is well worth their cost. The carriers are intended for these principal missions: a conventional war at sea with the Soviet Union; mounting sustained air attacks onshore, especially against countries with weak air forces; and showing the flag in such crises as the Bangladesh war. Also, the carriers compensate for the loss of overseas U.S. land bases, which, in recent years, have become more and more politically vulnerable.

Advocates say the 90,000-ton carrier, which concentrates many different capabilities in a single, mobile base, is highly efficient. All together, the armaments of the giant carrier are unequaled by those of any other ship or complex of conventional weapons in the world. As Navy Secretary J. William Middendorf II said in a recent speech, the carrier is "that single platform which is capable of carrying out all the missions of the U.S. Navy."

Mini Carrier a Threat

However many giant or midi-sized carriers are ordered in the near term, they still face the long-term threat of the 30,000-ton mini carriers which, its advocates say, is the best future solution. The mini looks promising because of the development of new technologies which enable smaller ships to perform many of the crucial functions of present-day carriers.

One technology that is frequently mentioned is the VSTOL aircraft, such as the Marines' British-built Harrier, and the more advanced versions under development by the Navy. The small space they require diminishes the raison d'être of today's carriers, namely their vast flight decks.

Skeptics point out that VSTOL aircraft are, from an engineering standpoint, inherently more complicated than conventional planes and will be costlier. Moreover, the larger engine and volume of fuel needed for vertical takeoff is a physical limitation which bars VSTOL from competing with most conventional fighter and attack planes.

But VSTOL's current performance is not the issue; the question is whether VSTOL can compete with conventional aircraft in range and payload by the mid-1980's. Harrier program chief Colonel John R. Braddon is optimistic because long-awaited advances in engine thrust-to-weight ratios, lightweight materials, and other needed things are finally coming to pass. "It seems reasonable that now, in the present state of the art, a competitive VSTOL is reasonably attainable," which would have "very great impact" on Naval ship design, he says.

Other new technologies, such as the cruise missile, could do many of the jobs now performed by the carriers' pilots and airplanes.

Richard Garwin, of the IBM Corporation, a well-known defense consultant who is something of a guru in military circles on the subject of new technology, believes that these developments make both the giant and the midi class carrier obsolete.

"It is the existence of the carrier, and the effort to make it look both necessary and durable, which has kept the Navy from

Zen and the Art of

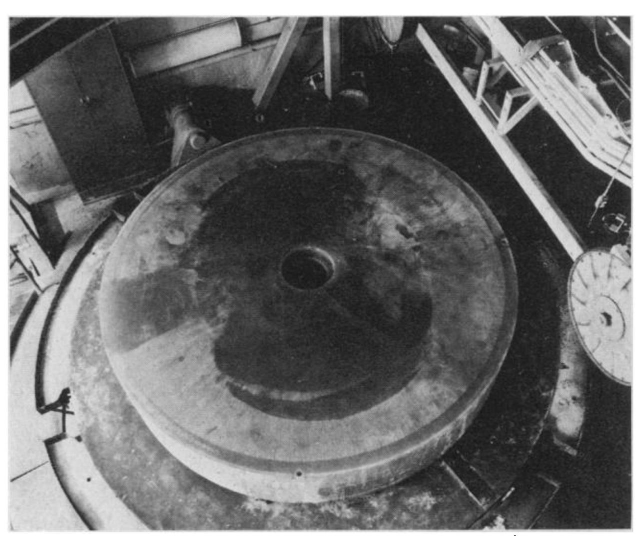
Sometime during the morning of 2 September, a large crack developed in the 12 ton disk of brownish glass that stands in the optical shop of Kitt Peak Observatory, Arizona. The glass monolith was being polished up to form the mirror of an infra-red telescope planned for Mauna Kea, a volcanic peak in Hawaii. The mishap, cause of which has yet to be determined, is an unusual accident in a craft which in some respects has not changed for centuries.

The Mauna Kea mirror blank cost $300,000 when the National Aeronautics and Space Administration bought it two years ago from the Owens-Illinois Glass Company of Toledo, Ohio. It will probably cost $500,000 to replace, if the crack cannot be contained. Norman Cole, master optician at Kitt Peak, believes he may be able to halt the crack by drilling a small hole at its end. If not, the glass can be cut into blanks for smaller mirrors of equal value to the original.

Telescope mirrors are gently concave surfaces where light is collected, focused up to a second mirror, and passed back through a hole at the center. The crack in the Mauna Kea blank starts at the central hole and extends for 86 centimeters toward the disk's edge. It appeared after only 6 weeks' work had been done on the blank. Had the crack come when the mirror was finished, some 18 months' labor would have been destroyed. What takes so long to bring a mirror to perfection are the constant stops for testing the surface. The 200 inch mirror of the Mount Palomar telescope took 8 years to polish into shape, not counting time out during World War II.

