The Power of Morphological Thinking

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Zwicky: The Outcast Genius Who Unmasked the Universe
by John Johnson Jr.
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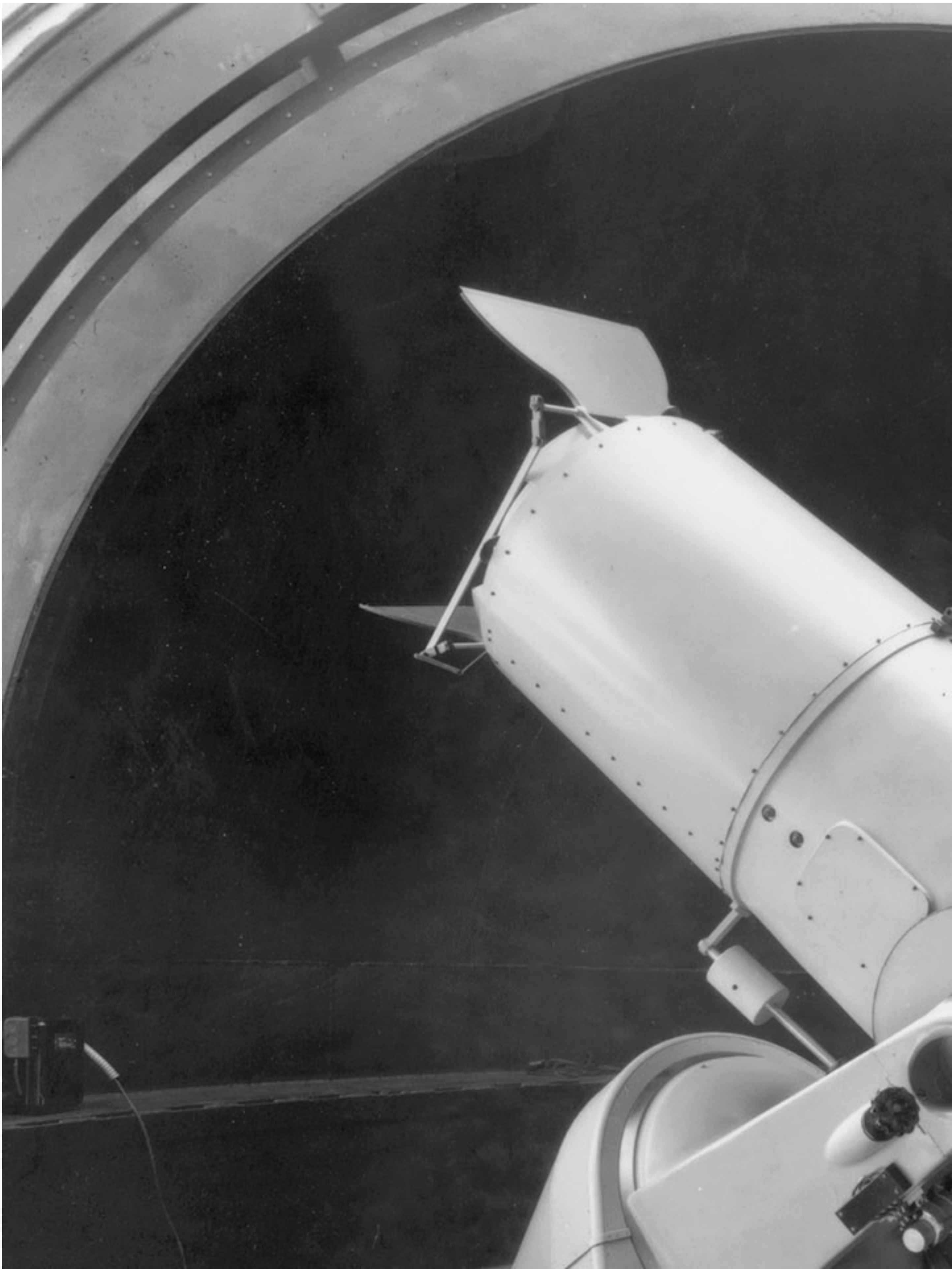

Caltech Archives

Fritz Zwicky at the Schmidt telescope at Palomar Observatory, California, circa 1936

Around the year 1935, a profound change occurred in the way humans imagine the universe. It was not sudden, but it was substantially complete within a few decades. Before the change, the universe was divided into earth and sky, the earth made of perishable stuff in constant turmoil, the sky made of immortal stuff, serene and ageless. After the change, the sky became like the earth, made of the same materials and shaped by violent dynamic processes that differed only in scale from similar processes on earth.

