February 2015

AEROSPACE AMERICA

Remembering AIAA's Jim Harford/page 4

$AVE BILLION$ ON YOUR FLEET

Stop wasting time and parts on no fault found Page 28

USAF's Otto on ISR planes/24

Small sats, big plans/40

A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

Video from GEO

A team led by Ball Aerospace figured out how to generate images by diffracting light through thin membranes of plastic. Someday, a 20-meter-diameter telescope made this way could look down from geosynchronous orbit to track vehicles or into space to characterize the atmosphere of exoplanets. Will scientists or the Pentagon adopt the technology? Ben Iannotta looks at the breakthroughs and challenges of the MOIRE program, short for Membrane Optic Imager Real-time Exploitation.

Engineers at Ball Aerospace had good reason to root for a dry summer along Colorado's front range in 2014. Inside a non-humidity-controlled room dubbed "the hangar," they had erected a set of six translucent plastic membranes held taut by aluminum frames. Their plan was to project a previously acquired image of Earth onto this membrane, a diffractive optical element, as if the element were looking down on Earth from geosynchronous orbit. The goal was to prove that a picture could be generated by a set of optics and a detector located 27 meters away. In space, these aft optics would be supported behind the primary element by a set of booms.

Generating images by diffracting light through membranes was a radical idea, and one that the Ball team began exploring for the Defense Advanced Research Projects Agency in 2010 under a program called MOIRE, for Membrane Optic Imager Real-time Exploitation.

Spy satellites typically look at Earth or peer into the cosmos by collecting light with carefully shaped and polished mirrors. This light is reflected onto a set of optics and detectors. The catch is that the mirrors must be supported by structures to keep them aligned and focused. The resulting mass is one factor limiting the size of apertures that can be launched by rockets. Using plastic membranes just 20 microns thick would open entirely new space telescope applications, Ball officials say. They're also careful not to oversell the technology. Because diffraction patterns must be tuned to narrow bands of wavelengths, a telescope made with plastic membranes will never replace the glass or metal variety. DARPA's main reason for supporting the research was the possibility that it could lead to a telescope large enough to produce black-and-white videos of vehicles moving across Earth's surface from geosynchronous orbit 35,000 kilometers above Earth. Unlike low-Earth-orbit satellites, such a spacecraft could stare continuously.

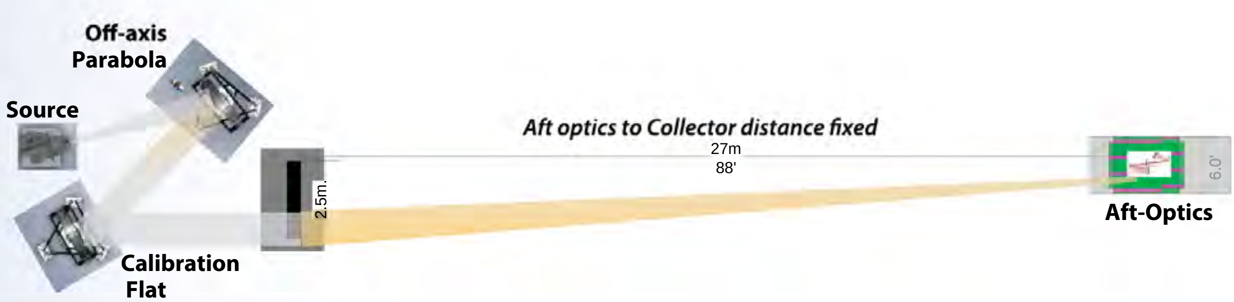
The membranes had one potential Achilles' heel in the ground demonstration at Ball. The hangar was not a vacuum chamber, and so the optics would be exposed to humidity. That was a problem, because engineers knew the material was prone to absorbing water.

