1. *"Where the action is"*

Some years ago, a *New Yorker* cartoonist made a profound and witty observation on the nature of life. He drew a primeval beach, lined with the giant ferns that have long since vanished from the earth. Crawling up out of the ocean was a clumsy, archaic fish — a coelacanth, or a close relative — while a few yards to the rear a companion lingered nervously in the deeper water. The intrepid adventurer, already half on dry land, was looking back at his anxious colleague. And he was saying, with a rather patronizing expression: "Because this is where the action is going to be, baby."

If such a prediction had really been made, half a billion years ago, it would have been remarkably accurate — but there would have been very little evidence to justify it. From the point of view of any fish, the land is a most unpleasant, hostile place. One would have to be crazy to explore it — and as for *living* there . . . !

Look at the disadvantages. In the sea, there is no such thing as weight; a hundred-foot whale floats as effortlessly as a one-inch jellyfish. On land, the relentless pull of gravity drags all creatures downwards from birth to death. Even when it fails to kill them outright, as it frequently does, it often cripples them through the physical defects it induces in bone and muscle.

The sea is also a far more benign environment than the land. It has none of the violent temperature extremes — ranging over more than two hundred and fifty degrees Fahrenheit — which occur between the tropics and the poles. There is no fierce source of ultraviolet radiation overhead, which can burn and even kill an unprotected organism. And apart from rare submarine earthquakes, it is always calm; only the uppermost skin of the sea is ever disturbed by storms.

Yet despite this, life came out of the sea — its ancient birthplace — and conquered the alien land. In so doing, it opened up whole new possibilities of existence which we now take for granted, but which would not have been at all obvious even to a fish of human intelligence — could one imagine such a thing — back in the Cambrian period.

Because it has many parallels with our present situation, it is worth pursuing this fantasy a little further. A genius-type coelacanth, peering up through the wavering surface of the water at the dimly seen world of trees, mountains, clouds, volcanoes, thunderstorms, could have made a good case for exploring this strange environment in the cause of science. He could have confidently, and correctly, pointed out that a wealth of new knowledge would come from such an investigation. He might have argued "How can we possibly understand our universe while we are restricted to one small portion of it?" And, slightly anticipating Marshall McLuhan, he might even have realized that he could not hope to study water — until he had left it behind him.

But not even the most brilliant and farsighted of fish could have imagined the ultimate consequences of the exploration — and colonization — of the land. He could not have anticipated the rise of new life forms, with much superior senses and greatly improved ability to manipulate the environment. Long-range vision, and the dexterity of human fingers, could never have evolved in the sea. Nor, in fact, could higher intelligence itself — simply because the benevolent sea does not provide the same challenges as the fierce and inhospitable continents. (Today's intelligent marine animals, the whales and dolphins, are of course all dropouts from the land.)

But, above all, our Paleozoic Leonardo could never have imagined the new technologies which would be discovered and exploited once life had escaped from the all-embracing sea. In particular, the very existence, and the infinite uses, of fire would have been utterly beyond his comprehension. The taming and control of fire is the essential breakthrough which leads to the working of metals, to prime movers, to electricity — to everything, in fact, upon which civilization depends. Though an underwater culture is not inconceivable, it would be forever trapped in the Stone Age.

There is no need to pursue the analogy further; the lesson is obvious. When we escape from the ocean of air, we will be moving out into a whole universe of new sensations, experiences, technologies — only a few of which we can foresee today. Zero gravity research, industry and medicine, which will be discussed in detail in section 4 of this chapter, open up such immense vistas that our descendants will find it impossible to believe that we ever managed without them. Yet the greatest boons from space, it is fairly certain, will come from discoveries still undreamed-of today. Waiting for us beyond the atmosphere are the equivalents, and perhaps the successors, of fire itself.

Prometheus stole the sacred flame from heaven and brought it down to earth as a gift to the human race; and on a pillar of flame man is now riding back into the abode of the gods. What other divine powers still remain there for us to discover — and to exploit?

When we regard space exploration from this point of view, we can see at once the ludicrous shortsightedness of those who have regarded it merely as a competition between two ephemeral political entities of the late second millennium. It is true that the "Space Race" was a fact of life in the 1960's, but the rivalry between Spain and Portugal was about as important — and as transient — in an earlier age of exploration.

There are some who may agree with these long-range historical, and evolutionary, implications of space travel, but would argue that they are so far in the future that they do not concern practical politics — that has to deal with the down-to-earth problems of transportation, housing, education, medical care, poverty, and so forth. Until these matters are settled, they ask, have we any right to throw billions of dollars into space?

There are so many answers to this question that it is difficult to know where to begin. At the most elementary level, it may be necessary to point out to some of the more naïve critics that the twenty-four billion dollars devoted to the space program was not spent on a kind of astronomical foreign aid program. It was all fed back into American industry, where it generated skills, hardware and technologies which in the long run will be worth far more than they cost — though it may be impossible to prove this beyond question for some years, just as no one could prove in 1903 that the Wright brothers had not wasted their entire investment. Moreover, much of the vast payroll of the space program has been injected into the more backward areas of the United States. The chambers of commerce concerned may not care to advertise the fact, but it could be claimed with some justice that the Apollo project did more to drag certain states into the twentieth century than a great many programs of direct social improvement.

There is a superficial reasonableness about another very common criticism of space expenditure. If one *is* determined to spend $24,000,000,000 — surely it could be better used to build schools, hospitals, homes, roads — or to pay higher salaries to teachers, policemen and other underprivileged public servants?

Yet indirectly, as we have pointed out, it has helped to do just this. How much more efficient the process would have been had the amount been devoted *entirely* to this purpose could be argued endlessly — but the discussion would be a complete waste of breath, for it would have no connection with the realities of political life. It has often been remarked that money "saved" from one worthwhile project cannot be switched to another, but has to be voted all over again — which in fact seldom happens.

The "spaceships or schools" argument is a particularly unfortunate example of this fallacious reasoning. Indeed, the space program is one of the best things that ever happened to the United States educational system, both financially and psychologically. The shock of Sputnik — America's technological Pearl Harbor — focused attention on schools and colleges in a way that nothing else could possibly have done.

Until October 4, 1957, even Admiral Rickover was a voice crying in the wilderness; after that date, education became a number-one priority, and suddenly the money became available. The very requirements of the space program created an unprecedented demand for highly qualified men, and NASA was to become a major supporter of university research. Far from space robbing the schools and colleges, it contributed both directly and indirectly to their financial well-being. One can sympathize with those irate scholars who see millions being devoted to space research, when they cannot get modest grants for their own pet projects; but they should realize that cutting space expenditure is much more likely to *reduce* their chances than to increase them. Budget-slicing is a contagious disease.

Moreover, the inspirational value of the space program is probably of far greater importance to education than any input of dollars. No one who has lectured extensively to young people can have any doubts of this, though it may not be realized by those elderly academics who, as is well known, are careful to have little contact with students. But a whole generation is growing up which has been attracted to the hard disciplines of science and engineering by the romance of space. This body of trained men will, in the years to come, be one of the world's greatest assets, and no price can be put upon it. The starry-eyed youngster of today, watching TV broadcasts from the moon, will be the inventor, discoverer or technical administrator of tomorrow. And it is worth pointing out, even at some risk of invoking the horrid specter of the "two cultures," that he will be among the students least likely to set fire to the dean's office, exchange fisticuffs with the campus police, or generally go to pot. . . .

Individuals, as well as societies, need goals to inspire them; otherwise their existence becomes pointless, and the realization of that fact (whether consciously or unconsciously) results in those psychological and social ills with which we are all too familiar. And however much that mythical creature, the hardheaded, practical man-in-the-street may resent the fact, the most inspiring goals often have no obvious connection with the problems of everyday life.

The supreme physical achievement of the age of Pericles is the Parthenon; the foundations might still be unlaid, had Phidias been compelled to justify his construction program by the improvements that would eventually result in Athenian housing. It is quite possible that such a "spin-off" did occur — but what does it matter? For more than two thousand years, the marble columns standing on the Acropolis have been among the most precious treasures of mankind — though doubtless the hoi polloi would have preferred better drains.

A few days after the first landing on the moon, this point was excellently made by the London *Economist* — a very down-to-earth journal, not noted for imaginative flights of fancy. In its editorial for July 26, 1969, the *Economist* remarked:

> And as the excitement dies and familiarity sets in, the voices that say the money could be better spent on ending wars and poverty on earth must gain converts.
>
> But this argument overlooks the factor in human make-up that sets us apart from the apes. When man first became a tool-maker, he ceased to be a monkey. The human race's way of sublimating its highest aspirations has been to build the greatest and grandest artifact that the technology of the time can achieve. Through the pyramids, the parthenons and the temples, built as they were on blood and bones, to the be-spired cathedrals conceived and constructed in ages of great poverty, the line runs unbroken to the launch pad of Apollo 11. Oddly — or perhaps not so oddly — the churchmen with their unstinting praise of the astronauts have recognised this where the liberally educated rationalists with their bored carping, and their ill-bred little jokes, have not. Spiralling to the planets expresses something in human nature that relieving poverty, however noble a cause that is, does not. And to the planets, sooner rather than later, man is now certain to go.

Unlike the pyramids and the cathedrals, the exploration of space will have so many practical justifications that our descendants will think us mad that we ever doubted its value. But they will remember us, when all the creations of our hands have passed away — because we were the first men to set our sign among the stars, and our feet upon the moon.

2. *The Price of Space*

HOWEVER great the benefits — scientific, cultural, philosophical — manned space flight may bring, it is obvious that at its present enormous cost it can never be much more than a very rare and exceptional form of activity. At the current level of spending, the United States might be able to afford a landing on the moon every couple of months, and the USSR could probably do the same. Any attempt to establish permanent bases on the moon would demand a greatly increased level of expenditure — and a manned expedition to Mars would cost several times as much as a lunar mission. Even a prosperous and scientifically oriented world state might be hard pressed to manage more than one planetary flight a year.

But this assumes that space technology remains at its present primitive level — which is absurd, though it is an absurdity constantly committed by scientists and engineers who should know better. The very first decade of the space age showed spectacular improvements in cost effectiveness; these will continue (though perhaps not at the same rate) and as the price per pound of payload in orbit steadily falls, so space operations will become more complex, more ambitious — and more commonplace.

Some actual figures from the recent past will give us a better perspective by which to judge the future. On January 31, 1958, the United States placed its first payload (Explorer 1) into orbit; it weighed only thirty-one pounds, yet was rightly regarded as an outstanding achievement. At that time, no one would have dared to predict that *less than ten years later* (November 9, 1967) a rocket capable of orbiting 140 *tons* would make a flawless maiden flight from Cape Kennedy, and would carry men around the moon by Christmas of the following year. . . .

Even more important than this amazing 10,000-fold increase in payload, however, was the reduction in the price tag. In 1958, it cost half a million dollars to put one pound in orbit. Ten years later, the Saturn V could do it for five hundred dollars — a mere one thousandth of the initial rate.

Now, it would be stupid to extrapolate these figures and to predict that by 1978 we will be orbiting million-ton payloads at a bargain rate of fifty cents per pound. The law of diminishing returns has already set in, and future improvements will become progressively more difficult. But they *will* occur, just as they have done in every other form of transportation, once the initial, experimental stage has been passed. As they do, the cost of space travel will continue to decline. A decade ago it was preposterous; today it is merely exorbitant. In a few years it will be extravagant — by the end of the century, no more than expensive. And in the early 2000's, flight between earth and moon will be an ordinary commercial operation.

It is important to realize that we require no hypothetical inventions or breakthroughs — no science-fictional "spacewarps" or gravity screens — to bring this about. Existing knowledge, materials and fuels are adequate; what is still required is the experience, skill and engineering competence which only time and millions of man-hours can provide. Once again, the history of aviation gives us some instructive parallels.

The first heavier-than-air machines could barely stagger off the ground supporting a pilot and zero payload. Even this had been roundly declared impossible by authoritative critics, who when confronted with a fait accompli retreated a few steps and declaimed "Well, the airplane's of no practical importance — it can never carry a passenger as well as a pilot." Although this prediction was also rather swiftly refuted, for its first decade the airplane was considered of use only for sport and, just possibly, military reconnaissance. It took the First World War to prove that it could carry useful payloads — needless to say, bombs.

Through the 1920's, imaginative writers produced a spate of now mercifully forgotten stories about sky pirates, aerial explorations of the poles and darkest Africa, and romances of transatlantic flight. The experts, of course, continued to know better. Listen to the astronomer William H. Pickering (no relation to Jet Propulsion Laboratory's William H. Pickering): "The popular mind often pictures gigantic flying machines speeding across the Atlantic and carrying innumerable passengers in a way analogous to our modern steamships. . . . It seems safe to say that such ideas must be wholly visionary, and even if a machine could get across with one or two passengers the expense would be prohibitive to any but the capitalist who could own his own yacht."

