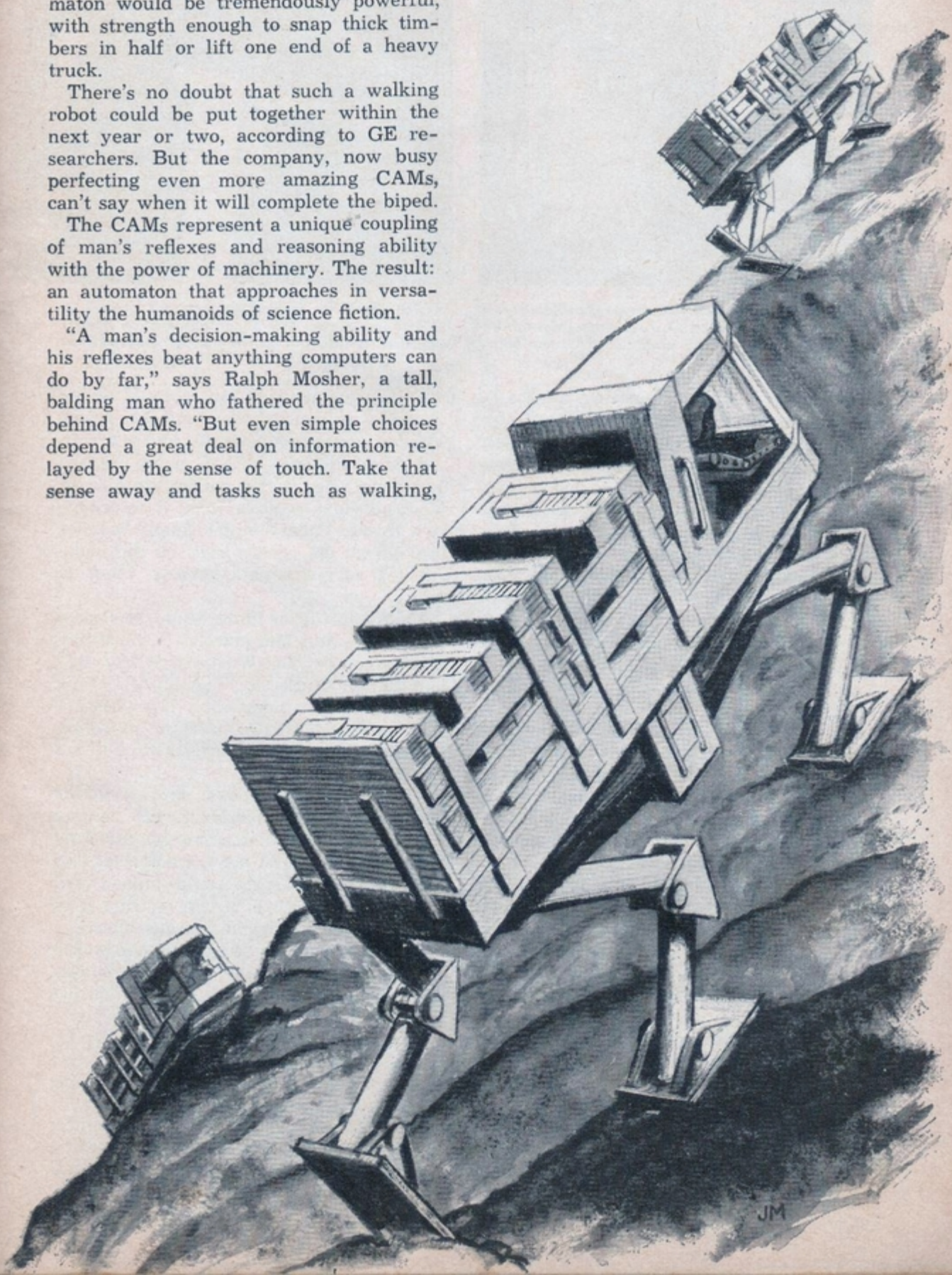
yard, clanging about on heavy steel feet, lifting bulky metal parts into place with its steel arms and making delicate adjustments with pincerlike hands. The automaton would be tremendously powerful, with strength enough to snap thick timbers in half or lift one end of a heavy truck.