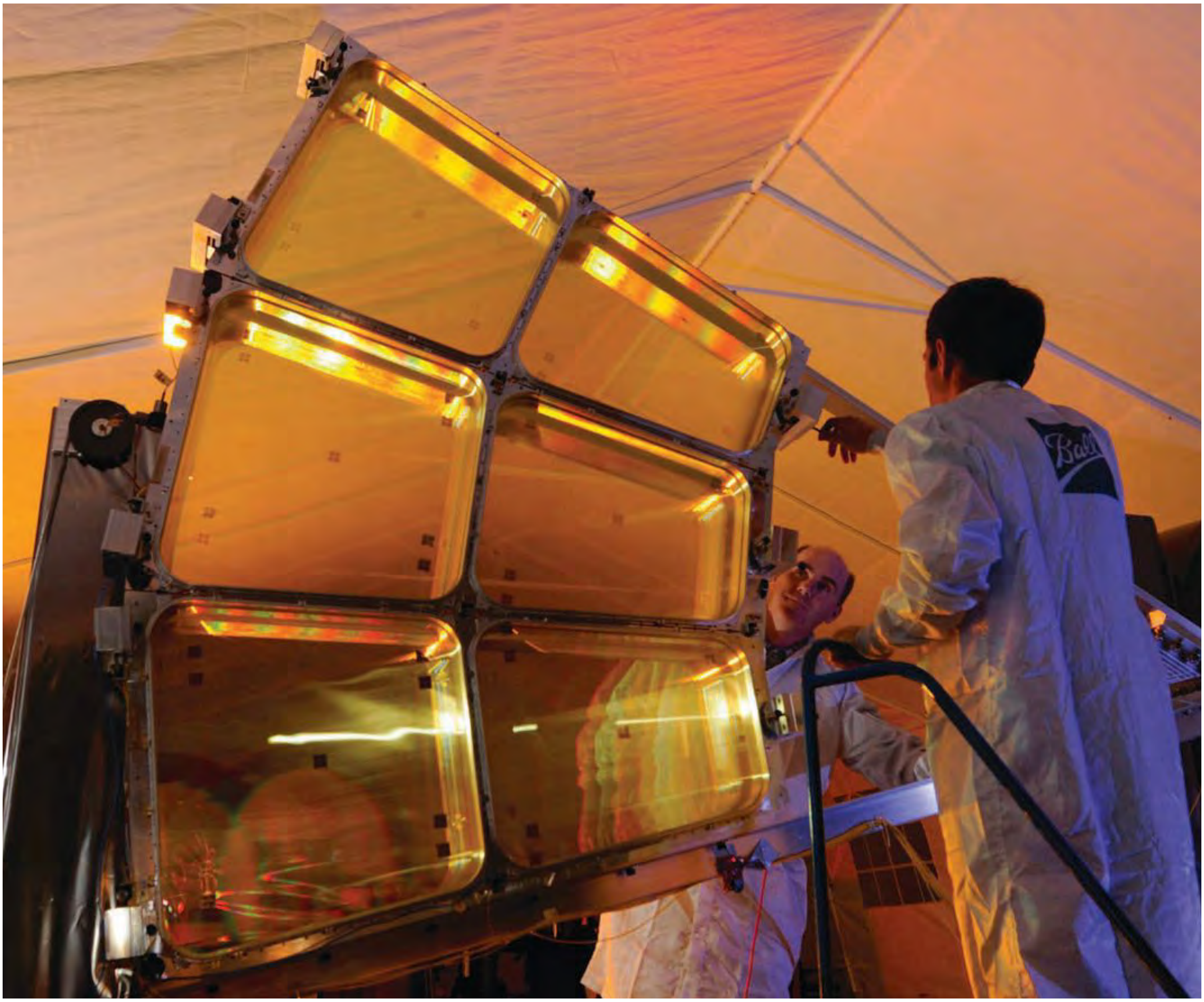
Sure enough, when they projected still images acquired by a WorldView satellite onto the membranes, the image quality was degraded by atmospheric turbulence inside the hangar and by the water absorption.

The images came through less

Simulating the view from geosynchronous orbit

The MOIRE program culminated with a 2014 test inside a Ball Aerospace facility in Boulder, Colorado. The source below projected a previously acquired image of Earth through a lens made of membranes to simulate the lens looking down from geosynchronous orbit. The Aft-Optics produced images.