Well, there are not too many yacht-owning capitalists among the thousands who are in the air over the Atlantic at this very moment; in this case the "popular mind" (one can almost hear the professorial sneer) was completely right, and the authority was wholly wrong. In the case of "negative predictions," this is quite a common phenomenon. The experts can spot all the difficulties, and lack the imagination or vision to see how they may be overcome. The layman's ignorant optimism turns out, in the long run — and often in the short one — to be nearer the truth.

When we look from the first airplane — the 1903 Wright Flyer — to the last of the propeller-driven airliners, such as the DC-6 just fifty years later, we see a perfectly uniform line of development without any jumps or discontinuities. All the major components of the DC-6 existed in embryo in the Flyer — engine, propeller, airfoils, fuel. The fantastic improvement in performance, which changed aviation from a dangerous sport to one of the world's greatest industries, was the result of countless steady but undramatic advances. Their cumulative effect, during half a century of research and development, transformed the airplane from little more than a toy to a dominant factor in global transportation.

It is instructive to list these advances, to see if they have any relevance to astronautics. They include: improved materials — especially the replacement of wood by metal; streamlining; the retractable undercarriage, which reduced unnecessary drag in flight; the variable-pitch airscrew, which allowed maximum propulsive efficiency over the whole range of operations; slots and flaps, which improved lift and landing characteristics; and supercharging, which allowed engines to operate in the thin air at high altitude. Another major development, though it did not involve the airplane itself, was the concrete runway, which permitted greater landing and takeoff speeds and much higher weights.

Now, there is nothing in this list that could not have been foreseen in 1903 — but even the most farsighted prophet could scarcely have imagined the combined effect of all these improvements — and the many others that also occurred. For separate increases in efficiency do not merely add; they tend to multiply, and the total effect is far greater than could ever have been anticipated by considering them individually. And because the human mind finds it easier to add than to multiply, it always underestimates ultimate possibilities.

With this history lesson as a guide, we may be able to make a better job of forecasting the future of astronautics. And, indeed, it is not difficult to see many ways in which the economics of space transportation may be drastically improved from the present figure of five hundred dollars a pound.

The first, and most essential, step will involve a complete break with today's space booster philosophy. It is impossible to tolerate indefinitely a situation in which a gigantic, complex vehicle like a Saturn V is used for a single mission, and destroys itself during flight. The Cunard Line would not stay in business for long if the *Queen Elizabeth* carried three passengers — and sank after her maiden voyage. Yet project Apollo is even more extravagant than this, because each mission also jettisons two enormously expensive pieces of equipment — the lunar module, and the service module. And even the command module itself, which does return intact, is not intended for reuse.

This really fantastic state of affairs is the result of an accident of history. Today's manned spacecraft evolved from missiles, which from the nature of things are expendable. But they might have evolved from aircraft, and indeed the pioneer writers on the subject assumed that space travel would come about in this way. They envisaged airplanes flying faster and higher, switching from propellers to rockets, and finally leaping out into space like flying fish escaping from the ocean. This certainly seems a more logical — if less melodramatic — way of doing the job; it is also the way it will *have* to be done eventually, if space flight is to make commercial sense.

It may well be argued that only the competition of the Cold War forced the development of man-carrying missiles, and that the "rocket plane" approach was the more natural and rational one. However, it would probably have taken much longer — and might therefore have been more costly — because it requires a much higher level of technical sophistication. We are now approaching this level, as a result of the experience gained with our first-generation vehicles, and can consider the next step forward — the reusable spacecraft, or space shuttle.

Ideally, the space shuttle should be able to take off like a conventional airplane, climb up to orbit, deliver its payload, reenter the atmosphere, and land on an ordinary runway, ready for another mission as soon as it has been serviced and refueled. Such a "single-stage-to-orbit" space transporter is still a long way beyond present capabilities, but there are intermediate designs that could be developed by the middle 1970's.

One concept employs the idea of drop-tanks — already commonplace on military aircraft, but taken here to its ultimate. Each stage of today's liquid-propellant spacecraft consists of huge tanks to which are attached a relatively small amount of electronics, control equipment, and rocket engines, the whole assembly being discarded as soon as the fuel is exhausted.

This is a very wasteful procedure, because the electronics, engines and so forth are ten or twenty times more expensive than the propellant tanks, yet are dropped with them. It therefore makes good sense to design a "core" vehicle, carrying payload, rocket engines and all the associated flight systems, and to surround this with a cluster of tanks which can be jettisoned when empty. In this way, all the costly equipment can be reused; if it was felt worthwhile it might even be possible to recover the empty tanks by parachute or rocket braking, so that they too could be brought back to the launch site and used again. There is an obvious analogy with the procedure used to extend the range of high-performance fighters; for spacecraft, however, the drop-tanks would weigh several times as much as the basic vehicle.

Another concept is the two-stage launch vehicle, in which the lower or booster stage, after its propellants are exhausted, can turn around and fly back to base, landing either as a giant glider, or with the assistance of small jet engines to give it additional range. A very similar idea appeared briefly in the early days of transatlantic flight, with the Mayo Composite Aircraft. This consisted of a large flying boat which carried on its back a small, high performance airplane, too heavily overloaded with fuel to take off under its own power. The flying boat thus acted as an aerial launch pad or reusable booster, which could be employed for an unlimited number of missions. The upper stage, when it had been lightened by burning most of its fuel, could make a normal landing at its destination.

This may be yet another example of an old idea, by-passed by the advance of technology, which makes an unexpected reappearance in a more sophisticated form. But there are many other concepts for cheap earth-to-orbit transportation being investigated by NASA and the aerospace industry; only time will tell if any of them are viable, or whether the answer to economical space travel lies in something which is not yet even a doodle on the back of an envelope. Nevertheless, with any luck the DC-3 of the space age should begin its career in the 1970's.

It is perhaps hardly necessary to point out that we also have to get away as quickly as possible from today's primitive "splashdowns." The USSR has always brought its astronauts down on land, and has thus been spared the enormous expense of maintaining large fleets of communications and recovery ships. Sea-based operations, of course, also impose great restraints on mission timing. Launches can take place only when weather conditions in the recovery area are forecast to be good, and as flight durations increase this will become less and less predictable. The situation is bad enough for the eight-day trip to the moon and back — but suppose a returning Mars expedition was lost, after two years in space, because there were storms in the Atlantic *and* the Pacific! It is obviously essential to develop techniques for coming down on land — preferably at a modest rate of approach on normal runways.

The experts who have made a special study of space-transporter concepts — such as Dr. George Mueller, NASA's associate administrator for manned space flight — believe that when all these ideas have been perfected, we will be able to put payloads into orbit at prices approaching five dollars per pound. This represents a hundredfold reduction of the present figure, which, it will be remembered, is itself a thousandfold improvement on the rate of ten years ago.

Looking still further ahead, we can also be quite certain that another factor will enter the picture — the technological breakthrough, which always occurs sooner or later. To revert once more to the history of aviation, we have seen how the Wright Flyer evolved smoothly into the commercially successful propeller-driven aircraft of the 1950's. But then the jet engine took over, and within a few years speed, payload, economy and comfort jumped to new levels. Inevitably, something like this will happen in astronautics.

That this is not just wishful thinking is indicated by the fact that we can already identify possible areas for such breakthroughs. They include: revolutionary new structural materials, such as carbon or boron composites, which are far stronger than steel but lighter than aluminum; use of the oxygen in the atmosphere to support combustion during the early stages of flight, so that the weight of oxidizer necessary for a mission is reduced; and, most important of all, nuclear propulsion.

The atomic rocket is a goal that engineers and scientists have pursued for more than twenty years; indeed, speculations about the use of radioactivity for space flight may be found in Goddard's notebooks half a century ago. Weight for weight, nuclear reactions liberate millions of times more energy than chemical ones; the three thousand tons of propellants in a Saturn V could — in theory — be replaced by a couple of pounds of nuclear fuel. However, pure energy is useless by itself. It can provide heat and light in abundance, but not propulsion. The only way in which the power of the atom can drive a spacecraft is by expelling matter — usually hydrogen gas — at high speed. This is still the thousand-year-old rocket principle, with nuclear instead of chemical energy driving the exhaust jet.

To put these ideas into practice has required an immense engineering effort on the part of NASA and the Atomic Energy Commission, but in December 1967 there was a full-power ground test of the NERVA (nuclear engine for rocket vehicle application) at the quaintly named Jackass Flats, Nevada. The engine operated at a thrust level of 55,000 pounds — which may seem a very modest figure when compared with the 7,500,000 pounds of the five F-1 engines which power the first stage of the Saturn V. However, NERVA ran for the fantastic time of one hour, compared with the F-1's mere two-and-a-half minutes, so the total impulse delivered by the two systems was almost the same. What is much more important is the fact that the nuclear rocket — though still at the very beginning of its development — is already about three times more efficient than the chemical one, and has an almost unlimited potential for growth.

Atomic spaceships could be flying in the late seventies, multiplying the payloads we can take to the planets. And during the coming century they will open up the solar system — as, a hundred years earlier, the internal combustion engine opened up the remotest places of the mother world.

3. *Expedition From Orbit*

It is now no secret that when President Kennedy committed the United States to a landing on the moon, the experts were bitterly divided over the best way of achieving this goal. Eventually, the choice was between two approaches: earth orbit rendezvous and lunar orbit rendezvous. The latter was finally adopted; it had the great advantage that the mission could be performed with a single launch vehicle, and because the lunar landing would be carried out by a specialized shuttle craft which would not be carried back to earth, the launcher rocket could be much smaller than the one required for a direct earth-moon return flight.

Yet earth, rather than lunar, orbit rendezvous offered many advantages, and the possibility of carrying out the mission with a vehicle a good deal smaller than the 6,500,000-pound Saturn V — a Saturn IV, let us call it. However, *two* Saturn IV's would be needed, and they would have to be launched within a short time of each other. If only the first got off the ground and the second was delayed by technical problems, the whole mission would have to be aborted. After elaborate calculations and at least one furious debate in front of an embarrassed President, it was agreed that lunar orbit rendezvous offered the best chance of fulfilling the prophecy "in this decade." Today, there are few who would argue against the wisdom of this decision.

Nevertheless, there can be little doubt that eventually *both* techniques will have to be exploited for maximum efficiency in space flight. This was pointed out decades ago by the pioneer writers on astronautics, and their line of reasoning can best be understood if we try to envisage what might be called the "ultimate" earth-moon transportation system. (Ultimate meaning what may be achieved within the next fifty years; beyond that, all crystal balls are made of frosted glass.)

Some of the required characteristics of the system will be obvious when we consider what is wrong with the present one. The appalling waste involved in throwing away expensive spacecraft and launch vehicles — the lunar module, the service module, the Saturn V itself — has already been mentioned. But this is only part of the sad story.

Look at the command module itself — the only component of the 363-foot-high Apollo-Saturn assembly that does come safely back to earth. A substantial fraction of its weight consists of the massive heat shield that protects it during reentry into the atmosphere, and therefore serves no purpose at all except during the last hundred miles of the half-million mile round trip. Yet this dead weight has to be carried all the way to the moon — and back! — at a cost of, literally, hundreds of tons of propellants.

The same argument applies to the three huge parachutes which lower the command module gently into the ocean; they operate only during the final two miles of the descent. And to make matters worse, they have to be designed to cope with the weight of the now useless heat shield, which has completed its task many miles overhead. The heat shield and the parachute are, of course, essential for the safety of the mission; the pity is that they have to be carried all the way to the moon, when they are needed only on the very last leg of the return journey. It would clearly be much more efficient if they could be left parked in earth orbit, to be picked up when they were needed just before reentry.

This is the philosophy underlying what have been called "orbital techniques," of which the Apollo mission's lunar orbit rendezvous is but one example. The aim is that of any experienced traveler: don't carry things you won't need, but make sure they are available when you *do* require them. And the laws of celestial mechanics, which allow us to leave supplies or equipment parked in space so that they can be located with astronomical precision a thousand years hence, cooperate ideally in this respect.

Although the pioneering studies of Tsiolkovsky in Russia, Oberth in Rumania and Baron Guido von Pirquet in Austria had emphasized the value of orbital rendezvous as early as the 1920's, the fact that spacecraft could meet and dock routinely at 18,000 miles an hour was not demonstrated until the brilliantly successful Gemini flights of the mid-60's. These — and their Russian Soyuz counterparts — are perhaps a better guide to future space operations than the Apollo mission, which was determined by deadlines rather than long-term economy.

What we may see now is the development of vehicles that are specialized for the different types of space operation, and can therefore operate with maximum efficiency in their particular regimes. The first would be the earth-to-orbit space transporter, or "space shuttle" discussed in section 2, designed to place payloads in stable orbits at an altitude of a few hundred miles.