The change from a peaceful to a violent view of the universe was the result of many discoveries by many scientists using a variety of instruments, but one man and one instrument made a major contribution to it. The man was Fritz Zwicky, the subject of a lively new biography, *Zwicky: The Outcast Genius Who Unmasked the Universe* by John Johnson, a writer of science books for children and a former science reporter for the *Los Angeles Times*. The instrument was a little eighteen-inch telescope that he installed near the summit of Mount Palomar in California in 1935, long before the big Palomar telescopes existed. That event made the year 1935 a turning point in the history of astronomy. Astronomy is the only branch of modern science that is easily understood by ordinary readers without technical training. Johnson has written a book that explains the astronomical facts simply and clearly without using technical jargon. But the emphasis is on the human characters, not on the science.

In 1935 Zwicky was thirty-seven years old and an assistant professor in the physics department at the California Institute of Technology, where he had arrived as an immigrant from Switzerland ten years earlier. Since he had studied mathematics and physics but had no professional training as an astronomer, he was excluded from the Mount Wilson Observatory, where world-famous astronomers such as George Ellery Hale and Edwin Hubble were in charge. Hale and Hubble had the biggest telescopes in the world at their observatory. Zwicky's small, cheap telescope was the second one built with a revolutionary design by Bernhard Schmidt, an optical technician working at the Hamburg Observatory in Germany. Zwicky happened to be a friend of Schmidt and persuaded him to build it and sell it to Caltech for a low price. That telescope was the first to be used at a good site for astronomical observations, where its superb optics could produce superb pictures of faint objects in dark skies.

The Schmidt telescope had an enormous advantage over other telescopes at that time: it focused light accurately over a wide field of view. Other telescopes had accurate focus over much smaller fields. This one could produce sharp pictures of the sky with an area a hundred times larger than other telescopes. Zwicky's eighteen-inch telescope at Palomar could cover the sky a hundred times faster than the hundred-inch telescope at Mount Wilson.

Zwicky was one of the first scientists to grasp that cosmic rays—the high-energy particles that incessantly bombard the earth from all directions—are convincing evidence of a violent universe. It had been known since 1912 that they came from outer space, but nobody knew where they originated. Zwicky realized that in order to fill the vast volume of space with high-energy particles, they must somehow be the result of violent events on a grand scale. In 1933 he proposed that cosmic rays are produced in supernovae, the colossal explosions that occur sporadically in distant galaxies. He also worked out a theory that a supernova is the gravitational collapse of the core of a massive star, followed by the outward explosion of the envelope of the star. The envelope is ejected into space, while the core collapses into a neutron star. Neutron stars were imagined by Zwicky as tiny objects of enormous density. In 1933 this picture of a violent universe was a wild speculation, only confirmed thirty years later when neutron stars were observed as pulsating sources of radio waves, with one of them embedded in the debris from an old supernova.

Zwicky understood that the way to observe such events in the universe was to take pictures of the sky as rapidly as possible and look for changes from one picture to the next. He did the first photographic Sky Survey covering big areas of sky. The little Schmidt telescope was the ideal instrument for this task. He had as much time as he wanted on it. None of the bigger telescopes was fast enough to do the job, and none was available for so much of the time. With the help of a single assistant, he finished his Sky Survey in five years.

In 1969 Zwicky published *Discovery, Invention, Research through the Morphological Approach*. It is a personal account of his life and work, explaining how his achievements in many different enterprises were based on a way of thinking that he called morphological. The morphological thinker discards all prejudices and all prior knowledge. Even highly reliable prior knowledge may be misleading. The thinker then makes a list of all possible explanations for a phenomenon and all possible inventions that might help gather information. Only after the list is complete is one of the explanations or courses of action chosen as most reasonable. Zwicky claimed that this way of thinking led him to many important discoveries that other scientists missed. He saw his decision to do a Sky Survey with the Schmidt telescope as a result of morphological thinking. It set the pattern for all the bigger Sky Surveys that have been the main business of astronomy ever since. In his book, he proudly described what he had done:

The Schmidt telescope on Palomar Mountain, whose construction I promoted in 1935 for the specific task of supernovae, which I suspected to be the most giant eruptions of energy in the universe that could actually be discovered and observed in action from their start…. Twenty of the very elusive supernovae were discovered by my assistant…and myself in the period from 1936 until 1941…. For the construction of the 18-inch Schmidt telescope, its housing, a full-size objective prism, a small remuneration for my assistant, and the operational costs for the whole project during ten years, only about fifty thousand dollars were expended. This probably represents the highest efficiency, as measured in results achieved per dollar invested, of any telescope presently in use, (and perhaps of any ever built, with the exception of Galilei's little refractor).

