ENGINEERING.—*The influence of space flight on engineering and science.*[1] MILTON W. ROSEN, Naval Research Laboratory. (Communicated by C. H. Page.)

Within the past few years many scientists have predicted seriously and confidently that human beings from the earth would, in the foreseeable future, travel to the moon and the nearer planets. The ranks of those who would dispute this prospect are diminishing rapidly. Although much of the progress is still guarded by military necessity, space flight is emerging as an activity in its own right—one that can command the efforts of many engineers and scientists.

In the United States the exploration of the upper atmosphere, the frontier to space, is a vigorous and continuing activity. Pilots of rocket aircraft have experienced conditions approximating those in free space, if only for a few minutes. The effect of space flight upon the human organism is being investigated—the U. S. Air Force maintains a Department of Space Medicine.

There is an international organization devoted to the promotion of space travel and there are space flight societies in 23 countries. Numerous journals exist wholly or in part for the publication of papers on astronautics and its allied fields—notable among these for the quality of its articles is the Journal of the British Interplanetary Society.

I shall try here to explain how the present state of affairs came about and also to forecast what might be the future influence of man's effort to travel in outer space.

The ancients, except for a few rare individuals with greater insight, conceived of the world as an enclosure; they stood upon the earth at the bottom and gazed upward at a blue ceiling upon which a multitude of lights, a few great and many small, seemed to move under the influence of an unseen hand. The atmosphere filled this enclosure and it was believed that if man had wings he could fly to the ceiling and determine the source of the lights. If a few philosophers guessed more nearly at the truth, certainly the average man had no better conception of the universe than the fanciful picture just described. There could be no valid idea of space flight until Copernicus, Kepler, and Galileo placed the earth in its true relation to the universe and at the same time gave dimensions to space.

When at last the moon and the planets were found to be material bodies not unlike our earth, it was possible to ponder whether the immense separating distances could be traversed by man or any man-made device. The situation was made even more discouraging when, in 1686, Newton (*1*) defined the nature and the magnitude of gravitational attraction. If previously there had been some fanciful hope of visiting celestial bodies, now surely it appeared that man was destined to remain forever a prisoner of his own planet. In view of the great distances, it seemed unlikely that the atmosphere could extend through interplanetary space, and any suspicion that it might was laid to rest when Torricelli's barometer was carried to a mountaintop and taken aloft by the early balloonists.

Although Newton brought man face-to-face with one formidable aspect of the problem, namely gravity, he also provided, in his three laws of motion, the key that would unlock the door to space. The fundamental equation of rocket action in free space and hence of space flight:

$$V_b = C \cdot \log_e \frac{M_o}{M_b}$$

where V = velocity of rocket at end of burning
C = velocity of exhaust jet
M_o = initial mass of rocket
M_b = mass of rocket at end of burning

is derived by integrating Newton's third law of motion. Nevertheless, more than two centuries would pass before anyone performed the integration or realized that the simplest embodiment of Newton's third law, a rocket, is the only machine capable of propelling itself in a vacuum.

While science gave no solution, and, indeed, many scientists despaired of finding one, the dream of travel to celestial bodies

[1] A lecture delivered before the Washington Society of Engineers, November 16, 1955.

was kept alive in fiction. One of the earlier references to rockets for propelling a space ship is found in the writings of Cyrano de Bergerac (*2*), but it is doubtful that Cyrano understood the rocket's essential role. Perhaps the most famous novel about space travel is Jules Verne's *From the Earth to the Moon* (3). Although Verne had expert scientific advice, he chose an impossible means of projecting his space ship—it was fired from a long cannon sunk in the ground. Probably Verne knew that no human could survive the acceleration of his projectile and that the projectile itself would disintegrate under the tremendous forces imparted to it. Yet, millions of readers believed his story; many thought it had actually been accomplished—so great was his art—and he created a myth that had to be destroyed before any scientific progress could be achieved. In his novel *The first men in the moon* H. G. Wells (*4*) felt no necessity for scientific rigor, and he conjured up a gravity-defying substance which he called "cavorite."