We are beginning to discover, somewhat to our surprise, that space is a remarkably benign environment — at least for machines. Once clear of the atmosphere and set circling at the correct speed, properly packaged supplies and equipment can remain as good as new for perhaps literally astronomical periods of time. For in space, neither moth nor rust corrupt — and it is relatively easy to guard against the minor hazards of cosmic radiation and micrometeorites. Even the first generation of space probes and satellites has shown astonishing durability, often far exceeding planned lifetimes. (Occasionally with embarrassing results, as when satellites' radio transmitters fail to shut up when their mission is completed.)

Men have also demonstrated that they can work in orbit, once they have grown accustomed to the peculiar conditions (and advantages) of weightlessness. It will therefore be possible to assemble, check-out, or refuel types of spacecraft designed to operate *only* outside the atmosphere, and which will not be handicapped by having to fulfill the very difficult requirements of withstanding the thrusts and vibrations of blast-off, and the searing heat and even higher stresses of reentry.

The Apollo lunar module was a first step in the direction of a true spacecraft, and fits rather well the description written some twenty years ago for *The Exploration of Space:* "It would be a very curious-looking contraption. Probably if we saw a photograph of one we would not realise we were looking at a spaceship at all, so alien might it be to our present-day [1951!] ideas . . . it would have no vestige of streamlining and could be of whatever shape engineering considerations indicated as best. . . . It would have about as much structural strength as a Chinese lantern." Apropos this last sentence, the lunar module crews have already commented on the "tin-foil and tissue paper" appearance of their vehicle, and the crinkling noises it makes when thrust is applied.

But even the lunar module has to be built to withstand, during the few minutes of the launch from earth, ten times the forces it will experience during the landing on the moon. It also has to be folded and packaged so that it will fit into its snug little garage in the Saturn third stage — a feat made quite difficult by its wide-spread undercarriage and the small forest of antennas sprouting from it. There is obviously a great deal to be said for assembling true spacecraft *in* space — their natural environment, where their form can be perfectly fitted to their function and no engineering compromises are necessary.

Before we achieve this rather sophisticated level of operations, refueling spacecraft in orbit will become commonplace. This will be particularly advantageous as soon as reusable space transporters are available, for one vehicle of modest size, shuttling propellants up to orbit in multiple flights, could do the work of a giant Saturn-type launcher costing many times as much — and, of course, capable of only a single mission.

There are several approaches to space refueling, and perhaps they will all be employed. One could launch spacecraft with empty propellant tanks, and then — in an exact analogy to aerial flight refueling — send up one or more tankers to rendezvous with it and pump propellants across through flexible pipelines or rigid couplings. Alternatively, complete modules full of propellants could be flown up and attached to the waiting spacecraft.

This last idea was demonstrated on two of the Gemini flights in 1966. Gemini 10 and 11 both made a rendezvous with target vehicles launched earlier by an Atlas-Agena, and still containing considerable amounts of propellant. Once the spacecraft were docked together (Gemini 11), the Agena motor was restarted, and the combined vehicle was boosted to then record heights. (Who would ever have dared to predict that in the *two* years between 1966 and 1968 the altitude record for manned flight would increase from 850 miles to 240,000 miles?)

Although the first space refuelings will be carried out by means of tankers designated for specific missions, the time should eventually come when it will be worthwhile building up fuel supplies in orbit — in other words, to establish satellite filling stations, perhaps at various distances from the earth. And going beyond this, one can envisage the construction of veritable space ports, providing all the facilities — servicing, communications, navigation, quarantine — that are found on their terrestrial counterparts. When one remembers that it was only fifty years from Kitty Hawk to Idlewild, another half century would be ample time for such a development, if there proves to be need for it.

We can imagine that at least three distinct types of vehicle will operate from such a space port. There will be the earth-to-orbit shuttles, which lift propellants, supplies, cargo and passengers up through the atmosphere and, after docking and unloading, reenter for another mission. They may resemble today's ultra-high-speed rocket aircraft, or they may have wings or rotors which unfold after they have lost most of their orbital speed against air resistance.

Then there will be the lunar landing ships — larger descendants of the Apollo lunar module — which will be totally unstreamlined and will have shock-absorbing undercarriages so that they can touch down on the moon. But unlike the lunar module, they will not abandon their landing-gear-plus-descent-stage on the moon; they will need it again for the next mission.

These lunar shuttles would first operate between earth orbit and the surface of the moon, but at a later stage they might become still more specialized. They might only ascend from lunar base to lunar orbit, and make a rendezvous there with a third type of vehicle — a pure-space ferry designed to operate between earth orbit and moon orbit.

Because it would never have to land on any celestial body — not even an airless, low-gravity one like the moon — the "deep-space" transporter could be a very efficient vehicle indeed. Heat shields, wings, landing gear — all would be unnecessary. Moreover, only very low-powered and hence lightweight rocket engines would be required to nudge it from orbit to orbit. It would probably employ some form of nuclear propulsion, and as a result of all these improvements its payload would be a very substantial fraction of its total mass — not the miserable one percent or so which is the best that surface-to-space launchers can achieve.

A full-fledged attempt to show these three types of vehicle was made in the movie *2001: A Space Odyssey*. The winged Pan American craft that deposited Dr. Floyd at the Orbital Hilton was an earth-to-space transporter. The spherical ship that descended onto the moon was an earth-orbit-to-lunar-surface shuttle. And the huge, segmented "Discovery" which carried HAL and his human colleagues to Jupiter was a pure space vessel — capable of planetary flybys, but never of landing.

Whatever advances may be made in spacecraft, however, the greatest hope for improvement — without which transportation beyond the earth will never be really economical — lies not in clever engineering, but in using the natural resources of the solar system. All our present manned missions labor under an inevitable, but quite crippling, handicap. We have to carry propellants for the homeward as well as the outward voyage. . . . This does not merely double the difficulties of a mission; it would be truer to say that it *squares* them.

Anyone who doubts this should consider the price of a transatlantic air ticket — if today's jets were unable to refuel when they landed, but had to carry sufficient reserve to get back to their base. In such circumstances, the gloomy prediction of Professor Pickering, quoted in section 2, to the effect that "even if a machine could get across with one or two passengers the expense would be prohibitive to any but the capitalist who could own his own yacht" would be very nearly true.

Obviously, refueling bases on the moon and planets are a very long way ahead, and will evolve only if there is a really substantial space traffic to justify them. But this involves a typical "chicken or the egg" situation — we will not have such traffic until we have developed the vehicles to make it feasible.

Though there will always be good reasons for scientific expeditions to other worlds — for the mysteries of the universe are infinite and inexhaustible — large-scale space flight will have to pay for itself. That it will someday do so is as yet an act of faith, made reasonable by the fact that *every* form of exploration man has ever attempted has eventually led to economic benefits.

But it is not an act of blind faith, or a mere argument from analogy. Within the first decade of the space age, overwhelming practical reasons for the exploitation of this new medium had been demonstrated. There were even strong indications that no land on earth — not even the gilt-edged sidewalks of Manhattan — was as valuable as the unmarked strip of sky exactly 22,300 miles above the equator, where the synchronous satellites hover effortlessly over the same fixed spot on the globe.

We will now take a closer look at the forthcoming business of space — the next Industrial Revolution. It will provide the answers to many of the questions raised here.

By the time we have built the spacecraft that will be needed to service the orbital laboratories, workshops, factories, observatories — even hospitals and hotels — of the next generation, we will as an inevitable by-product have developed most of the technology, and the hardware, for the exploration of the moon and planets. And having won that power, it is inconceivable that we will not use it.

4. *The Business of Space*

Whenever new territory has become available to mankind, it has sooner or later been developed, colonized, or otherwise exploited; there are no exceptions to this rule, if a sufficiently long time scale is adopted. From discovery to full exploitation however, may take anything from a century to several hundred thousand years.

For example: men (or their immediate ancestors) have been in Africa for at least a million years, and there is still plenty of room there. North America was discovered very much later — a mere ten or twenty thousand years ago — yet, as is all too obvious, much of it is hopelessly overexploited. In some parts of California, the sequence from first scout to second mortgage has taken only a couple of lifetimes.

The Antarctic was first glimpsed in 1820, and its population density even now is less than one man per thousand square miles. The continental shelf became generally accessible in the 1950's; though some parts are already overrun with tourists, its *permanent* human population is still zero. These are the last two frontiers left on earth; it can hardly be doubted that foreseeable technologies are perfectly capable to turning them both into industrial slums within a century — and will indeed do so if we are not careful.

In the sections that follow we shall be talking about the colonization of the moon and planets, but long before we embark seriously upon such projects there is work to be done much closer to home. For just beyond the fringes of the atmosphere lies an almost perfect vacuum, that will soon be more valuable to mankind than any piece of terrestrial real estate stuffed with dross like gold or gems.

Since the beginning of history, much human effort has been devoted to reaching high ground, for a very wide variety of purposes. These have included communication (by the use of semaphores and mountaintop beacon fires); reconnaissance (Moses viewing the Promised Land); defense (innumerable castles and hilltop fortresses); Revelation (Moses again, receiving the Laws); and exotic articles of commerce (ice from the Alps to cool Nero's brow in the hot Roman summer). All these examples have — or will have — strikingly close parallels in space.

We can now reach the highest possible ground by launching ourselves, with our tools and our instruments, beyond the atmosphere. Artificial satellites can be established in orbits at any angle to the earth's axis, and at any altitude. They can move in paths that are perfectly circular, or highly eccentric — swinging out beyond the moon, and dropping back to within a few hundred miles of the earth. There is an orbit for every taste; but by far the most valuable one is that at a height of 22,300 miles, directly above the equator.

For here, and only here, a satellite can be "geostationary" or synchronous — that is, it can hover motionless over the same spot on the earth. Though this seems like pure magic, it is an elementary consequence of the law of gravity. The moon takes twenty-seven days to go around the earth; if it was closer (as indeed it was in the remote past, and may one day be again); it would complete its circuit more swiftly. The law governing altitude and period was discovered by Kepler in 1617; thereafter, any astronomer could have calculated that a satellite at a height of 22,300 miles would take exactly one day to circle the earth. It could therefore remain apparently fixed forever in the sky, because it would be moving along its orbit at the same rate as the planet spinning beneath it.

In effect, therefore, the laws of celestial mechanics allow us to construct a line of invisible towers, 22,300 miles high, completely around the equator. If we placed them a mile apart, there would be room for 160,000 separate satellites or space stations in this band of sky — every one hovering motionless above the hemisphere beneath it, and thus able to watch over, or communicate with, half the planet.

The economic and political consequences of this will be incalculable, and we have seen merely their beginnings in the setting up of Intelsat, the global satellite communications system. It is already hard to remember that, only a few years ago, radio and telephone links across the great oceans were scarce and often unsatisfactory — while TV service was completely impossible. Yet now we take it for granted when we watch an Apollo splashdown, in full color, while it is actually happening in the central Pacific. This is entirely due to the still relatively primitive communications satellites of today.

Tomorrow, as "Comsats" become more powerful and can carry more circuits, they will trigger an accelerating revolution in human affairs, perhaps even exceeding that wrought by the printing press. *Direct* broadcasts into the home will eliminate the need for thousands of ground stations — and so will open up the remotest and most backward parts of this planet to modern communications, with all that this implies for education, culture, business and politics. A hundred years ago, the electric telegraph made possible — indeed, inevitable — the United States of America. The communications satellite will make equally inevitable a United Nations of Earth; let us hope that the transition period will not be equally bloody.

Comsats can also, if used properly, improve and immeasurably enrich the everyday life of the individual. Although the multiplicity of television and radio channels will simultaneously multiply the amount of airborne trash, they will also make possible high-quality information services which are totally uneconomic today. By the 1980's, every home could have a display console on whose screen could be flashed instantly any picture or text stored in any library on earth. "Orbital newspapers," updated every hour, could be available on a global basis. Doctors, lawyers, engineers, scientists — in fact, all professional men — could have their own information channels which could keep them up to date in a way which today's journals and abstracting systems are hopelessly failing to do. If necessary, coding systems could ensure that only authorized viewers could tune in to these specialized services. The greatest use of "pay TV" may be to worldwide professional organizations and hobby clubs.

But this merely hints at the ultimate consequences of the satellite communications revolution. The telephone transformed business and social life, at the beginning of this century; the forthcoming home console will have an even greater impact, because it will allow men to meet effectively face to face, to exchange any type of information, to converse with their computers and consult information banks — without ever leaving home, unless they wish to do so.

Consider the implications of this. It means the eventual end of our present office-oriented society, with its twice-a-day traffic jams. It may even mean the end of the city — for one of its main functions will cease to exist, when men anywhere on earth can be, in all but physical fact, in each other's presence at the touch of a button. The motto of the future will be "Don't commute — communicate." And thus the automobile, which has destroyed so much of our environment, will itself be superseded by a later technology — giving us, hopefully, a chance to repair the ravages it has wrought.