Another outcome of morphological thinking was Zwicky's discovery of dark matter in 1933 through careful analysis of observations of a large cluster of galaxies. He found that the galaxies in the cluster are moving at such high velocities that they cannot be held together by the gravitational attraction of all the visible mass in the cluster. To keep the cluster from flying apart, there must be about four hundred times more mass present in it than we can see in the galaxies. Eighty years later, the evidence for dark matter has been abundantly confirmed, but its nature and origin are still unexplained. Dark matter is another major mystery in a universe that we are just beginning to explore.

Zwicky applied morphological thinking to all aspects of his life, not only to astronomy. Besides his career as an astronomer, he had three other careers in which he was an outstanding leader: as a military engineer building weapons, as a pioneer explorer of space using rockets, and as a rebuilder of libraries in many countries to repair the destruction caused by World War II. He played a major part in the organization of two large institutions, the Aerojet Corporation for developing and producing weapons and the Jet Propulsion Laboratory for exploring space. Zwicky felt a moral obligation to use his gifts as a scientist to lead efforts to solve important problems of all kinds. He saw clearly in the 1930s that the most urgent problem was to organize an effective military defense of free societies against Hitler and Stalin. That was why he became a designer of weapons and a leader of military engineering projects.

It was important to Zwicky's military thinking that he was intensely Swiss. He was a citizen of Canton Glarus, in the medieval heartland of Switzerland. Canton Glarus is a small and rugged mountain valley that won its independence in a famous battle in 1352, defeating the Austrian Empire and joining the Swiss confederation. For six hundred years the canton has practiced direct democracy, with all male citizens voting as legislators in a public assembly. The traditional culture of Switzerland rests on two basic principles. First, every male citizen is a soldier, trained and equipped to defend his homeland against invaders. Second, a Swiss citizen remains a citizen for life, even if other citizenships are acquired. These two principles made it natural for Zwicky to promote military defense in several countries. Morphological thinking and Swiss thinking fit well together, encouraging him to walk freely across national as well as professional boundaries.

In 1940, when Hitler's armies defeated France and his air force was attacking Britain, Zwicky decided it was time for him to act. He went to Britain to talk with leading scientists about weapons and found two well-placed physicists who were willing to listen, Patrick Blackett and Frederick Lindemann. Blackett had been a navy officer in World War I and was highly respected in professional military circles. Lindemann was a friend of Winston Churchill and became his scientific adviser when Churchill became prime minister.

Zwicky discussed with them various inventions that might help Britain defeat Hitler. His favorite was long aerial mines (LAMs), based on the idea that mines could destroy aircraft in the air as effectively as they destroy ships at sea, if they could be given a vertical reach extending over a few miles. A LAM was a long vertical wire with an explosive package hanging at the bottom and a helicopter or a parachute or a balloon supporting it at the top. If an aircraft flew into the wire, the wire would cut a groove in the leading edge of a wing, then slide upward in the groove until the explosive hit the underside of the wing and detonated. The 1940 Battle of Britain was a fight between two air forces for command of the air over southeast England. Zwicky imagined that it could be won by the British with LAMs deployed in large numbers over the southeast coast so that German aircraft could not penetrate British airspace.

Blackett rejected the LAM as an impractical solution to the problem of air defense. German aircraft flying low over the English Channel could cross the coastline in far less time than it would take to put a barrier of LAMs in place. The LAMs would need to be constantly replaced, which would be slow and complicated. And it was easy to imagine simple countermeasures that the Germans could attach to the wings of their aircraft to make LAMs ineffective. Blackett thanked Zwicky for his advice and sent him back to America.

Unexpectedly, LAMs emerged later in Britain as a serious concern. It turned out that Zwicky had convinced Lindemann that they might be a decisive weapon, and Lindemann had convinced Churchill. Churchill insisted that considerable efforts be expended on testing and deploying them. In spite of his demands, no LAMs were ever operationally tested. Zwicky's first venture into war-fighting was a lamentable failure. He never imagined the two inventions that gave Britain, and later the United States, military advantages against Hitler: microwave radar and computer-aided code-breaking.

