Then: Embracing Asymmetry

From wartime optics to vision correction, early freeform surfaces left rotational symmetry behind in pursuit of additional degrees of freedom.

1910s: A stretched view
First used in periscopes during World War I, anamorphic lenses constitute one of the earliest examples of asymmetric optics. In Henri Chrétien’s anamorphic-lens cylinder periscope design, the toroidal surfaces achieved a stretched horizontal field of view by having two radii along two orthogonal axes. This allowed soldiers access to a wide-angle, 180-degree view outside of an extremely small opening in military tanks. After the war, Chrétien tweaked this same design for photography and cinematography.

1972: Polaroid and presbyopia
Early applications in ophthalmology and photography drove commercial interest in freeform optics. The 1970s witnessed the introduction of the Varilux 2 progressive lens for presbyopia, featuring a totally aspheric design and manufacturing process, the varifocal Alvarez lens, which is still in use today, and the SX-70 Polaroid camera. The viewfinder in the SX-70 used nonrotational aspheres to create the first instant single-lens-reflex camera on the market. Interestingly, this design was very similar to the progressive ophthalmic lens—but turned upside down.

2002: Tackling manufacturing
The difficulty with freeform optics is designing and manufacturing complex, asymmetric surfaces, so the processes and computing power that enable the precision optics industry have played a large role in the freeform revolution. Computer numerically controlled cutting (CNC), for example, was a major advance. This automated method employs software embedded in a microcomputer attached to the tool to streamline the fabrication process. Another milestone was the diamond turning machine, specifically the shift toward multi-axis diamond turning around 2002.
Now: The Future Is Freeform

Today, freeform optics may be found in both Earth- and space-based telescopes, head-up displays, compact imaging systems and more.

2019: Fabrication advances
Both fabrication and design innovations are driving freeform optics forward. In 2019, the Hong Kong Polytechnic University unveiled a multi-jet polishing technology that can improve surface quality for freeform products with complex designs. And OSA Fellow Jannick Rolland’s team at the University of Rochester, USA, has developed a method that predicts whether freeform surfaces will work well in a particular system, and the specific design that should be used.

2020: Astronomical applications
Last year, research organization TNO delivered a spectrometer for the Sentinel-5 satellite instrument, which is part of the European Copernicus program for monitoring Earth’s atmosphere. The lightweight and compact Offner-type spectrometer was adapted to use freeform optics and an aspheric off-axis grating, and it sports unique mirrors that are polished to less than a nanometer’s smoothness, allowing for less disruption from stray light.

2021: Metasurface + freeform
On the application front, one major area of interest for freeform optics is AR/VR, as freeform surfaces promise lightweight, compact form factors and the ability to correct for distortion when projecting a straight image onto a curved surface. Toward this goal, a team at the University of Rochester, USA, recently introduced an optical surface that integrates the benefits of freeform optics with metasurfaces. The “metaform” mirror enables design degrees of freedom to support next-generation AR displays.

NEXT STEPS: Freeform optics are complex to design, prototype, test and measure, and with additional complexity comes additional time, effort and cost. In the future, new methods will be needed to address these concerns, including everything from better polishing tools to ensure surface quality to more supportive software. Ever-quickening computational speeds and fabrication innovations are expected to go hand-in-hand to make freeform dreams a production reality.

For a list of references and further resources, go online: www.osa-opn.org/then-now/freeform.