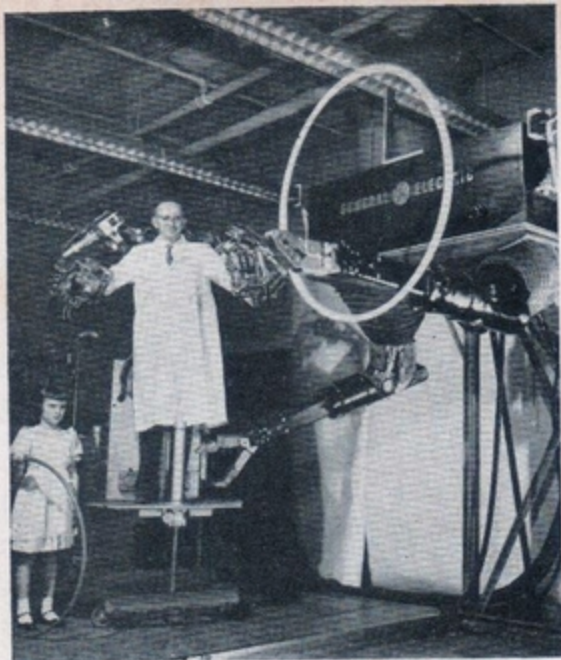
There's no doubt that such a walking robot could be put together within the next year or two, according to GE researchers. But the company, now busy perfecting even more amazing CAMs, can't say when it will complete the biped.

The CAMs represent a unique coupling of man's reflexes and reasoning ability with the power of machinery. The result: an automaton that approaches in versatility the humanoids of science fiction.

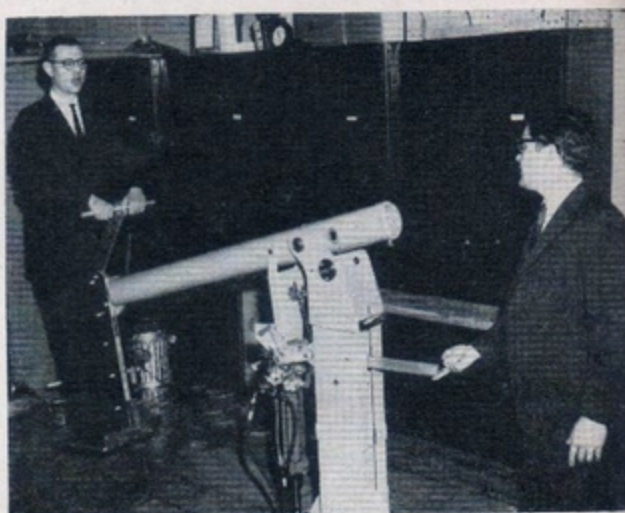
"A man's decision-making ability and his reflexes beat anything computers can do by far," says Ralph Mosher, a tall, balding man who fathered the principle behind CAMs. "But even simple choices depend a great deal on information relayed by the sense of touch. Take that sense away and tasks such as walking,

QUADRUPED ROBOTS, now under consideration for the Army, would be used primarily as cargo carriers in rough or marshy country, where even tanks bog down





INVENTOR RALPH MOSHER makes Handyman spin hoop. Machinery around Mosher's arms transmits every motion to the robot's arms and pincerlike hands



FINGER PRESSURE applied by author is enough to lift 150-pound man. This boom was used in the development of system for controlling robot's limbs

opening a door, or squeezing a tube of toothpaste become major problems."

CAMs incorporate a sense of touch. By a system called force feedback, the operator of a CAM feels the strains and stresses in the robot's limbs and body as though they were his own. The operator's arms, legs, and body are strapped into mobile, jointed frames called follower racks. Like an external skeleton, the follower racks pick up his every move, causing a corresponding, but amplified, motion in the CAM's analogous limbs and body.