It will indeed be ironic if those who attack the space program because it diverts funds from urban improvements are opposing the only force that can solve the problem — by abolishing it. This shows the danger of short-range, unimaginative thinking; major crises often demand radical and unorthodox solutions, as Hercules demonstrated when he cleansed the Augean stables by diverting a river through them.

Much nearer to the present, but of equal economic and social importance, will be the impact of the meteorological and earth resources satellites. The first are already changing weather forecasting from an art to a science; the second will eventually detect mineral and oil deposits, crop diseases, regions of land and ocean fertility, forest fires, water and atmospheric pollution, and multitudes of other phenomena of vital concern to mankind. It has been conservatively estimated that, when they are fully operational, these satellites will save enough money, and create enough new wealth, to pay for any conceivable space program.

It is often argued that all these services can be provided by unmanned, automatic satellites like Early Bird, Tiros, Essa and Nimbus, the pioneers in the field of space utilization. This, however, completely misses the point. As satellites grow larger and more complex — and our global society comes to depend upon them more heavily — the stage will very soon be reached when space-borne installation, repair and maintenance crews will be absolutely essential. There have already been cases where satellites costing tens of millions of dollars have been rendered completely useless by the failure of some small component; as one embarrassing example, just before the launch of Apollo 11 a vital communications satellite was put out of action because the bearing of a rotating antenna seized. Today, all we can do is launch another satellite and write off the first one; tomorrow, as the expense and difficulty of space transportation decreases, orbital repairs will become routine. This will result in a double saving, for it will no longer be necessary to build satellites to the fantastic standards of reliability now demanded. When they are designed for maintenance, and not for indefinite life, the cost of satellites will drop from Rolls-Royce to Volkswagen levels.

As orbital operations become more and more commonplace, we will develop the most economical mix of manned space stations and unmanned satellites. There are many tasks, such as the collection of huge amounts of scientific or meteorological data, relaying of radio and TV, or the establishment of navigational grids, which do not require human intervention except at rare intervals. But there are other types of activity which would be very difficult, or virtually impossible, without the participation of men on the spot.

Perhaps the most important of these is scientific research. For years, astronomers have dreamed of establishing observatories above the murk and haze of the atmosphere, so that, for the first time, they can see the universe as it really is. Climbing a mere hundred miles can bring the stars and planets ten times nearer, for the performance of our instruments has long been limited by the air above us, not by optical considerations. In space, telescopes could at last function with one hundred percent efficiency.

The first robot astronomical observatories have already been launched, and the torrents of information which they are sending back have revealed a new cosmos; it is as if a fog has lifted, and we are starting to see an unsuspected landscape. But the great orbiting telescopes of the future — larger than any that will ever be built on earth — will require teams of highly trained specialists to install and operate them. Only routine observations can be mechanized; for active research on the frontiers of knowledge, the scientist must be there to adjust, modify — and often rebuild — his own instruments.

This is even truer in physics than in astronomy; the very idea of operating an experimental lab through remotely controlled puppets would be enough to make a Rutherford or a Fermi turn in his grave. Moreover, many of the greatest breakthroughs in science have come from the observation of some unexpected and often trifling anomaly — exactly the sort of thing no robot or telemetering system would be likely to detect.

Orbiting laboratories will soon give us an unprecedented opportunity of studying matter, and the laws of nature, under wholly new conditions. Never before have we had access to a virtually perfect vacuum, of unlimited extent. In the past, a major part of the effort and expense required to run any physics lab has gone into the production of high vacuua, so that materials and atomic particles can be observed without contamination. Vacuum chambers more than a few feet across are very expensive; a space lab need only open the door, and it has a vacuum reaching all the way to the stars.

However, it is the condition of weightlessness (often inaccurately called zero gravity) that gives us the most exciting opportunities for research in space. Weightlessness can never be truly simulated on earth, except for a few seconds in freely falling containers or diving aircraft. But in orbit — as the world knows from Apollo telecasts, not to mention countless science-fiction movies — it is the normal state of affairs.

In this novel regime, liquids form themselves into perfect spheres, smoke does not rise (because no direction is "up") and the behavior of objects is controlled by forces such as electrical and magnetic attraction, adhesion and surface tension, which on earth are usually masked by gravity. When all vestige of weight is removed, we will be able to study chemical and physical reactions at a new level of sophistication. It is even possible that we will at last be able to make fundamental advances in our understanding of gravitation itself, when we can neutralize its influence. Studying gravity here on the earth's surface, where we are wholly under its control, may be as futile as trying to unravel the behavior of sound in the high-decibel environment of a discotheque.

Among the most promising areas of weightless research are investigations of living organisms, because gravity is a major factor controlling growth and other aspects of physiology. Even before Laika orbited in Sputnik 2, medical scientists devoted a good deal of effort to launching mice, dogs, monkeys and other small animals into space. When the researchers can accompany their subjects, and indeed share some of their experiences, progress in this field should be greatly accelerated.

It is possible that orbiting space labs may give us fresh insights into molecular biology — the fundamental science of life. If we can study cells under weightless conditions, we may gain new information about the laws that control their growth and reproduction. Any knowledge in this area could contribute to an understanding of one form of cell growth that concerns us all — cancer. Although it is never possible to predict beforehand what may come from the opening up of a wholly new field of inquiry, or the discovery of a new technique, it never fails to produce advances that could not have been achieved in any other way — especially by a direct assault on the problem.

Those well-meaning people who say "Why not spend the money used for space on cancer research?" should remember the obscure German physicist of the 1890's who attempted to find what happens when electricity is passed through rarefied gases. Doubtless his friends occasionally suggested that he should do something that would benefit mankind; luckily, Röntgen continued with his experiments. And he brought about the greatest advance in the history of medicine — for he discovered X-rays.

Lest it may seem naïve to expect dramatic advances in medicine to come from space research, it is worth mentioning that Dr. Christiaan Barnard, who should know something about the subject, has proposed to NASA a series of experiments on the behavior of DNA molecules and immunological mechanisms (graft rejects) in the absence of weight. And looking very much further ahead, there are dazzling prospects for new forms of therapy in zero-G hospitals. The removal of all weight would be an immeasurable boon to patients suffering from severe burns, and recovering from many types of operation; it would also eliminate one of the commonest and most painful of complaints, the bedsore.

It will be quite a few years before we can transship sick and injured people up to orbit, though doubtless the concept of the air ambulance would have seemed equally incredible to the Wright brothers when they began their experiments. Before the end of the 1970's, however, we may well see the beginning of specialized manufacturing processes in space.

There are many items of regular commerce whose price-to-weight ratio is so high that even a $500-a-pound freight charge would be trivial; obvious examples are rare pharmaceuticals, electronic components, and the movements of high-quality watches, but there are countless others. Not only will many products be much cheaper when we can manufacture them in vacuum or weightless conditions; there will be others which can be made *only* in space, and can then be shipped back to earth.

There are already a few processes which depend upon the temporary absence of weight. One may be encountered in any kitchen — when the cook turns over a flapjack by flipping it in the air. Those who have tried other methods of inversion *not* utilizing free fall will confirm that they are tedious and messy. . . .

A less trivial use of weightlessness was invented about two hundred years ago for the manufacture of lead shot. Some unknown genius realized that if one pours molten lead through a sieve at the top of a high tower, by the time it reaches the bottom, surface tension will mold it into a perfect sphere. By varying the mesh of the sieve, shot of any size can thus be produced very cheaply in unlimited quantity. Any alternative method of manufacture would almost certainly be orders of magnitude more expensive.

Even these simple examples are enough to hint at what may be done when we can maintain the state of weightlessness indefinitely. The manufacture of perfectly spherical (and even hollow) ball bearings more cheaply and with a higher degree of tolerance than is possible on earth is one suggestion that has been made. Another is "foamed metal." Normally, if gas is blown into molten metal, it will rise to the top. But if there *is* no "top," it will stay where it finds itself; the result could be gas-and-metal foams which would be extremely light, yet might have all sorts of useful mechanical properties.

In much the same way, pseudo-alloys could be made of metals which do not mix, and normally separate into layers when poured together. Whole new areas of chemical, electrical, biological, and metallurgical experimenting and manufacturing will become possible. What the space industries of the future may do is limited only by our imaginations; and we know so little, as yet, of this strange new realm that we can be quite certain all our guesses will fall short of the truth. If today we are shooting billions of dollars into space — it is because we will get trillions back. This is no wild exaggeration; in a mere half century, mankind has already spent almost a trillion dollars on airplanes. And space is going to be with us for a long, long time to come. . . .

Finally, although the subject may seem frivolous, let us not overlook the use of space for recreation. This, after all, will be the greatest industry of the centuries that lie ahead, when the computer has taken over mankind's traditional chores.

As soon as the cost of earth-to-orbit transportation descends below ten or so dollars a pound, space tourism will become feasible. For at least twenty years various travel organizations have been issuing, as a publicity stunt, reservations for flights to the moon. They may have to honor them sooner than they expected.

The magnificent color photographs and movies already taken of the planet earth by our outward-bound astronauts provide one completely adequate reason for going into space; the view is superb — and inexhaustible. We here at the bottom of the atmosphere never look twice at the same sky, or the same pattern of land and sea. Yet how much more varied will be the perpetually changing vista of the entire globe, with its bands of clouds, its cyclonic storms, its white pencils of jet streams, its veiled glimpses of deserts and mountains and savannas!

Five years before the launching of the first satellite, when that event still seemed decades in the future, an imaginative editor commissioned me to write an article on an orbital vacation resort. I suggested that it would be in two portions — one with gravity, one without, so that the residents could get the best of both worlds. This could be achieved if it was built in the form of a central, fixed ball, surrounded by a slowly rotating ring, so that the whole structure would look rather like the planet Saturn.

> Most vacationers [I wrote in *Holiday,* November 1953] go up there to enjoy the fun and games under zero-gee — but weightlessness is not so amusing when you want to eat a meal or take a bath, and some people find it impossible to sleep under free-fall conditions. Hence the dual-purpose design of the hotel. The central ball contains the gymnasiums and the fantastic swimming pool, while over in the ring are the bedrooms, lounges and restaurant. As the ring rotates, centrifugal force gives everyone inside it a feeling of weight which can't be distinguished from the real thing. . . .
>
> . . . Because "Up" always points to the center of the ring — to the invisble axle on which it turns — all the floors are curved, like the inside of a drum. . . . When you're dining, your table seems to be at the bottom of a smoothly curving valley, while everyone else is sitting at improbable angles up the slope. . . .

A dozen years later, Stanley Kubrick persuaded MGM to construct this scene, at almost the cost of the real thing, in the "Hilton Space Station" sequence of *2001: A Space Odyssey.* Even before it had appeared on the screen, Barron Hilton had used stills to illustrate a lecture he delivered at a Dallas symposium on the commercial uses of space. And at the same meeting Dr. Krafft Ehricke had carefully worked out the economics of an orbiting hotel on a rate-per-day basis.

Meanwhile, back in 1953:

> Ignoring such activities as poker and canasta, which are highly independent of gravity, there are two classes of recreation aboard the hotel. In the ring you can play most of the games that are found on Earth — with suitable modifications. The billiard tables, for example, have to be curved slightly; at first sight it looks as if they dip down in the middle, but in this radial gravity field, this makes them behave like flat surfaces. You very quickly get used to this sort of thing, though it may throw off your game for awhile when you return to Earth.
>
> However, since there seems little point in going out into space to indulge in terrestrial-type sports, most of the excess energy in Sky Hotel is expended in the zero-gee rooms aboard the ball. The one thing that nobody misses is a chance to do some flying — *real* flying, of the kind we've all dreamed about at some time or another. You may feel a little foolish as you fasten the triangular wings between your ankles and wrists and secure the free ends to your belt. Certainly your first few strokes will start you turning helplessly over and over in the air. But in a few hours you'll be flying like a bird. . . .

When the first men on the moon were bounding about on the lunar surface, obviously having a good time, they were pathfinding for generations yet unborn. Our picture of space is not complete if we think of it only in terms of power and profit and knowledge; for it is also a playground whose infinite possibilities we shall not exhaust in all the ages that lie ahead.

5. *The Next New World*

ANYTHING written about the moon at the beginning of the 1970's will probably look silly in the 1980's, and hilarious in the 1990's — particularly to the increasingly numerous inhabitants of our first extraterrestrial colony. For the moon is now changing before our eyes, and will continue to change with every successive landing.

To the small handful of astronomers who paid any attention to it a generation ago, the moon seemed a completely lifeless, static world, where nothing had happened for millions of years, or would ever happen again. Although its cratered countenance gave unmistakable proof of catastrophic violence in the past, its history seemed essentially over. The main interest of observers — nearly all amateurs — lay in mapping its spectacular surface features, and arguing endlessly about their origin. The futility of those arguments can be judged by the fact that, even under the best viewing conditions, earth-based instruments cannot detect objects on the moon less than half a mile across. There was no way, therefore, of learning anything about the small-scale nature of the lunar surface; in this atmosphere of ignorance, the most fantastic theories could flourish without danger of refutation. One German astronomer maintained, with Teutonic fanaticism, that the moon's visible features are made of ice; another observer put forward the delightful suggestion that its characteristic circular walled plains are coral atolls, left high and dry by retreating oceans.