By the beginning of the twentieth century the physical sciences had advanced to the point where it was inevitable that someone would develop a valid theory of rocket action and would apply the theory to the problem of escape from the earth. The task was accomplished by three men working independently in three different countries. The three had much in common—they were teachers, one at a small university, the other two in secondary schools.[2] Each one pondered the problem for many years before committing his findings to publication. But what is most important, all three were motivated by the desire to explore interplanetary space and presented their findings with conviction, even though they were regarded by most of their contemporaries as prophetic dreamers. The men and their works are now well known. They are:

Ziolkovsky—*The exploration of cosmic space by reaction machines*, 1903.

Goddard—*A method of reaching extreme altitudes*, 1919.

Oberth—*The rocket into interplanetary space*, 1923.

[2] One, Oberth, became a teacher after his fundamental work had been completed.

Any one of these three publications, had it been widely read and accepted, would have sufficed to lay the groundwork for space travel, because each man clearly understood and asserted the following fundamental concepts:

1. That escape from the earth is possible by the application of a moderate acceleration over a substantial period of time—at least several minutes.
2. That such acceleration can be produced in a vacuum by a rocket.
3. That the rocket must (a) have high thermal efficiency (i.e., high velocity of the ejected matter) and (b) consist mainly of propellant material (i.e. have a high ratio of fuel weight to total weight).
4. That high thermal efficiency would be obtained most readily from the chemical combustion of liquid fuels.

Ziolkovsky (*5*) started by examining Jules Verne's cannon and also the balloon as a means of reaching very high altitudes. Both approaches died quickly under mathematical analysis. He proceeded next to the rocket and developed the fundamental equation previously noted. Realizing that energetic fuels were required, he determined from thermochemical calculations the heat release of various liquid combinations. When he computed the velocity that could be attained, in theory at least, he realized it was sufficient for escape from the earth.

Goddard (*6*), alone of the three, proceeded from experiment to theory. Using smokeless powder in a heavy-walled steel combustion chamber he produced a jet velocity of almost 8,000 feet per second, a sevenfold improvement over ordinary rockets and the highest velocity of matter attained up to that time outside of electrical discharge tubes. Also, he proved by tests in a vacuum that a rocket does not produce its force by pushing on the air behind it, a fact he knew from basic physics, but that he felt had to be demonstrated. He observed correctly that the jet velocity was greater in a vacuum, but he attributed it erroneously to more efficient ignition. Although Goddard did not turn to liquid fuels until after his basic paper was published, he achieved the first flight of a liquid rocket, an event that took place on March 16

1926. Goddard (*7*) continued his experiments for more than two decades during which time he developed, in rudimentary form, almost every component of modern rocketry. Not one of his components would be considered reliable by present-day standards; realizing the prodigious task he had set out to accomplish, he would repeatedly add a new component before perfecting the previous one. In retrospect, it appears that Goddard was attempting, single-handed, to encompass the entire field of liquid-rocket development, a task that would eventually tax the abilities of thousands of engineers and scientists.

Oberth (*8*), in his treatise, gave the most complete theoretical analysis and carried it farther into the realm of space travel than either of the others. He stated at the outset the four propositions he would attempt to prove:

1. Considering the present state of science and technology, it is possible to build machines that could rise beyond the atmosphere.
2. After further development these machines will be able to attain such velocities that, left undisturbed in the depths of outer space, they will not fall back to the earth and will even be able to leave the zone of terrestrial attraction.
3. These machines could be constructed so as to transport human beings, probably without damage to their health.
4. Under certain economic conditions the construction of such machines might be profitable.

Oberth began by developing the theory of the liquid-rocket and describing its construction. He proceeded to discuss applications of the rocket, first as a high-altitude sounding vehicle, then as an earth satellite, and finally as a space-ship for interplanetary travel. He developed the concept of synergic (minimum energy) ascent trajectories. Without doubt, almost every later book on space flight owes much to Oberth's encompassing study.