But the follower racks serve another purpose. As the CAM does work, from balancing itself to carting boulders, its joints undergo stress. Part of this stress is hydraulically fed back to the follower racks, causing a proportionate strain in the operator's muscles. A simple adjustment increases or diminishes the amount of stress the operator feels.

Although CAMs haven't yet reached the stage of assembly-line production, they're already being eyed for scores of jobs that demand the reasoning power and dexterity of a man and the strength of a bulldozer. Some possible applications:

- Builders could use CAMs to lift steel girders into place, raise walls of prefabricated houses, tote materials around a construction site. CAMs with steamshovel-sized scoops replacing hands could dig tunnels, basements, or trenches, easily maneuvering where ordinary equipment couldn't be used. They would be especially helpful in archeological excavation where

their delicate sense of touch would be invaluable in uncovering ancient towns without damaging structures and artifacts.

- After disasters, CAMs could replace telephone poles, string cables, stack huge sandbags, and remove tons of wreckage at a throw. Others might simply wander through an emergency area on the lookout for survivors and remove them to safety.

- CAM artificial limbs might be linked to nerve centers and muscles in the stump of an amputee. The Woodrow Wilson Rehabilitation Center in Virginia is looking into just such a possibility. If successful, such limbs would pass a sense of feeling to remaining muscles, perhaps even to the nerves.

- Shipyards, auto and aircraft plants and other heavy manufacturing centers could use CAMs to assemble big but sensitive equipment. At piers, truckyards and rail terminals, CAMs could unload and load tons of cargo in a trip, putting it in place as easily as a child stacks blocks.

Improvements already envisioned would extend the range of the CAMs' usefulness even more. "There's no reason why the operator has to be inside his CAM," explains Mosher. "You could link the two by radio." Such a system, while probably at least a decade away from perfection, has incredible possibilities.

A remote-controlled CAM, for instance, could reconnoiter the ocean's floor, noting geological formations, locating mineral

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deposits, charting current changes, exploring—perhaps even salvaging—ancient wrecks. The operator, probably linked by cable in this case, could control his automaton from a ship miles above. Similarly, far-flung scientific outposts in the arctic, jungle, or desert could be manned and run by radio-controlled CAMs, their human masters comfortably lodged hundreds of miles away.

Useful on the Moon?

Employing CAMs to aid space exploration opens up the most dramatic possibilities. Once established on the moon, astronauts could use CAMs to explore the terrain, pick up crash-landed supplies, repair data transmitting equipment. CAMs could even build, staff and operate other moon stations, guided by the movements of spacemen strapped to follower racks deep within a safe shelter or even orbiting in a rocket.

The idea of CAMs originated nine years ago when the General Electric Co. was in need of an especially delicate manipulator to handle experiments with an atomic aircraft engine. Manipulators with the theoretical dexterity to turn screws, fit parts and assemble close-tolerance components were available. But they always turned out to be clumsier and more inefficient than expected. The company asked Mosher, a mechanical engineer in the General Engineering Laboratory, to try to design a manipulator that could handle the task.

"I realized that after a certain point improvements in mechanical dexterity added little to a manipulator's performance," says Mosher. "So I began wondering why a human being is so efficient and a slave robot so awkward. Soon it was obvious that the manipulator's operator was missing what he ordinarily experiences, a sense of feel."

Mosher toyed with several methods of restoring a tactile sense to a manipulator's operator before he hit on force feedback. The idea itself wasn't new; power steering, for example, which became popular in the early 1950s, uses the same principle. But no one had ever applied it to a high performance slave robot. When Mosher did, the difference was dramatic. "We didn't just make a better manipulator," he says. "Adding touch created an entirely new kind of robot."