It is easy enough for us to laugh at these ideas now that we have photographs showing every boulder on the moon, and have brought its rocks and soil back to earth for chemical analysis. Yet we must realize that it will be decades — perhaps centuries — before we have uncovered all the secrets of the world next door. Even on our own planet, which we have been able to examine in intimate detail for thousands of years, there are still plenty of major mysteries which can be guaranteed to disrupt any geological convention. To imagine that we will have discovered all that there is to know about the moon after a few Apollo landings is ludicrous. They will merely whet our appetite; Neil Armstrong's remark that he and Aldrin felt like small boys in a candy shop, because there was so much to see and do, will be echoed for a long time to come.

The moon's total surface area is almost 15,000,000 square miles — roughly equal to that of Africa, or the two Americas combined. Until the coming of the space age, only one hemisphere had ever been seen by man; in the remote past, friction probably produced by tidal forces robbed the moon of its rotation, so that now it keeps the same side always turned toward us. This visible face, as is obvious even to the naked eye, is about equally divided into light and dark areas; the dark regions are relatively flat and uniform plains (the *maria* or seas) while the light areas are mountainous highlands.

It appeared reasonable to assume that conditions would be much the same on the invisible "far side" — but this has turned out *not* to be the case.

There are almost none of the great dark plains on the hidden face of the moon; it is virtually all hill country. Why this should be so, nobody knows; it is certainly strange that the earth has somehow affected the topography of the land on which it never shines. And it is also strange to think that the moon would be considerably brighter in our skies if it had come to rest the other way around. Obviously there is some good reason why it did not do so; like the Apollo command module when dunked into the ocean, it may have a Stable 1 and a Stable 2 position.

Another surprise was the nature of the lunar surface itself. As no telescope could reveal anything smaller than the Pentagon building, the detailed texture could only be a matter of speculation, and rival theories could make convincing cases for hard lava, finely powdered dust, and needles of glasslike rock. But the Luna and Surveyor automatic probes, and later the Apollo astronauts themselves, found that the surface layers consist of soft dirt, which behaves rather like the damp sand left at the edge of the retreating tide. It might almost have been designed for the safe reception of descending spacecraft.

These examples are merely the first of innumerable surprises — some of them perhaps less pleasant — which the moon will spring upon us as we explore it. For we must never forget that we are dealing with an entire world, where we may find a range of geological features and environments almost as varied as on earth. Besides the obvious plains and highlands, there are canyons, deep crater pits, impressive near-vertical cliffs, meandering valleys which appear to be the beds of dried-up rivers — though whether of water or lava remains to be discovered — low domes that may be the roofs of bubbles blown in molten rock, and immense sheets of once-fluid material (again, presumably, lava) which has flowed for hundreds of miles, drowning the hills and craters in its way.

Though they have not yet been discovered, we may also expect to find caves and those curious pipes — as much as a mile long and fifty feet wide — sometimes formed in the neighborhood of volcanoes by rivers of molten rock. Because of the low gravity, these "lava tubes" might be much larger on the moon than on earth, and could provide very useful shelter. It is also quite possible that a certain amount of igneous activity still takes place from time to time; the evidence for this comes from reported red glows, the "moonquake" tremors picked up by lunar seismographs, and the clearly marked trails of giant boulders which ground disturbances have sent rolling for hundreds of yards. Any residual volcanic activity would be of the greatest importance to explorers; it could provide sources of heat during the long lunar night, and supplies of useful chemicals brought up from the deep interior of the moon.

There are many lunar vents and craters which have dark stains around them, where gases appear to have emerged and produced some kind of fallout over areas of hundreds of square miles. The materials involved will probably be carbon and sulfur compounds, and as they will almost certainly be associated with water vapor, this raises a fascinating though admittedly very remote possibility. Even if ninety-nine percent of the moon is completely sterile, the existence of small "oases," with microclimates of their own, is not wholly out of the question. These little islands of life — isolated from each other by an impassable wilderness as hostile as space itself — might have undergone quite separate evolutionary sequences, and it would be a great mistake to assume that any life forms that have managed to survive on the moon would be primitive. They are much more likely to be very specialized indeed; it may be rash, therefore, to relax the elaborate precautions of the Lunar Receiving Laboratory completely, even if half-a-dozen Apollo landings show no trace of biological activity. Our early expeditions will all be in fairly accessible places; who can say what may be lurking in the rugged foothills of Tycho, among the 30,000-foot-high peaks of the Leibnitz Mountains, or in the vast, drowned crater of Tsiolkovsky, which dominates the far side?

Perhaps even more to the point — what may we find when we start to dig? It has often been suggested that there may be underground ice on the moon; if there are local sources of heat, there may also be underground *water.* In the finest and most poetic of all spatial romances, *The First Men in the Moon,* H. G. Wells envisioned a luminous Central Sea "in perpetual flow around the lunar axis" and winding through labyrinths in which lurk "terrible and dangerous creatures that all the science of the Moon has been unable to exterminate." He described the capture of one "many-tentaculate, evil-eyed black thing" concerning which: "Afterwards, when fever had hold of me, I dreamed again and again of that bitter, furious creature rising so vigorous and active out of the unknown sea. It was the most active and malignant thing of all the living creatures I have yet seen in this world inside the moon. . . ."

Fantasy, of course. But such fantasies — if they have a plausible scientific basis — can serve a useful purpose in preparing us for the strangeness we will encounter as we venture out into the universe. The moon, in all probability, has no Central Sea, no vestige of life. Yet it may have other things quite as interesting, and even more surprising.

It is one of the characteristics of life (whether intelligently directed or not) that it radiates out from some original source and eventually occupies every possible biological niche. We are now trying to prevent this happening on the moon at one level, while encouraging it at another.

The first effort is doomed to failure, if it has not failed already. Contamination of the moon by terrestrial microorganisms may have occurred as early as 1959, when Luna 2 impacted in the Mare Imbrium; it is even more likely to have begun with Apollo 11, despite the stringent precautions taken. A great deal of equipment (not to mention bags of body wastes) was left at Tranquility Base, and although the raw ultraviolet radiation of the unshielded sun is an excellent sterilizer, any agile microbe would be perfectly safe from that danger a couple of millimeters underground.

As manned lunar operations become more extensive, efforts to keep the moon biologically clean will become hopelessly impractical, and may in any case prove to be scientifically unnecessary. And eventually, of course, we will deliberately introduce plants (and animals) onto the moon, in an effort to set up balanced life-support systems. This will mark the real beginning of lunar colonization, after the hit-and-run raids of the 1970's.

The parallel has often been drawn between the exploration of the moon and of the Antarctic, which had no permanent inhabitants until very recently. Then, as part of the 1957–58 International Geophysical Year — which also ushered in the space age — the United States Navy built the Amundsen-Scott South Pole Station, and men learned to survive even in the depths of the fearsome Antarctic winter.

With the exception of water and air, everything needed for survival in the Antarctic has to be shipped and flown in from other continents. Yet if it was worth the effort, the polar base could be made almost self-sufficient. The largest single item on the list of supplies is fuel oil for power and heat; this could be readily replaced by a nuclear reactor — as indeed has been done in Antarctica. And food, the other major import to Latitude Ninety South, could be produced there if a closed cycle economy was developed. One can imagine large conservatories in which crops would be grown during the long hours of daylight, or under artificial illumination during the night. Some of the plants could be eaten directly, others converted into protein by being fed to livestock — or, more probably, treated by purely chemical methods. Of course, all organic waste products would be cycled back into the system — which, apart from the inevitable losses, would be self-sustaining. It would be a small working model of the earth itself.

Today, it is not economically worthwhile to go to this trouble; it is far cheaper to fly in supplies. But the situation will be very different on the moon, for it will always be much more expensive to transport goods from earth to moon than from New Zealand to the South Pole. It also appears, somewhat surprisingly, that the lunar environment may be in many ways more hospitable than the Antarctic; although the absence of an atmosphere greatly increases the complications of living, it is perhaps better to have no atmosphere at all than one at minus ninety degrees Fahrenheit, and moving at a hundred miles an hour. . . .

A vast amount of paper work has been devoted to the construction and maintenance of the lunar base, and the time is rapidly approaching when theory must be put into practice. It is generally assumed that we will start with inflatable shelters, pumped up with oxygen brought from earth, and continually regenerated by chemical purification systems. However, if large numbers of people are ever to exist on the moon, this can only be a short-term solution. It will be essential to obtain oxygen — and as many other expendables as possible — from local resources. This is where supplies of free water would be so important, as water is ninety percent oxygen.

If water is not available, we will have to use rock. Most people are quite surprised to discover that the soils and stones of the earth's crust contain approximately fifty percent of oxygen; as expected, this has also proved true of the moon. In principle, therefore, we can generate an atmosphere from the lunar rocks by chemical engineering techniques — though at the cost of a great deal of hardware and considerable amounts of power.

Perhaps we can persuade growing plants to do the work for us; after all, they originally produced the oxygen we parasitic animals breathe here on earth. They could certainly be used, inside a lunar base, to regenerate the atmosphere by removing the exhaled carbon dioxide. Most projects for permanent settlements on the moon feature enclosed gardens or farms, where swiftly maturing crops could be raised during the fourteen days (earth time) of continuous sunlight.

Once this technology has been perfected, and lunar settlements have become self-sufficient in the basic necessities of life, they could be made of virtually any size. It is perfectly reasonable to talk of roofing the smaller craters, and building cities inside them — *if* there is any occasion to do so.

At this point in time, no one can say whether such grandiose schemes will ever be required. We may well discover all that we wish to know about our giant natural satellite by a network of automatic recording instruments, plus occasional traverses by parties of scientists and technicians. In this case, the permanent population of the moon may never be much larger than that of the Antarctic — say, about one thousand.

On the other hand, it seems more likely that the moon offers such opportunities in almost every scientific discipline that it could keep armies of researchers busy for generations. Consider geology (or selenology) alone; there are secrets waiting on the moon which will reveal the past of our own planet — including, perhaps, the full explanation of the metal and mineral deposits upon which human civilization depends. It has been well said (by Michael Collins, among others) that the moon, which has not been scoured by billennia of rains and winds, may be a Rosetta stone carrying on its surface the story of the solar system. The pages of that story have long been lost on earth; their rediscovery would be of inestimable scientific and economic importance.

Many of the types of research and production (excepting only weightless manufacturing) that could be carried out in space stations could eventually be transferred to the moon — which has the enormous advantage that it could provide unlimited amounts of raw material in situ. The astronomers might find it a firmer base for their great telescopes; the physicists could build their giant particle accelerators on the lunar surface, where the necessary vacuum is provided automatically. On earth, we are already contemplating atom smashers a mile in circumference; the accelerators of the next century may be wrapped around the moon. . . .

All these ideas are doubtless laughably crude and unimaginative, compared with the fantastic realities that lie ahead. The ultimate uses of the moon are still hidden from us in the mists of time, as effectively as the value of Alaska was concealed from those congressmen who, in 1867, castigated Secretary Seward for squandering $7,200,000 on a worthless wilderness of snow and ice.

But perhaps its greatest service to our descendants will be as a launching platform from which they can reach still stranger and more marvelous worlds. Because of the low gravity, it is comparatively easy to take off from the moon; in terms of energy, it is more than twenty times harder to escape from the earth. It follows, therefore, that if we can locate supplies of rocket propellant there — and hydrogen is the best — the moon could serve as the ideal base for the exploration of the solar system.

We are indeed lucky to possess, so close at hand, a celestial neighbor which can serve us as a stepping-stone to the stars, and as a proving ground on which to test our techniques for the exploration of remoter worlds. From now onwards, the moon is irrevocably bound up with the future of mankind.

And well before the end of this century, the first human child will be born there. It would be interesting to know the nationality of its parents; but such fading symbols of the old world will not be long remembered, in the fierce and brilliant light of the lunar dawn.

6. *The Solar Century*

DURING the week of the first lunar landing, there was a sudden change of focus of the human imagination. Until then, the moon had been the limit of most men's thoughts; that we might soon walk on its surface — though accepted as a logical possibility — was something that the mind could not really grasp. Then, almost in a moment, dream became reality; Armstrong and Aldrin might have explored no more than a few square yards of the Sea of Tranquility, but no one could doubt that the entire moon had now come within reach. Its exploration, and perhaps its colonization, was only a matter of time.

In a few dazzling hours, a once mythical world had become real estate. And because the human spirit must always have fresh goals, the new frontiers of the imagination swept overnight out to the planets. Men began to speak of Mars as only months before they had spoken of the moon.