Whereas the first quarter of this century provided the theoretical background for space flight, the second 25 years may be viewed as the period of experimental preparation. It saw the liquid-fueled rocket develop as a practical engine for the propulsion of aircraft and guided missiles. Many fuels and oxidizers were explored—a few saw widespread use. An assortment of auxiliary hardware—pumps, turbines, valves, and regulators—was developed to feed and control the rocket motor. The steering of a large rocket vehicle was mastered by means of gyroscopes and jet controls. Great progress was made in the aerodynamics of supersonic flight, in structural design, and in the use of high temperature materials.

Of the early experimenters three groups were most noteworthy. The work of Goddard as an individual has been referred to previously. In Germany the Verein für Raumschiffahrt, fired by Oberth's monumental work, undertook to develop a small workable rocket called, appropriately, minimum-rakete (Mirak—for short) (*9*). In the course of several years they made hundreds of static firings and numerous brief flights. The American Interplanetary Society drew its inspiration largely from abroad, so secretive was Goddard about his experiments. Indeed, when in May 1933, the Society finally achieved a first liquid-rocket flight, they were unaware that Goddard had progressed far beyond his first flight seven years before. It is unfortunate that the British Interplanetary Society was prevented from experimenting with rockets, a situation frequently lamented by its founder, Philip Cleator (*10*).

The V-2, whose development started in the middle of this period, was the largest single engineering advance in the field of rocketry. By applying thousands of engineers and scientists in a concerted effort, the German government was able in six years to transform the liquid-fueled rocket from a small, sputtering vehicle, capable of ascending a few hundred feet, into a giant projectile with a range of 200 miles and a velocity of one mile per second. The V-2 was a material embodiment of Oberth's ideas and, although he conceived the liquid rocket as a vehicle for space travel, he also foresaw its possible use as a bombardment weapon. Actually, he hoped that the rocket missile would be a deterrent to rather than a tool of war.

After the war the major activity leading to space flight took place in the United States in the form of upper-air research with instruments carried in rockets. In a continuing program, scientists from government laboratories and universities explored the upper atmosphere using at first captured V-2 rockets and later, as they became available, Aerobees and Vikings. Both Viking and Aerobee were designed specifically for probing the atmosphere in the region between 50 and 150 miles above the earth. A few of the more important accomplishments of this program are noted. Knowledge of the pressure, temperature, density, and ionic content of the atmosphere has been extended up to 135 miles by direct measurements. The solar spectrum has been recorded in the far ultraviolet. X-rays have been detected in solar radiation and their role in the formation of the ionosphere has been postulated. The number and the mass distribution of primary cosmic rays have been recorded in emulsions carried aloft in rockets. Small animals, monkeys and mice, were sent aloft and their physiological reactions observed during a period of weightlessness. For nine years man had been exploring the frontier of space as a prelude to flight beyond the atmosphere.

It is always tempting to draw parallels and it might appear, at first glance, that the advance toward space flight parallels the progress of aviation, with the latter preceding in time. The same elements of progress are evident in both fields, but one can not fail to note the differences and contrasts.

Although much theoretical work had been done on fluid mechanics and experiments performed in wind tunnels and with gliders, there was at the time of the first mechanical flight no adequate theory to explain the lift of a winged vehicle (*11*). We knew that the Wright brothers' plane flew, but we could not explain why or how it flew. By contrast, the motion of a rocket, as we have seen before, was well understood before Goddard's first flight attempt. This is no paradox—it is apparent that the mathematical treatment of flight within the atmosphere is much more difficult than the analysis of flight in free space.

In both fields there was a period when development was nourished mainly by amateurs; in aviation it was the first decade of this century, for rocketry the late twenties and early thirties. In both cases the advance was given great impetus by a war; the first World War for aviation, the second for rocketry. But I doubt if there is in the history of aviation any single step forward comparable in magnitude to the creation of the V-2. Aviation has been characterized by gradual, steady development, fostered to a large extent by its economic returns as well as its military advantages. There have been several significant milestones; one of the most noteworthy was the development by Major Whittle and others of the turbojet engine, which in the short space of a dozen years has completely displaced the piston-driven propeller in high speed military aircraft and may soon dominate the field of commercial aviation.

