

# Engineers rescue aging satellites, saving millions

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Researchers have used a new technique to save \$60 million for broadcasters by extending the service life of two communications satellites. The technique works by applying an advanced simulation and a method that equalizes the amount of propellant in a series of fuel tanks so that the satellite consumes all of the fuel before being retired from service.

The two satellites would have been shut down prematurely and wasted remaining fuel if not for the new technique developed by researchers from Purdue University and Lockheed Martin Corp., said Steven Collicott, a Purdue professor of aeronautics and astronautics.

Communications satellites, which are maintained in proper orbit about 22,500 miles above Earth by firing small rocket thrusters, must be replaced shortly before they run out of fuel. Enough fuel must remain to get the satellites out of orbit to make room for their replacements.

Some aging communications satellites are each equipped with four fuel tanks. If one of the tanks empties before the others, the satellite loses control and should be decommissioned, wasting the remaining fuel in the other tanks, said Boris Yendler, senior thermal system analyst at Lockheed Martin Mission Services in Sunnyvale, Calif.

The Purdue and Lockheed Martin engineers not only determined precisely how much fuel remained in each tank, but they also used a technique to "rebalance," or equalize, propellant levels in all of the tanks.

The engineers kept the twin satellites operating an additional six months, which translates into about \$60 million in revenue for the broadcast companies that owned the satellites, Collicott said.

This work, led by Dr. Yendler, represents the first time such a fuel gauging and rebalancing has been carried out in commercial communications satellites," Collicott said.

Findings are detailed in a research paper published in the July-August issue of the *Journal of Spacecraft and Rockets*. The paper was written by Yendler, Collicott and Timothy A. Martin, an engineer at Lockheed Martin Space Systems Co. in Denver.

Although it may sound like a simple task, precisely monitoring the quantity of propellant in a satellite's fuel tank is not so easy.

It's not like a car's fuel tank, which has a little float that sits on top of the gasoline and moves a lever," Collicott said. "Floats don't work in space because everything is floating."

The problem's complexity is illustrated by the level of skills needed, said Collicott, adding that most researchers involved in such work have doctoral degrees in aerospace engineering.

The new technique works by using a computational simulation to determine the precise three-dimensional distribution of fuel in each tank. Then, engineers analyze data from the satellite showing how the tanks respond when they are heated by onboard heaters. The heaters are routinely used to keep fuel from freezing as a satellite rotates away from the sun. But data related to how the tanks respond to the heating can be analyzed to reveal precisely how much fuel remains in each tank.

If you put two saucepans on the stove, one with a lot of water and one

with a little bit of water, the one with the little bit of water heats up quicker," Collicott said. "And we use the same principle, basically. But since in orbit the liquid is in a state of weightlessness, it doesn't sit neatly in the bottom of the saucepan in orbit, so my part is predicting where the liquid sits. Once we know where the propellant is in the tank, then Dr. Yendler can use a high-resolution thermal model to determine how much fuel is in the tank."

The technique uses temperature data that are already routinely collected, meaning it requires no additional satellite hardware and can be applied to existing spacecraft.

After applying their technique to the twin satellites, the researchers discovered that one of the four fuel tanks in each satellite was nearly empty.

Because of the design of the propulsion system, if one tank had emptied out that would have ended the profitable life of the satellite, wasting all the fuel in the other three tanks," Collicott said.

The reason for this effect is that the system relies on compressed helium to push fuel through a valve in each tank. When the valves are opened, fuel flows into rocket thrusters, which are fired periodically to reposition satellites.

The tanks are pressurized with the helium. If one tank runs out of fuel, the next time the valve in that tank is opened to ignite the rocket thrusters, the helium from that tank mixes with fuel going to the thrusters from the other tanks, preventing the thrusters from firing and shutting down the propulsion system," Collicott said.

Once the imbalance in fuel is determined, however, the propellant can be equalized in all four tanks by a process called "thermal pumping."

In thermal pumping, if you heat up the three tanks containing more fuel and you keep the emptier tank cooler, the helium gas in the three warmer tanks expands, pushing the liquid fuel into the emptier tank," Collicott said. "The difficult part is figuring out how much heating is needed and how long it will take to move the fuel into the emptier tank. My collaborators detected the fuel imbalance and designed a way to reprogram the heaters so that we could even out the propellant load over all four tanks and therefore maximize the mission life."

The research paper details two portions of the work needed to accomplish the fuel equalization: how to perform the "thermal gauging" that determines how much propellant is contained in the tanks, and then how to accomplish the rebalancing.

It took a year and a half of thermal pumping, carried out at different times, to accomplish the rebalancing," Yendler said. "We were really excited to see that we could take our new propellant-gauging method to provide this lifetime maximization in satellites that were never designed to have anything like this done to them."

Communications satellites cost about \$100 million and sometimes as much money to launch them into a geosynchronous orbit. They generally have a 15-year lifetime, bringing in \$5 million to \$10 million a month in revenue.

Understandably, broadcast companies are very concerned about when a satellite needs to be replaced," said Collicott, who has been developing the simulation since the early 1990s. "A lapse in service would have tremendous impact on their business."

The satellites eventually were shut down in mid-2003. The satellite owners were kept confidential in the research paper.

Collicott developed his simulation based on a mathematical model created in the early 1990s by Kenneth Brakke, a mathematics professor at Susquehanna University. The model was initially used to describe the mathematics seen in simple phenomena such as the formation of soap bubbles or the "capillary rise" when a straw is placed inside a glass of water; the water level inside the straw rises higher than the level in the glass.

The exact same physics, the wicking action, is responsible for positioning fuel inside fuel tanks in space," Collicott said. "Here on Earth, we see this capillary action only on very small length scales because gravity generally overwhelms it. But in space the weight of the liquid is irrelevant."

Consequently, the effect is exaggerated in space, making it more difficult to predict the liquid's movement and its location inside the tank. The four spherical tanks in the twin satellites contained sheet metal vanes that create corners to use for wicking to control the movement of fuel.

Modern satellites generally have a single fuel tank, but it was common years ago to design satellites with more than one tank," Yendler said. "Consequently, there are many aging satellites in orbit that could benefit through thermal gauging and rebalancing, and corporations are interested in maximizing their revenue."

Source: Purdue University

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