From Mosher's work came Handyman, a pair of arms with pincer hands sensitive enough to pack eggs, strong enough to crush golf balls, and adroit enough to light

a match. The robot proved to be the most effective linking of man to manipulator ever built.

But it did have serious drawbacks. One was the electronic force feedback system, which used sensors in the robot's pincers and arms to pick up and relay stress. The electronic equipment was bulky and far too complex to be practical. In addition, the cost of the servo mechanisms and follower racks was prohibitive for anything but specialized projects. General Electric put Handyman and similar CAMs to work in its own plants. But their complexity and expense nixed plans for continued development.

Then, Army tactical problems, especially those growing out of the Vietnam conflict, revived interest in the robots. Tanks, trucks, mobile guns and other vehicles work fine on even rarely traveled trails. But muddy or potholed roads of a 10 percent grade or more often stop them in their tracks. Millions of dollars worth of high-horsepower equipment becomes hopelessly mired in spots where a mule or horse could walk through easily. Worse, brush-fire skirmishes often occur where there are no roads and equipment has to be laboriously carried in by hand.

To get more mobility from military hardware, the U.S. Tank and Automotive Center in Michigan had experimented for years with hopping, creeping, jumping and walking vehicles. All had been too clumsy and mechanically complex to really be efficient. Then, three years ago, top brass heard of Handyman and asked GE if the idea of force feedback could be used to develop a truly practical walking machine.

The company asked Mosher to find out. Substituting a more efficient and simpler hydraulic feedback system for the electronic relays, he came up with the Pedipulator, built in 1964. The machine proved beyond a doubt that a man could master a walking CAM. "In fact, I'm personally convinced that biped CAMs can ski," says Mosher.

Army to Test Four-legged Unit

Impressed, the Army studied the full potentials of CAMs. Result: PM has learned the Department of Defense and the Army Tank and Automotive Center soon will ask GE to turn out a semiamphibious four-legged, cargo-carrying CAM. The first test rig is due in late 1966.

The Army gives several reasons for shifting emphasis from two to four legs, all involving tactical usefulness. A four-legged CAM can't be knocked over as easily as a biped. Its silhouette will be

lower, making travel through low-lying jungle underbrush easier. Then, most important, a quadruped will be able to carry (on its back) more equipment than a biped could.

More information about this CAM will undoubtedly be released in coming months. But many details are already known. The quadruped will be about 4 feet wide, 10 feet long and 10 feet tall. The operator, in a cab at the robot's head, will sit upright and use a crawling motion to run the vehicle, his legs governing the robot's hind members, his arms controlling the forelegs. The cargo rack, directly behind the control cab, will take a payload of 500 pounds. A gas turbine engine will probably power the hydraulic servo and feedback system. The CAM will travel at about the speed of a man's brisk walk.

Eyeing the Civilian Market

Even though GE is currently focusing on a quadruped, there's little doubt work will continue on a biped CAM, too. Since much of the research and development going into the quadruped can be applied to a biped as well, spin-off from military-sponsored research will probably hasten the appearance of economical two and four legged CAMs on the civilian market.

Far-out scientific speculation suggests the next big, if distant, step in CAM development. Simply thinking a movement sends a small electrical current to the muscles normally used for that motion, a current that present medical technology can pick up from the skin. With electronic sensors replacing follower racks, a man might someday be able to control his CAM by just *thinking* an action. The force feedback, in this case, would have to be induced in his muscles by a current sent directly by the CAM instead of the operator's brain. If and when this development ever arrives, most physical work, from painting a house to fighting a war, could be done from comfortable armchairs. ★★★

First torpedo capable of being launched from airplanes going at speeds up to 400 knots has joined the Navy. It's the Mark 46, the Navy's first torpedo to use solid rocket fuel for propulsion. It is "capable of overtaking the most elusive submarine target known," the Navy said. It tracks its victim by both sending out sonar waves and listening for echoes or by merely listening for underwater engine sounds. The torpedo can also be launched from ship tubes and drone helicopters.