In pursuing this rather loose parallelism I have tried to estimate what period in the history of aviation corresponds to the present status of space flight. It seems to me that we are now at a point roughly corresponding to the period before Lindbergh's historic flight across the Atlantic. The significant event we are awaiting is the first orbital flight of a manned earth satellite.

In both cases, at the time being considered, the vehicle had been developed to a reasonable degree of reliability and many flights of shorter range and duration had been made. But again, there is a significant difference. Aviation has always implied manned flight—in rocketry most of the progress thus far has been made in unmanned, automatically-controlled vehicles. Our technology has advanced to the point where we need not risk human life in experimental rocket-flights—on the road to space, instruments will always go first and will point the way for men to follow.

Prior to establishing the first manned satellite two important techniques will have to be mastered. First, there will be a period of experimentation with unmanned, instrumented satellites during which time problems of propulsion, staging, and navigational control will be worked out. The environmental hazards—cosmic radiation, meteors, solar heat (and the absence of it), and possibly weightlessness—can be evaluated.

Worldwide realization that this first problem is being attacked vigorously came when, on July 29, 1955, President Eisenhower announced that the United States would launch small instrumented satellites during the International Geophysical Year (1957–1958). By their statements in support of the President's announcement, many noted scientists attested to the feasibility and usefulness of the instrumented satellite. It is significant, also, that the United States invited international cooperation and offered to make its scientific findings available to all nations.

The second problem is the one of safe return to the earth's surface. The relative speed of roughly five miles per second between the orbiting vehicle and the earth's surface must be brought to zero. Obviously, this will be done by allowing the satellite to transfer its energy to the atmosphere. But this process must be controlled with great precision, lest the satellite absorb too much of the energy in the form of heat. Much will be learned by observing the return of instrumented satellites, but the final preparatory steps will probably involve manned flights at gradually increasing re-entry speeds.

I have placed Lindbergh's flight and the first manned satellite in juxtaposition because one has and the other will, I believe, so excite the world's imagination that future progress will be greatly accelerated. One can not say when the desired event will take place—much hard work remains to be done—but it is not uncommon for scientific achievements to precede their predicted arrival. The mechanical components, engines of sufficient power and controls of requisite precision, are within sight. If it is argued that the human hazards are great and, at present, poorly understood, let it be remembered that the first orbital flight need only be brief—a matter of several hours. In this respect the ordeal may be less prolonged than Lindbergh's flight, but certainly no less demanding upon the pilot's judgment and courage.

We have seen that although space flight is yet to be achieved, its prospect has had, in the last fifty years, an appreciable influence upon science. The greater influence by far lies in the future. The advances in our technology necessary to achieve manned flight in space and those required to exploit it can be readily delineated. But a more important result will, I believe, be the impact of space flight upon scientific thought and education.

In America today we are faced with a serious shortage of engineers and scientists even though the demand is great and the remuneration is ample. Almost every prospective technical graduate of our universities is showered with offers of employment and our newspapers and magazines are filled with advertisements for men with technical training. The most appalling aspect of this situation is that it is likely to continue for many years. A recent survey shows that the study of physics in our public high schools has been declining for more than half a century. Whereas in 1895 more than 95 percent of high-school graduates had taken a course in physics, by 1952 only 21 percent of graduates had ever studied it (*12*). For many years the increase in high-school enrollment more than offset the decrease of specialization in physics, but now the waning interest is taking its toll. Today only about half of the public schools offer a course in physics, and a quarter of these have no laboratory facilities. There is a critical shortage of science teachers, due in part to the attractions of industry, but more so to the lower status and wages accorded the teaching profession. But these factors can be remedied with sufficient effort—a deeper and more serious cause is the lack of interest on the part of our youth. Why do they turn away from a career in science? We can only grope for the answer. Perhaps they sense, better than their elders, that too much of our scientific talent is engaged in the unproductive task of developing weapons for war. Is there much inspiration to devote one's life to this end, especially when we are rapidly approaching the borderline of total destruction?