Zwicky tried again in 1940 to be helpful to the defenders of freedom, this time in his native Switzerland. He volunteered his services to the Swiss government as a military adviser, suggesting a scheme for deploying Swiss fighter aircraft on mobile runways floating on mountain lakes, where they would be difficult for German aircraft to find. Even if the Germans had air superiority over most of Switzerland, Swiss aircraft could survive and protect troops in the mountains. The Swiss authorities politely informed him that they did not need his services. Without his help, they successfully kept Hitler out of Switzerland. Swiss cities were bombed accidentally from time to time by British and American aircraft, less frequently by Germans.

Zwicky's career as a rebuilder of war-damaged libraries began in 1941, when he decided that the problem of reestablishing a peaceful world after the war was as important as the problem of defeating Hitler. He used the morphological method to identify the most effective way for him to contribute to the postwar restoration of international friendship and decided that scientific journals were the best tool for this purpose. In one day in 1941 he collected eighty-three volumes of the *Astrophysical Journal* that had been discarded as surplus by various institutions in California.

At first, he worked single-handedly, collecting and packing volumes into boxes for future shipment to damaged libraries, but he was quickly overwhelmed by the quantity of journals. He then established the Committee for Aid to War-Stricken Scientific Libraries and used his formidable talent as a fund-raiser to pay for the packing and shipping. When the war ended, the committee was ready to start shipping boxes of journals to France, Germany, Korea, Japan, Taiwan, the Philippines, Nigeria, and other countries where war had destroyed buildings and interrupted communications. It continued for ten years to collect and distribute journals on an enormous scale, with a total value of about $1 million at 1950 prices. The committee remained active until 1957, when Zwicky disbanded it to devote the next ten years of his life to astronomy.

Meanwhile, he had been working with Aerojet Gen to develop and produce rockets for the American military. He was not giving strategic advice but doing experiments with rockets and jet engines. In 1943 the company established a research department with Zwicky as director. In an amazingly short time he was supplying the US Navy with large numbers of jet-assisted take-off (JATO) engines. The JATO engine was a quick-burning high-thrust rocket. A pair of them attached to the sides of an aircraft could push it into flight from a short runway on the deck of a small aircraft carrier. They made it possible for small US carriers to destroy larger Japanese carriers. Zwicky's leadership as a scientist and as a manager produced an abundant supply of JATO engines that helped to cripple the Japanese navy in 1945.

Zwicky was aware of the German rocket program that bombarded London with a substantial number of V2 rockets in 1944. He knew that the Germans' rocket technology was in many ways ahead of that of the Americans, and he considered it important to ensure that the German rocket experts fell into American, not Soviet, hands. Following his usual custom, he took personal charge of things and a few days before the war ended arrived in Germany, where he found

Wernher von Braun, the leader of the rocket program. He quickly established friendly relations with him, discussing opportunities for von Braun and his team to continue their work in America and smoothing the way for them to find homes and jobs in Alabama rather than in Siberia.

After the war ended, the Aerojet company grew rapidly, moving from JATO engines to long-range missiles and spacecraft of many kinds. Zwicky continued to direct the research department, receiving clearance to work on top-secret air force and navy projects while refusing to become an American citizen. In 1949 he was the first noncitizen to be awarded the Presidential Medal of Freedom, the highest civilian honor of the United States. The citation said that he received it for many services to the US military, but mainly because he "contributed immeasurably to Air Technical Intelligence." This phrase does not spell out what Zwicky did. It is easy to guess that he was teaching the US Air Force how to fly high over Soviet territory using U2 airplanes equipped with cameras of advanced design. His unique skill as an astronomical photographer was precisely what was needed to give spy planes high optical performance with a wide field of view.

Zwicky was as zealous in his opposition to Stalin as he had been to Hitler. He had been an enemy of Communism long before Stalin took power in Russia. During World War I, Zwicky was a student in Zurich while Lenin was living nearby. While waiting for his chance to start a revolution in Russia, Lenin tried to arouse revolutionary activities among the workers of Zurich, organizing gangs of young hooligans to engage in brawls with the Zurich police. Zwicky was alarmed and disgusted by his firsthand observation of Lenin's tactics. He left school for a while to organize a federation of Swiss workers and employers to promote reform without revolution. Thirty years later, he was a veteran cold war warrior, eager to beat Stalin in the skies over Russia.