Ball Aerospace

For a test of lightweight optical technology, Ball Aerospace engineers erected a set of six 20-micron-thick diffractive optical elements on a frame to represent one-eighth of a 5-meter-diameter membrane telescope.

clearly than hoped, but they came through. The team is upbeat about the achievement. "We put [the membranes] together with the aft optics. We actually built the camera end, the detector end, and we got images out," says Ball's Jeanette Domber, a deployable structures expert and the company's MOIRE program manager. "I'm not aware of anybody else who's done that with an end-to-end telescope that has a membrane primary," she adds.

DARPA, per its usual process, supported the technology development and has now moved on. Ball is trying to find a government agency or scientific organization to pick up the technology, help refine it, and ultimately launch a membrane telescope into space. Ball officials say such a telescope could be used for anything from monitoring methane in Earth's atmosphere to characterizing the atmospheres of exoplanets to receiving scientific data beamed back optically from deep space.

"We've been talking with a number of folks, and there's definitely a lot of interest in the technology," says planetary astronomer Makenzie Lystrup, who is in charge of Ball's business development for the MOIRE technology. "I think it's just a matter of figuring out how to transition" the technology.

The objectives of such a spacecraft would probably be specific, given the narrow band.

"Because you have the large aperture, and a good angular resolution, you might be able to look at maybe a specific planet that [the Kepler Space Telescope] has identified and try to characterize the atmosphere, or just look and see if there's water there," Domber says.

An early challenge for the MOIRE team was to find the right material for the membranes. They had to support the diffractive patterns etched into them without deforming.

"Since the spacing of the diffractive edges sets the operational wavelength, any change in those dimensions due to thermal effects [on the membranes] changes the operating wavelength, defocusing the image," Domber says. "We chose [the Novastrat polyimide] because we can tailor the properties of it, specifically the coefficient of thermal expansion to be what we want it to be for the entire system to work properly."

Novastrat was supplied by NeXolve Corp. of Huntsville, Ala.

Another key factor was the etching process, whose development was led by Lawrence Livermore National Lab in California. Before the MOIRE program, the state-of-the-art diffractive etching process was an entirely different approach also pioneered by Livermore. Under a program called Eyeglass, Livermore figured out how to draw diffraction patterns onto glass by controlling a liquid etchant through fluctuations or gradients in surface tension, called the Marangoni effect. In 2002, the Eyeglass team built a 5-meter-diameter diffractive prototype lens made of 72 segments for optical testing, according to a report on the project.

There was a big architectural challenge for the Eyeglass team, though. Their diffraction patterns resulted in long focal lengths, too long for even deployable booms to accommodate. The Eyeglass telescope concept therefore called for launching two discrete spacecraft separated by a few kilometers, with one spacecraft carrying the primary collection element.

"When most people hear that you're looking at a diffractive system for imaging, this is the system that they're thinking about," Domber says. "We were able to come up with a design that you could fit on a single spacecraft and in optical terms is relatively fast in comparison."

The key was the new etching technique devised at Livermore, which allowed for finer diffraction patterns and shorter focal lengths. Using a master pattern, an ion tool etches complex patterns into photoresist material applied to the membranes. "That same glass master is used to make a bunch of membranes with this pattern on it over and over again, which is why it's cheaper — or one of the reasons why it's cheaper — compared to polishing a glass optics," Domber says. "About 1 to 2 microns of material is etched away from the surface, and that's what creates the diffractive pattern on the membrane."

Finer patterns meant shorter focal lengths. Instead of the primary element being kilometers away from the focal plane, it would be 50 meters away, supported by three foldable, deployable booms devised by ATK.

A 50-meter boom and 20-meter membrane telescope — the size DARPA wants someday for video — is still too big to fit inside a rocket shroud. So, the MOIRE team came up with a concept to fold up the booms and membrane segments, and rely largely on their stored energy to deploy them.

"Once the launch locks are released, because of the strain energy in the system, [the primary] wants to deploy to a flat state," Domber explains.

The booms also want to be in their deployed state, she says. Inside the rocket, "they compact down into a footprint less than 2-feet tall and they're going to deploy out 160 feet," she says. They're deployed with the aid of a motor and lanyard. Once in place, "they're very stiff. They have good thermal properties. They can carry cabling with them, and they're very reliable," she adds.

If all goes as Ball hopes, the MOIRE team will get to prove this technology in space.

Ben Iannotta
BenI@aiaa.org