I believe that space flight might serve in no small measure to turn men's minds toward a more appealing scientific goal. As the exploits of Cabot, Drake, and Davis inspired many generations of Englishmen to turn to the sea, so may the first astronauts reawaken our youth to the romance of scientific exploration.

REFERENCES

(1) Newton, Issac. *Philosophiae naturalis principia mathematica.* 1687.
(2) Cyrano de Bergerac. *Voyage dans la lune.* 1649.
(3) Verne, Jules. *De la terre à la lune.* 1865.
(4) Wells, H. G. *The first men in the moon.* 1901.
(5) Ziolkovsky, K. E. *Collected Works.* 1933.
(6) Goddard, R. H. *A Method of Reaching Extreme Altitudes.* Smithsonian Miscellaneous Collections. 1919.
(7) Goddard, R. H. *Rocket development.* New York, 1948.
(8) Oberth, H. *Wege zür Ramuschiffahrt.* 1929.
(9) Ley, W. *Rockets, missiles, and space travel.* New York, 1951.
(10) Cleator, P. E. *Into space.* London, 1953.
(11) von Kármán, T. *Aerodynamics.* Cornell University, 1954.
(12) Kelly, W. C. *Physics in the public high schools.* Physics Today, March 1955.

NATIONAL ACADEMY MEDAL AWARDED TO DR. WATTS

The James Craig Watson Medal of the National Academy of Sciences has been awarded to Dr. Chester B. Watts (WAS), of the United States Naval Observatory, in recognition of his outstanding contributions to astronomical research. The Medal will be presented to Dr. Watts during the Annual Meeting of the Academy to be held in Washington, April 23–25, 1956.

Dr. Watts, who is director of the Six-Inch Transit Circle Division of the Naval Observatory, has been engaged during the greater part of his 45 years at the Observatory in determining positions of the sun, moon, planets, and stars. Such measurements provide the basic data for the study of the motions of celestial bodies both within the outside the solar system. Since 1934 Dr. Watts has been chiefly responsible for the Six-Inch Transit Circle. With a judicious combination of mechanical, optical, photographic and electronic techniques, he has brought the instrument to a higher state of perfection than any other of its kind. He recently designed and supervised the construction of a new Nine-Inch Transit Circle at the Observatory. In spite of his skill in perfecting his instruments, Dr. Watts remained dissatisfied with the precision of his measurements, which are based on observations of the edge of the moon's disk. The edge that we see is always irregular because of the high mountains and low valleys on the moon's surface. Also, a slightly different aspect of the edge of the moon is seen from time to time. These factors have limited the precision with which measurements could be made. About 11 years ago, Dr. Watts undertook to survey that part of the moon's surface (comprising some 18 percent) that presents itself on the edge of the moon, and to make this survey of a surface some quarter of a million miles away accurate to within about 50 feet. His survey is now virtually complete. The work required some thousands photographs of the moon, the invention and construction of an automatic photoelectric machine for tracing the profile of each photograph and drawing it on a strip of paper 30 feet long, the design and construction of analogue computers for analyzing the profiles and translating them into numerical form, the devising of means for integrating the profiles into a representation of the surface of the moon in the vicinity of the edge, and finally the development of the most readily usable form for publication of the results. The completed work will be published shortly.

The Watson Medal was established in 1874 by the bequest of James Craig Watson, a member of the Academy and Director of the Washburn Observatory of the University of Wisconsin. He provided in his will that the medal should be awarded "to any person in any country who shall make any astronomical discovery or produce any astronomical work worthy of special reward as contributing to our science."

Is there any thing whereof it may be said, See, this is new? it hath been already of old time, which was before us.—Ecclesiastes i:10