Some of this talk was uninformed speculation — post-Apollo euphoria

— by those who had no idea of the technical problems involved. It might almost be compared with the hopes ignorantly expressed, at the end of the eighteenth century, by the people who believed that now men had risen into the air by the newly invented balloon, they could easily fly on to the moon. It was not quite as simple as that; the lunar voyage had to wait for another two hundred years. . . .

This time, however, the popular reaction was somewhat more in accord with the facts. Although — even at its nearest — Mars is almost a hundred and fifty times further away than the moon, in frictionless space distance is no measure of difficulty. Once a rocket has escaped from the earth's gravitational field, which it has to do even to reach the neighboring moon, it requires very little extra fuel to travel on to Mars, Venus, or indeed any of the planets.

The chief problem in manned interplanetary travel is not propulsion, but life-support. If we employ the orbits which require the minimum fuel — as we will be compelled to do in the early days of exploration — the very shortest round trips will last about two years. This means that we must preserve life in space for a hundred times the duration of a lunar journey; thus vast improvements in our present systems are required. One of the most important functions of manned space stations will be to test and develop methods of air and temperature control, as well as food regeneration which can be relied on for periods of years. This can be done safely in an environment which is only a few hours' flight time away from earth; if anything goes wrong, one can come home in a hurry. This would not be true, halfway to Mars. . . .

Even when we are fairly confident of our techniques, it would be rash to set out for Mars or Venus in a single spacecraft. When he sailed for the New World, Columbus very wisely used three ships. That would be a reassuring number for our early interplanetary expeditions.

At a reasonable rate of development — assuming *no* crash programs — such expeditions should be possible in the 1990's. Even if we made no deliberate attempt to reach the planets, well before the end of this century we would have automatically evolved all the necessary techniques during the exploitation of earth-orbital and lunar space. Thereafter, the opening up of the solar system would be inevitable.

Before we go to the planets, we will know far more about them than we do today, when most of our ideas are still little better founded than the early speculations about the moon. Powerful telescopes in orbit, and TV cameras carried on space probes like the Mariners and Voyagers, will have dispelled much of our present ignorance. But there is no substitute for a man on the spot, and in the case of the planets there is another reason — often overlooked by those who advocate purely robot explorations — why we must eventually send our eyes and brains across the abyss.

We can, and probably will, examine much of the moon with the aid of unmanned "lunar rovers" under radio control from earth. But the moon is only *two and a half seconds* away by radio waves; there is time to react to emergencies (such as rocks or crevasses in the line of travel) or to take advantage of those unexpected opportunities which are the essence of successful exploration.

Such operation in real time will be quite impossible on the planets. Even when Mars is at its closest, a radio signal takes five minutes for a one-way journey. If one of our Martian rovers got into trouble, it would be ten minutes before our corrective instructions could reach it — fifteen before we could know if we had done the right thing — twenty before we could change our minds. And this is the *minimum* time lag; for the outer planets the delay would be several hours. Though we will be able to give our robot explorers a great deal of autonomy, so that they can look after themselves in most foreseeable situations, when it comes to really strange and hostile environments it will be essential to have human controllers only a second or so away — that is, in orbit around the planet being explored — if not actually on its surface.

A striking example of the limitations of robot scouts was given recently by Dr. Ernst Stuhlinger of the Marshall Space Flight Center. In January 1967, with Dr. Wernher von Braun and Dr. Robert Gilruth, he visited the U.S. Antarctic Base to get a better understanding of the problems of interplanetary exploration. They were shown around by one of the local biologists who "pointed out to us the various forms of algae and arthropods that live in that region, and he described their ingenious ways of adaptation to this unusual environment. Each rock sample which he selected with the trained eyes of the research biologist contained on its protected underside some specimens of algae, mites or small insects; the samples which we untrained space engineers picked up did not show any traces of life. 'No wonder,' said Dr. [Russell] Strandtmann. 'This is the difference between a live, alert, intelligent, highly trained and motivated scientist, and a lifeless robot. Do you see now,' he added, 'why we scientists believe that man should go in person to the Moon and to Mars?' "

When nuclear propulsion is perfected, it will be easier (and cheaper) to reach the nearer planets than it is now to travel to the moon. And as our technology continues to advance, the velocities we can attain will steadily rise. Flight times will drop from months to weeks — and ultimately to mere days. We will be able to travel anywhere we wish in the solar system, and visit all the children of the sun.

Some of those are very strange offspring indeed. Yet perhaps we had better get used to the fact that *our* planet is the anomaly, with its hard, cold rocks and its unique, oxygen-bearing atmosphere. Any explorers from interstellar space might overlook it completely during their first examination of the solar system; they might notice only the four "gas giants" Jupiter, Saturn, Uranus and Neptune. Compared with these monstrous worlds the so-called terrestrial planets earth, Mars, Venus and Mercury are insignificant dwarfs, huddling round the warmth of the central sun.

It is almost half a billion miles to Jupiter, and nearly three billion to Neptune, the outermost of the giants. Yet despite the unimaginable distances involved, we have an opportunity of examining *all four* of these worlds within the next two decades — using the launch vehicles we already possess. An automatic probe aimed toward Jupiter in 1977 could swing past that planet in 1979 and, if its timing was correct, could get a boost from the Jovian gravity field which would flick it on to Saturn. Here the same thing would be repeated, when it arrived in 1981, and four years later it would reach Uranus. Cannoning off a third gravitational field in this game of cosmic billiards, it would arrive at Neptune in 1989, after a total flight of twelve years. Although this may seem a long time — and it will pose some very severe problems to the electronics designers — the direct flight *to Neptune alone* would normally take twenty years.

Opportunities for this multiple mission (the "Grand Tour") — occur only in the period 1976–78. Thereafter, the planets will not get lined up properly again for a hundred and seventy-five years. It will be a pity if we miss the best chance to survey *all* the giant planets, this side of the year 2153.

Even by that date, it seems unlikely that we will have got very far in unraveling the mysteries of Jupiter, the lord of them all. Mere statistics cannot convey the sheer size of Jupiter; it means little to say that the planet has 11 times earth's diameter and 318 times its mass. There is one mental image, however, that does give a faint impression of Jovian magnitude. If some cosmic collector of worlds skinned our planet and pinned its pelt like a game trophy on the face of Jupiter, it would appear there about as large as India on a terrestrial globe. In other words, Jupiter is to earth as earth is to India; anyone who has ever flown over the endless plains of *that* country may well feel numb at the thought of exploring Jupiter.

However, it is by no means certain if Jupiter has a solid surface to be explored. All we can see through our telescopes are the outer layers of a colorful and extremely turbulent atmosphere which consists largely of hydrogen, methane and ammonia. The rapid spin of the planet — despite its size, its rotation period is only ten hours — produces trade winds that must make ours seem like gentle zephyrs; the resulting immense belts of cloud, parallel to the equator, give Jupiter a characteristic banded appearance.

The nature of these clouds, if that is the appropriate term for them, is a major mystery. Hydrogen, methane and ammonia are quite colorless — yet the Jovian atmosphere shows a wide range of pinks and blues and salmons. Its most conspicuous feature, the 30,000-mile-long oval known as the Great Red Spot, has even been described as brick-red, though sometimes it fades (or sinks?) to invisibility.

Because it is at five times the earth's distance from the sun, Jupiter might be expected to be extremely cold; this is certainly true of its upper atmosphere. However, recent observations indicate that it is not quite as cold as it should be; like our own planet, Jupiter appears to have internal sources of heat. Some tens or hundreds of miles below the clouds it may be warm enough for water to exist in the liquid form; and given sufficient time, water plus hydrocarbons plus energy may add up to life.

A generation ago, practically all scientists would have dismissed the idea of life on Jupiter as absurd, owing to the "poisonous" nature of its atmosphere. But we now realize that this is a very naïve and self-centered viewpoint; modern biological theories suggest that the ancient earth, some four billion years ago, had a gaseous envelope much like Jupiter's — and it was in such an atmosphere that primitive life first arose. Only at a much later stage, when plants evolved, were the hydrogen-bearing compounds methane and ammonia replaced by oxygen; not until then could animal life appear. It is *oxygen* which is a deadly poison to primitive organisms — and, indeed, even to man if the pressure is increased too greatly.

Jupiter may, therefore, be in the very early stages of biological evolution; this could explain some of the extraordinary colors in its atmosphere, typical of many complex organic compounds. Whether this is fantasy or an exciting reality, we should know very soon, thanks to astronomical instruments in earth orbit. But it will be a very long time before we can actually send instruments — or men — down into that witch's brew of an atmosphere, stirred by storms and fertilized by bolts of lightning more powerful than any on earth.

The three other giants — Saturn, Uranus and Neptune — appear to be quite similar to Jupiter, except that they are considerably smaller and much less active. (But even the smallest, Neptune, is three and a half times the diameter of earth!) Saturn, however, has one unique and famous characteristic, its beautiful system of rings, which form a kind of multiple halo in the planet's equatorial plane. Although they appear solid when viewed through a telescope, the rings are actually composed of myriads of small particles in independent circular orbits. They are probably dust and ice; it may not be too far from the truth to say that Saturn is surrounded by a perpetual hailstorm.

The four giant planets possess twenty-nine known moons between them, and there must be many others still undiscovered. Jupiter (twelve satellites) and Saturn (ten) are almost small solar systems in themselves; indeed, some of their moons are comparable in size to the planets Mars and Mercury. However, because of their great distances, they appear as little more than pinpoints even in our most powerful telescopes. We can only assume that they are frozen, lifeless hunks of rock and ice.

Even so, they may have many surprises — and at least one of these worlds already presents us with a tantalizing mystery. Iapetus, the ninth moon of Saturn, is about six times brighter on one side of its orbit than on the other. There must be some remarkable formation — almost a giant natural mirror — flashing sunlight back at us from certain angles of illumination.

Saturn's largest moon, Titan, is sufficiently massive to hold an atmosphere — a tenuous one — of methane gas. *Any* atmosphere is useful for braking purposes, and methane is a particularly valuable substance, since it is twenty-five percent hydrogen. One day, our nuclear rockets may refuel here; Titan may be the key to the outer planets and beyond.

Until well into the next century, however, most of our manned explorations will be directed to smaller, more earthlike planets closer to the sun. Mercury, Venus and Mars all lie within a few months' flight time, even by today's slow-moving spacecraft, and they are all solid bodies, upon which it will be possible to make landings. Whether it will be desirable to do so is quite another matter.

Mercury, so close to the sun that the radiation it receives is ten times more powerful than on earth, may closely resemble the moon. Too small to retain an atmosphere, it is so hot that metals could melt in its equatorial regions. During a century of observation, astronomers had convinced themselves that the little planet keeps the same face always turned toward the sun, as the moon does toward the earth. Thus a whole science-fiction mythology had arisen, describing a world one side of which was frozen in perpetual night, while the other burned forever beneath a pitiless sun.

To the great embarrassment of astronomers, radar observations showed in 1965 that this simple, Dantesque picture is just not true. Mercury does know day and night, like any well-appointed planet; it spins on its axis once every fifty-nine days. This does little to alleviate its climate, but the extremes of heat and cold encountered there do not present a serious problem to space technology. Moreover, by a careful choice of latitude and time, it would be possible to find landing areas on Mercury where — for periods of several weeks — earthlike temperatures occurred.

There can be no doubt that men will one day visit Mercury, if only to install or service automatic monitoring equipment. Whether permanent bases will ever be established there is a question that only the future can decide. The reasonable assumption is that such a blistering lump of rock will have few resources and fewer attractions, except to a handful of devoted astrogeologists.

But nature is infinitely varied, and there may be much more on Mercury than we can possibly imagine today. For one thing, it seems to have an inexplicably high density — as if, for some peculiar reason, it is a repository of

heavy metals. Commenting on this, the British mathematician R. A. Lyttleton recently informed the Royal Astronomical Society that "Mercury may well be the strangest planet in the solar system." This is a startling assertion; perhaps we should not write off this little world too quickly as an unimportant lump of rock.

However, not even those hardy optimists, the science-fiction writers, really expect to find any form of life on Mercury. Although it is not too difficult to imagine organisms that could survive there (particularly underground, where the temperature would be moderate), if the planet never possessed oceans, biological evolution could not have started. Yet again, we are talking of life as we know it; we should prepare ourselves for the discovery that we know very little about it indeed.

Of all the planets, the one for which we had the highest hopes was Venus. Almost a twin of earth in size, with a gravity very slightly weaker so that it would produce a mild buoyancy, Venus also comes closer to the earth (26,000,000 miles) than any other body, except for the moon and a few stray planetoids — wandering mountains about the size of Central Park. Though it is considerably nearer to the sun than our world, its permanent covering of brilliant white clouds reflects ninety percent of the solar heat back into space. For this reason, it was hoped that its temperature would not be excessively high. Nowhere else in the solar system seemed a more likely abode of life; the dazzling cloud cover at once evoked images of oceans and rain-drenched forests, perhaps trampled by great beasts like those that our own planet knew in the days of the dinosaurs.