All through his life, Zwicky loved to engage in public disputes with his colleagues, to prove them wrong and also to insult them personally. He arrived at Caltech at the same time as two other young men who made brilliant careers in later life, the German astronomer Walter Baade and the American physicist Robert Oppenheimer. He made enemies of both of them, by calling Baade a Nazi and Oppenheimer a Communist. He took special delight in attacking famous people in high positions that he considered undeserved. He was friendly to students and children, hostile to journal editors and senior professors. His colleagues, having no wish to fight with him, found it best to ignore him.

Johnson shows us a vivid picture of Zwicky at a dinner party in 1942:

Zwicky loved talking about Morphology. He launched into a detailed description of how he approached every problem. Morphology was not just a way of thinking, he said, it was "a way of life…attempting to realize the genius of each individual and each race." The prime directive, as he put it, was "to generalize all problems before drawing fallacious conclusions." In practice, this meant keeping one's mind open to all possible solutions, no matter how seemingly impractical…. He believed that "if the earth and humanity are going to survive at all, the next cultural style will be that of the age of morphology."

After he reached the age of sixty, Zwicky became increasingly isolated. In 1955, in spite of his Medal of Freedom, he had lost his military clearances. Intimidated by Senator Joseph McCarthy and other demagogues in Congress, the Air Force demanded that Zwicky become a US citizen if he wanted to continue to work on Air Technical Intelligence. He resolutely refused. He would always remain Swiss, and so his military career ended. In 1962, for the same reason, he was forced to resign from his job at the Aerojet Corporation.

For the next few years he worked full-time as an astronomer. As a Caltech professor he had his share of observing time on the two big telescopes, the 100-inch on Mount Wilson and the 200-inch on Mount Palomar. He discovered a total of 123 supernovae, a large enough number for him to identify several different types with different patterns of behavior. He completed his monumental six-volume catalog of galaxies and clusters of galaxies, summarizing the results of the Sky Survey done twenty years earlier with the little Schmidt telescope. In 1966 he retired as a Caltech professor and lost his access to all the telescopes. Finally, in 1968 he was banished from his office and given a meager space in the subbasement of the Caltech physics building. At the age of seventy, all his careers were over, and his achievements were largely forgotten.

But Zwicky's final years were not gloomy. He married twice, and his second marriage was to a much younger woman who bore him three daughters. Margrit Zürcher was also from Canton Glarus and knew how to handle his stormy temperament. He doted on his wife and daughters and settled into a harmonious family life. In the last year of his life he paid for a stylish wedding in Switzerland for his middle daughter and presided at the ceremony, where he preached a sermon full of fatherly advice, urging her to use morphological methods to deal with the problems of matrimony.

Zwicky's success as a morphological thinker gave rise to an often-repeated joke that the morphological method is an infallible way to make correct decisions, with one defect: it only works if your name happens to be Zwicky. The joke is usually true, but not always. Theodore Taylor was another scientist who used the morphological method. Taylor was an undergraduate at Caltech who became a personal friend of Zwicky and learned the method directly from him. After World War II ended, Taylor was at the Los Alamos laboratory designing nuclear weapons—a job well matched to morphological thinking. Taylor imagined all possible arrangements of nuclear materials and picked out those that were best suited to particular military missions. He quickly became the leading developer of small weapons at Los Alamos, changing the main thrust of the laboratory from megaton monsters to kiloton devices that became tactical weapons. Morphological thinking gave us tactical nukes.

After a few years at Los Alamos, Taylor turned his morphological thinking to the design of spacecraft. He looked without prejudice at the whole range of possible spacecraft and chose the design best suited to the task of exploring the entire solar system at an acceptable cost. It would use small nuclear bombs in large quantities to propel spacecraft with thousand-ton payloads to high velocities, enabling them to reach Mars in a few months and Saturn in a few years. He gave the name Project Orion to his plan and organized it as a private venture funded in part by the US Air Force at the General Atomics company in California. Besides being a spectacularly thunderous way to travel to the planets, Project Orion would have given Taylor an opportunity to put his bombs to better use than killing people. The project ended after the 1963 Partial Test Ban Treaty made nuclear explosions in space illegal. The memory of the project remains, like Zwicky's Long Aerial Mines, as a demonstration of the power and the limitations of morphological thinking.