The Mauna Kea blank is 3 meters in diameter and 76 centimeters (30 inches) thick. There are still only six telescopes in the world with mirrors more than 3 meters in diameter. Norman Cole has done two of them—the 4 meter at Kitt Peak and its sister at Cerro Tololo in Chile. The Kitt Peak mirror took 3½ years to polish. With that experience, Cole and his team managed to rush the Cerro Tololo mirror through in 2½ years. Astronomers say it's just a whisker better, too. The other four big telescopes are the 200 inch at Mount Palomar, the 120 inch at the Lick Observatory in Santa Cruz, the new 154 inch Anglo-Australian telescope at Siding Spring in New South Wales, and the Russian 236 inch (6 meter) at Zelenchukskaya in the northern Caucasus. The Russians are rumored to have lost at least one and maybe two of these 6 meter mirrors to cracks.

Preparing a mirror is both craft and science. Some techniques of fine polishing, "figuring" as opticians call it, haven't altered much in 200 years. Jeweler's rouge is still the abrasive used in figuring. But mirrors nowadays are made of glass-



considering, developing, or presenting any alternatives," Garwin told *Science*. "It has impeded naval R & D. It has impeded naval thought. . . .

"What has changed," he says, "is that airplanes have become very much more effective in attacking ground targets," with precision guided weapons instead of gravity bombs. The performance standard for the carrier and its complement of airplanes has been, he says, how many tons of explosive can be dropped from the airplanes after they leave the carriers on bombing missions. "But if you can do the same thing with one-tenth the payload, that measure of effectiveness becomes meaningless."

Tactical cruise missiles launched from smaller ships or submarines can launch sustained attacks against land targets. The self-guided vehicles—small enough to fit into ordinary torpedo tubes—can be programmed before launch to find and strike their fixed ground targets, just the way pilots aboard the carriers get their instructions in the briefing room before a day's sorties. Hence this job can be done from smaller ships or submarines.

U.S.S. John F. Kennedy

Cruise missiles, which the Soviet navy has in abundance, also make the carrier's flight deck more vulnerable to air attack. Defenders of giant carriers claim that improved countermeasures have kept the carriers invulnerable in nearly all situations, but they also concede that the carrier flight decks can be disabled if subjected to a con-

Big Mirror Making

ceramics, materials whose thermal coefficient of expansion is magically near zero. Glass-ceramic mirrors do not change shape as the night cools, which is one advantage. Another, for the optician, is that he needn't wait until the mirror has cooled before testing for his next polish.

The optician's nightmare, of course, is shaving off too much. "On the glass surface there are mountains and valleys of the order of a millionth of an inch high," says Cole. "You have to whittle away the tops of the hills and mountains until you meet the level of the lowest valleys. If you overshoot, you create new valleys and have to start over."

Machines cannot work to such fine tolerances. The mirror is coarsely shaped by diamond-studded grinding wheels, then the opticians take over with their rouge. At first they rub away at large areas for several minutes at a time before stopping to test their progress. As the surface approaches perfection, they polish for just a minute at spots a square inch or so in area. It takes a knowledge of optics and at least 2 years on-the-job training before a polisher is let loose on a large mirror blank. The job may sound monotonous, but Cole does not find it so. "I have been doing this for more than 20 years but there are some days when I get up in the morning and do something wrong and think I have not learned a thing."

Mirror making is an art that progresses in delicate interplay with the other components of a telescope. At one time it was the mirrors that limited the accuracy of observation. Now the master opticians do their job so well that the photographic emulsion is becoming an important limitation. Its place is being taken by arrays of light-sensitive diodes, a windfall from the picturephone industry. The diodes can measure light from objects only 1 percent brighter than the black night sky. "It's incredible how much light we were throwing away 10 years ago," observes Peter Boyce, a National Science Foundation astronomer concerned with the instrumentation of telescopes.

Many advances in design, Boyce notes, come from people with smaller telescopes; they have to try harder. A 90 inch telescope with today's detectors has the seeing power of the 200 inch at the time it was built. At some observing sites the unevennesses in the earth's atmosphere have become the stumbling block to further accuracy. With the earth's atmosphere removed, mirrors once again become the limiting factor. The Large Space Telescope, 95 inches in diameter, is scheduled to enter orbit in 1982. Charles Odell, the NASA scientist in charge of its design, intends its mirror's surface to be more perfect than than of any earth-bound instrument. The Mount Palomar 200 inch telescope, he says, "doesn't approach 1/20th of a wavelength in its system accuracy, which is probably justified at that site because seeing is not particularly good. At good sites, like Kitt Peak and Cerro Tololo, it's worth going to 1/20th of a wave. The Large Space Telescope mirror will have a surface accuracy of 1/50th of a wavelength." The wavelength of light, taken at the midrange of the visible spectrum, is 6×10^{-5} centimeter.

The space mirror must also excel in lightness. Exploring ways to honeycomb the glass at the back of the mirror, NASA ordered mirrors from the two principal makers of giant telescope blanks, Owens-Illinois and Corning Glass. The first blank of Cer-Vit, the glass-ceramic pioneered by Owens-Illinois, cracked during heat treatment in the plant. A second was ordered, but NASA decided that Corning's material, called Ultra Low Expansion Quartz, would be safer to core out because the mirror can be constructed in several layers, which are then fused together. The second blank of Cer-Vit was donated to the telescope NASA is building on Mauna Kea. It is this blank that last month sprang a crack at Kitt Peak.

—NICHOLAS WADE