Alas for these dreams! One by one we have been forced to relinquish them. First the spectroscope revealed that the atmosphere contains huge quantities of the suffocating gas carbon dioxide — which precluded any form of animal life, but did not eliminate plants. Then earth-based measurements of the radiation from the planet indicated that it was far hotter than anyone had imagined; so hot, in fact, that water could exist there only in the form of steam.

For a few years ingenious theories "explained away" these observations, but the last faint hopes for a merely tropical Venus were shattered by the Mariner II flyby of 1962, and finally laid to rest by the Russian Venera probes of 1969. As these descended into the atmosphere, they registered not only very high pressures (comparable to those a thousand or more feet down in our oceans) but temperatures of 800°F. Conditions on the surface of Venus appear roughly similar to those inside a blast furnace.

That still leaves Mars, beloved by romantic writers for almost a hundred years, largely thanks to the report in 1877 of a network of fine lines (the so-called canals) covering the surface of the planet like the map of an international airline system. It is now known that the canals are illusory; although there are some rather diffuse linear features, Mars in close-up is no more artificial-looking than the moon. In fact, as the brilliantly successful Mariners 4, 6 and 7 showed, it very closely resembles the moon, being covered with craters of all sizes up to at least a hundred miles in diameter.

Yet there is one all-important difference between Mars and the moon — and that is the presence of an atmosphere. That Mars has an atmosphere had been known for almost two centuries, because its surface features are occasionally obscured by mists or clouds. However, it is not an atmosphere which we could possibly breathe, for it contains virtually no oxygen. Even if it were pure oxygen, it would still be useless to us — for it is much thinner than the air on the summit of Mount Everest.

Nevertheless, any atmosphere, as long as it is not an actively poisonous one, is probably better than none. The tenuous Martian atmosphere acts as an effective screen against the small meteorites that might otherwise pepper the planet's surface, and it moderates the temperature extremes. It may also help to circulate the small (but possibly vital) amount of water vapor that exists on Mars.

The public attitude toward Mars has oscillated between extremes of pessimism and optimism, as a kind of overreaction to each new advance in knowledge. When the Mariner TV cameras showed a bleak, cratered landscape, there was an immediate assumption that the planet had now been proved to be lifeless. This was absurd; much better pictures of earth, from considerably shorter ranges, have shown no signs of life here! This question may not be settled even when we have landed robot probes on Mars, as Dr. Stuhlinger's experience in the Antarctic demonstrates. Once again we are faced with the difficult problem of proving a negative. If there *is* life on Mars, the proof may be obtained within a decade, or even less; but if there is not — it may take a century of careful examination to demonstrate this beyond doubt. Though large and active life forms could hardly be overlooked, it seems likely that anything surviving in such a rugged environment would be small, inconspicuous, and restricted to a few favored locations.

It might also have to be mobile to avoid the long, ferocious winters; although on a summer afternoon the equatorial temperature may rise to the seventies, the average temperature is below freezing point — and the minimum may be *two* hundred degrees below zero Fahrenheit.

But Mars is a small world — half the diameter of earth — and its year is almost twice as long; moreover, it has no seas to act as barriers to migration. Thus any creature which could travel a modest five miles *per day* need never experience winter.

It is said that a famous astronomer once received this message from William Randolph Hearst: "Is there life on Mars? Please cable one thousand words." He got the reply "Nobody knows" — repeated five hundred times.

Now at last there is a chance of a more informative answer. And if it should be "No," that will only be temporary. In what is, from the astronomical viewpoint, a mere flicker of time, there will be life on Mars — and perhaps most of the other planets and their satellites. It will have come from mother earth.

7. *Interplanetary Man*

WHILE man's first footprints are still fresh upon the moon, it may seem slightly premature to discuss the exploration — and colonization — of the planets. Nevertheless, at the present rate of technological progress, such developments would appear to be inevitable during the next century. They may, indeed, be its prime concern — as the exploration of *this* earth has been a principal activity of the centuries since Columbus.

The solar system appears to have been admirably designed for the purposes of transportation — which may or may not impress the exponents of the "as God intended us to" school of thought. In the first place, although the planets move at considerable speeds, they all travel in the same direction — counterclockwise around the sun, for an observer at earth's North Pole. If any planet traveled in a retrograde orbit (i.e., clockwise) the problem of reaching it would be enormously increased.

To give a somewhat oversimplified example: earth and Mars move along their orbits at average speeds of 66,000 and 54,000 miles an hour. In changing from one planet to the other, therefore, it is necessary to make an adjustment of 12,000 miles an hour, which is a fairly modest figure even in terms of present-day rocketry.

Had they been traveling in *opposite* directions, however, the relative velocity to be overcome would have been the huge figure of 120,000 miles an hour, or ten times as much. And since the energy of a moving object depends on the square of its speed, this means that the difficulty of the transfer would be increased by a hundred — making Mars almost as inaccessible as the nearer stars.

A second simplifying factor is the relative flatness of the solar system; the planetary orbits all lie in very nearly the same plane, like the tracks of a circular race course. Only Mercury and Pluto — the two eccentrics at the opposite ends of the system — depart from this rule; their orbits are tilted at seven and seventeen degrees respectively to that of the earth, and even these inclinations are not likely to cause major problems.

A third reason for the — relative! — ease of interplanetary flight is much less obvious, and is not shown on any chart of the solar system. The planets are all held in their orbits by the gravitational grip of the sun, but that grip weakens very rapidly with distance. Moving outwards from the sun is like climbing up a steep hill; at first the slope is almost vertical, but presently it becomes less precipitous. And at last, it flattens out into a level plateau.

All the planets, even innermost Mercury, are far, far out on the fringes of the sun's gravitational field; by the time we get to earth, that field has been reduced to a mere ten-thousandth of its initial value. It therefore requires very little energy — or fuel — to travel from one planetary orbit to another; moving around the solar system is rather like gliding over a smooth but very slightly tilted sheet of ice. Once you set off in the right direction at the correct initial speed, the journey itself is effortless. Most of the work has to be done at the beginning of the trip, in escaping from the gravity of the earth.

It is easy to imagine a planetary system where this was not the case, and enormous amounts of energy would be needed to get from one orbit to another. We might thus be in the frustrating position of being able to reach the moon without difficulty — while the planets were virtually unattainable. So we should be thankful for the solar system we have. . . .

Though energy — which is simply the ability to do a measured amount of work — costs money, it is one of the cheapest commodities available. It can be purchased in many ways; in the modern world, the commonest and most convenient sources are the gasoline pump and the electric power outlet. When we look at various space missions, and see what they would cost purely on the basis of energy, the results are somewhat astonishing.

To lift a man all the way from the earth to the moon would require only ten dollars' worth of electrical energy. The cost of escaping from the moon itself is a ridiculous fifty cents; from the planets Mercury, Venus, Mars and the satellites of *all* the planets, only a few dollars. Naturally, it is more expensive to leave the giants; the worst case is that of Jupiter, whose titanic gravitational field requires three hundred dollars of energy for neutralization.

The fact that it cost not ten dollars each but nearly ten billion each to set the first men on the moon is some measure of our present ignorance and inefficiency. And here is another statistic: eight hundred pounds of kerosene and liquid oxygen, value thirty-five dollars, liberate enough energy to take a man from the earth to the moon. Yet the Saturn V burns a thousand *tons* per passenger.

In section 2, we indicated some of the methods by which today's absurd economics may be improved at least tenfold, and ultimately by even larger factors. At the same time, it is necessary to remind ourselves yet again that the future always contains unexpected and unpredictable developments, which invariably narrow the gap between the impossible and the easy.

All our ideas about travel beyond the earth are based upon rocket technology, and indeed we have no other means of propulsion in the vacuum of space. (Even the various nuclear and electric thrusters still depend upon the same principle of reaction or recoil.) However, it may well be that the rocket's history will parallel that of the balloon — which lifted mankind into a new element, but was eventually superseded.

A Saturn liftoff is the most magnificent spectacle yet contrived by man; yet there must be better ways of achieving the same result, more compatible with nervous old ladies visiting their grandchildren on the moon, as well as with the peace and quiet of the countryside. The history of technology teaches us that the right tool always arrives at the right moment; witness how the transistor was ready when the Space Age dawned.

It may be a pure coincidence, but it seems slightly uncanny that success in the long search for gravitational waves was announced only a month before the first landing on the moon — by Dr. Weber of the University of Maryland. The old dream of controlling gravity may be a complete delusion — or it may foreshadow a basic industry of the twenty-first century. Anyone who is unwilling to admit this possibility should remember that when Hertz demonstrated the existence of electromagnetic waves in 1886, he saw no practical use for them. Now there is no man alive who is not affected by the radio networks that enmesh the globe — and are already stretching out to the planets. Perhaps the cycle is beginning again, and may lead to feats of space engineering as incredible to us as television would have been to the Victorians.

Even if such scientific breakthroughs do not happen (which is perhaps the most unlikely of all possibilities!) the entire solar system will become accessible to us during the coming century. Voyage times first measured in years will shrink to months, then to weeks, as nuclear propulsion systems become more efficient. On this planet, the evolution from the sailing ship to the intercontinental jet took three thousand years; the parallel evolution in space may take only a hundred.

And given the solar system — what will we do with it? At the very least, we will establish scientific bases on the more stable and hospitable bodies — such as Mars, Mercury, and the major satellites. Of these, the most important may be Titan, the giant moon of Saturn, which is almost as large as Mercury. However, it may not be unique as a source of methane (and hence hydrogen) for our nuclear rockets. Two of Jupiter's satellites, Ganymede and Callisto, are of about the same size as Titan, and may also serve as bases for the exploration of the outer planets.

Exploring the twenty-nine known (and probably many undiscovered) moons of the four great worlds Jupiter, Saturn, Uranus and Neptune is a task which may take generations; today, it is quite impossible to predict how rewarding, or otherwise, it will be. But exploring the giant planets themselves will be immeasurably more difficult; indeed, it may never be attempted by men, only by instruments. Even if the so-called "gas giants" possess solid surfaces, they may be so far down in their turbulent atmospheres that the pressures may be more crushing than in our deepest oceans. A spaceship capable of landing on (in?) Jupiter would have to be far stronger than any bathyscaphe designed to sound the Pacific trenches, and would have to be powered by energy sources completely beyond any technology we know today. And as an additional minor drawback, the intrepid crew would have to operate in a gravitational field that gave them two-and-a-half times their normal weight.

It would be rash to state that such feats will never be attempted, but more within the range of foreseeable engineering would be the exploration, by what have been called "buoyant stations" (i.e., balloons) of the atmospheres of the giant planets. Combination airship-spaceships, drifting or actively cruising at altitudes where the pressure was not impossibly high, may one day serve us as mobile manned bases on these strange worlds. From such floating platforms, we may send instruments, and beams of radiation, into the inaccessible depths thousands of miles below.

A lighter-than-"air" vehicle for the Jovian atmosphere poses some fascinating technical problems. Jupiter's atmosphere is mostly hydrogen — and as this is the lightest of all gases, what can we possibly put in our balloons so that they will float in such a medium? The answer can only be hydrogen itself — but *heated.* The recent surprising revival of hot-air ballooning as a sport may have important repercussions, half a century from now. It is quite conceivable that some youngster, soaring in today's skies, may be learning skills he will apply in wildly different surroundings, where the horizon is three times further away than on earth. . . .

We may also explore Venus by balloon long before we land on its dully glowing surface — probably first starting at the poles. Venus, unlike the earth, has its spin-axis almost at right angles to its orbit; having no axial tilt, it consequently has no seasons. The polar regions of the planet must therefore be, permanently, hundreds of degrees colder than the lower latitudes. If there are mountains here, water might exist on them — and some wildly optimistic scientists have even suggested the possibility of ice, which could reopen the whole question of Hesperian life.

However, it seems far more probable that any life on Venus (as on the moon) will be imported from earth. The astronomer-biologist Carl Sagan has suggested "seeding" the cloud layers with specially developed microorganisms, which could float in the turbulent upper atmosphere and feed on the immense quantities of carbon dioxide present. While doing this, they would release oxygen, and as their numbers multiplied there would be an ever-accelerating transformation of the atmosphere. In a relatively short time (perhaps, centuries, perhaps even decades) the process which took geological ages on earth would have progressed far enough to make Venus hospitable to men.

Similar suggestions have been made regarding Mars, which may also possess vast quantities of oxygen locked up in its surface rocks. The material of the reddish Martian "deserts" may be iron oxide, and bacteria exist which can release its oxygen and leave the iron. This, in fact, is precisely how some of the great terrestrial iron deposits were formed. The bacteria involved have already had an immense economic impact on our own planet; one day we may set them to work again on other worlds.

These suggestions are by no means the most ambitious that have been put forward by reputable scientists. As early as 1948, the famous California Institute of Technology astronomer Fritz Zwicky — who was then heavily involved in the establishment of the American rocket industry — startled his colleagues by proposing the *reconstruction of the solar system.* He predicted that the time would come when man's increasing powers over his environment would allow him, literally, to move worlds, and thus to place the planets in orbits that would give them more favorable climates.

Even more mind-boggling ideas have been discussed by the British mathematician Freeman Dyson. He has argued that no intelligent species would tolerate indefinitely the fact that more than 99.9999999% of its sun's radiation is lost in space, and only a few billionths are intercepted by the planets. As the power requirements of a civilization increased, it might be necessary to dismantle a few planets and shield the sun completely with energy-absorbing screens.

This raises another question, first discussed by Tsiolkovsky during the 1920's in his pioneering studies of astronautics. *Do we really need planets?* When we have solved the purely technical problems of sustaining life in space, why should we continue to tolerate the perpetual drag of gravity, which cripples and sometimes kills us, and perhaps shortens our lives? The blissful weightlessness of free fall has now been experienced by a handful of astronauts — but has also been glimpsed by millions of skin-divers. It has its inconveniences, but these are easy to overcome. We evolved in the weightless environment of the sea; when we get into space, we may discover that this is where we really belong. . . .

Forty years ago, in an astonishing and recently reprinted book *The World, the Flesh and the Devil,* the British physicist J. D. Bernal suggested that eventually most of mankind would live in spherical space cities a few miles in diameter, moving in independent orbits around the sun. If this is correct, it is possible that far more people will live *off* the earth than the approximately one hundred billion who have lived on it since the dawn of time.

We must face the possibility — even the probability — that all our history on this world is but prelude to a far more complex future on an infinitely wider stage. On and among the planets we may see the founding of new societies, new cultures — perhaps even new species, as our descendants naturally or artificially adapt to alien environments.

There are some who may recoil in horror from these vertiginous glimpses of a cosmic future, or may feel that even to discuss them diverts attention from the immediate and desperate problems of our present age. That danger indeed exists; here — and only here — the tired old charge of "escapism" may sometimes be made against those whose eyes are fixed upon the stars.

Yet to let our minds wander from time to time in the centuries still far ahead may serve a useful purpose. It can help to put our present troubles in their true perspective — and it can remind us all what we stand to lose, if we do not solve them.

8. *The Shores of Infinity*

THE story of man has been one of expanding horizons; even today, there are a few Stone Age cultures where the limits of the unknown are only a dozen miles away.

First by land, thanks to conquerors and travelers like Alexander the Great and Marco Polo, the world widened. Yet not until the development of the sailing ship, and the arts of navigation, did Columbus, Magellan and their successors reveal the true lineaments of the globe. The fantastic cosmographies of the Dark Ages, with their mythical realms and monsters, lost their power over the minds of men. For the last four hundred years, every educated person has lived in essentially the world our parents knew.

But not the world *we* know. In one brief decade, our imaginations have had to encompass the moon. We can pinpoint the very moment when it ceased to be a heavenly body and became a place; it was November 23, 1966, when Lunar Orbiter 2 radioed back to earth the historic photograph of the Copernicus crater — and for the first time we looked not upon, but *across*, the landscape of another world.

In a few more years, we will experience the same revelation with Mars, Mercury, Venus. . . . Before the end of this century, the entire solar system will have become the background of our lives, as robot probes penetrate to its farthest reaches, and men prepare to follow them. Human thought will undergo another change of scale, comparable to that which occurred during the first Age of Discovery, half a millennium ago.

But for all the obvious parallels, there will be a profound difference between these two eras. Columbus and his fellow navigators were filling in the details of a world which, though large, they knew to be finite. The men of the twenty-first century will always be aware that, far beyond their widest voyaging, the stars and galaxies are scattered across a volume of space which is unimaginably large, and may indeed be infinite.

There is a familiar household object which gives a good idea of the scale of the solar system, and of the gulfs beyond. Take an ordinary twelve-inch LP record, and imagine that the hole in the center is the earth's orbit — 180,000,000 miles wide. Then Pluto lies on the rim, and all the outer planets are scattered across the disc; Saturn is at the edge of the label.

As yet, we have just started to explore the hole in the middle, which contains the sun, Mercury and Venus, and have sent a few probes a tenth of an inch outwards toward Mars. The remainder is still unknown, though already within our reach if we are prepared to spend years in silent coasting through space.

On this scale, the very nearest of the stars — and therefore the closest possible system of other planets — is three-quarters of a mile away. Our sun is a barely visible speck of dust, one of a hundred thousand million which on the average are about a mile apart. The whole collection of suns (the Galaxy) forms a disc about five times the diameter of earth. Even with this drastic reduction, our model has got a little out of hand. . . .

It is not surprising, therefore, that we do not know if there are any other solar systems besides our own. Across gulfs which shrink the sun itself to a feeble star, even a giant planet like Jupiter is utterly invisible. Nevertheless, there is indirect evidence that a few of the neighbor stars do have dark, planet-sized companions, and today most astronomers think it likely that the majority of suns possess solar systems. From this, it is an easy step to assume that planets bearing life — and intelligence — are commonplace throughout the universe.

This is probable; the alternative — that this tiny earth is the *only* inhabited planet in a cosmos of at least 10,000,000,000,000,000,000,000 suns — seems the wildest fantasy one can imagine. But at this stage of our knowledge there is no proof whatsoever that any life, or any intelligence, exists beyond the solar system. Some scientists, rashly ignoring the lessons of the past, have denied that such proof will ever be obtained; they feel that the distances involved present an insuperable barrier to knowledge. And they ridicule the idea that living creatures — men or other beings, should they exist — can ever span the abyss between the stars.

The development of space flight itself shows how dangerous it is to make such negative predictions. Moreover, in this case they can be shown to be false, at least to a high degree of probability. There may indeed be absolute bars to interstellar *travel* — but if so, they must be based on factors not yet known. What is already certain is that there are no serious difficulties in establishing interstellar *communication* — always assuming, of course, that there is someone to talk to at the other end. . . .

The quite amazing development of radio astronomy during the last thirty years has given us all the technology required. The gigantic antennas designed to catch faint, natural signals from the depths of space, and the sensitive receivers to amplify them, are the very tools needed for this task. In barely more than half a century since Marconi flashed his first signals across the Atlantic (a feat then widely declared to be impossible!) we have developed equipment with which we can talk to the stars.

No one has yet tried to do this, though there have been limited attempts to listen for intelligent messages from space. If these are ever discovered, it is likely to be as a by-product of some radio-astronomical investigation, because no one is going to tie up millions of dollars' worth of equipment on a random search that may last for decades — or centuries — with no certainty that it will ever meet with success. The detection of the extraordinary pulsars occurred in just such a fashion; at first, their trains of accurately timed radio pulses appeared to fit exactly the specifications of intelligent signals. Now it seems that they can be explained as a natural, though very surprising, phenomenon; the sharply defined pulses may be produced by spinning "neutron stars" — dense bodies only a few miles in diameter, yet weighing as much as the sun.

To be quite certain that we are receiving intelligent signals, we must prove that they carry some kind of message, even if it is not one that we can interpret. So far, there is no indication that the pulsars — or any other sources of radiation in space — are doing this.

That discovery might come at any moment, and would have a shattering impact upon human philosophy, religion and perhaps even politics. The mere knowledge that another intelligence existed somewhere else in the universe would affect our thoughts and our behavior in a myriad subtle ways. At the very least, it might cause our quarrelsome species to close its ranks.

Beyond this, the possibilities are so numerous that speculation is limited only by the laws of logic. Just a few of the questions that might arise are: does the message contain any useful information? (It would be possible to transmit a cosmic encyclopaedia, and an advanced, benevolent civilization might do so.) Should we attempt to answer? (It might not be worth it; if the message came from the Andromeda galaxy, it would have been on its way since the first ape men experimented with clubs. On the other hand, if it came from one of the nearer stars, our reply could be received in a decade or so.) And perhaps most interesting of all: is the source approaching? ("We shall be landing on the White House Lawn/Red Square in thirty minutes . . .")

The theme of cosmic confrontation is, of course, the classic stand-by of the science fiction writers, but it is now time that we took it seriously. (In the past it has sometimes been taken too seriously, as in 1938 when Orson Welles's *War of the Worlds* radio play spread panic across the eastern U.S. seaboard.) Some writers have expressed perhaps premature thanks for the existence of "God's quarantine regulations," which may allow us to communicate across the interstellar distances, but which will prohibit any form of physical contact.

It is true that the distances involved in flight to the stars are about a million times greater than those which must be crossed to reach the planets; but this does not imply a proportionate increase in difficulty. It is a surprising fact that a Saturn V could send a payload of many tons clear out of the solar system — to reach, for example, Sirius. But it would take a few hundred thousand years to get there.

However, this is at the very beginning — the log-canoe stage — of our space technology, which will advance beyond recognition in the centuries to come. There is no theoretical reason why speeds which are a substantial fraction of the velocity of light may not be ultimately achieved, at least by robot probes on one-way missions. This would make the closer stars perhaps twenty years away, and it would be surprising if, during the next few centuries, we do not attempt to send successors of today's Mariners and Voyagers to the nearest stellar systems.

But what of *manned* flight? It has been said that interstellar travel is not an engineering problem, but a biological one. Certainly, biological techniques — known or foreseeable — give a number of possible solutions.

One is the multi-generation starship, a mobile, self-contained worldlet which might cruise for centuries, until the descendants of the original voyagers made planetfall in a new solar system. Another way of arriving at the same result would involve suspended animation (hibernation); if this proves to be impossible with human beings, then we might send frozen ova, which were automatically fertilized a couple of decades before the end of the voyage. The children thus born could be reared by robot nurses, and in due course introduced to their distant heritage of human knowledge and history.

If this particular idea sounds nicely calculated to bring a gleam of maniacal delight to the eyes of Dr. Strangelove — can anyone doubt that we would attempt it, if the sun was about to explode and we had the time and the technology thus to make our race immortal? The galaxy is full of detonating stars — how many doomed races may already have tried such desperate experiments? As already remarked, our island universe, the Milky Way system, contains a hundred thousand million stars. Equally significant is the fact that it has existed for at least five thousand million years — that is, more than a million times the duration of human history. Over such expanses of space and time, anything that is technically possible has probably been achieved not once, but over and over again. There may be innumerable cosmic arks, making their lumbering way between the stars. . . .

It is possible that even interstellar travel may not be particularly time consuming — at least, from the viewpoint of the travelers themselves. As is widely known, though imperfectly understood, Einstein's theory of relativity predicts that as velocities approach that of light (186,000 miles a second, or 670,000,000 miles an hour) time itself appears to slow down.

This prediction has been experimentally verified with high-speed atomic particles, and has fascinating consequences for space travelers. It means (in theory at least) that journeys of any distance are possible during the span of a human life, and indeed in as short a period of time as may be desired, *if* there is enough power to give the necessary speed, and the crew can withstand the acceleration involved. To give a concrete example (taken from Shklovskii and Sagan's book *Intelligent Life in the Universe*) one can imagine a spaceship setting out for the Andromeda galaxy at a constant acceleration of one gravity, so that the crew would experience their normal weight. If this acceleration could be maintained, the crew would be twenty-eight years older when the ship arrived at Andromeda.

Now this is very surprising — because light takes about two million years to make the same journey, and nothing can exceed the speed of light! Yet no contradiction is involved. From the point of view of outside observers, the spaceship never quite attains the speed of light, and so the voyage lasts a full two million years. But to the travelers — and all their clocks, since everything in the ship is equally affected — only twenty-eight years would have elapsed. They would have no way of telling that anything peculiar had happened to them, unless they turned around and went straight home. Then, fifty-six years older, they would land on an earth where four million years had passed. . . .

If anyone asks: "How long did the voyage *really* take?" the answer is that both figures are correct — it all depends on the observer. One day, this "time-dilatation" phenomenon may cause little more surprise than the fact that it can be noon in New York, when it is 5 P.M. in London.

A trip to Andromeda is a rather extreme case, but journeys to the neighboring stars, out to a few dozen light years away, do not appear quite so far-fetched; for example, the bright star Vega (distance twenty-six light years) could be reached in about six years of ship time and the twelve-year-older crew could return home fifty-two years after they had left. This would give them at least a sporting chance of seeing their children again. . . .

Unfortunately, the levels of power and energy needed for these interesting feats are of such a magnitude that we do not know, even in theory, how they may be attained. The ultimate form of nuclear propulsion, involving the *total* conversion of mass into thrust with a hundred percent efficiency (which is certainly impossible) would be utterly inadequate, and power outputs comparable to those of the sun would be needed for the more ambitious relativistic missions.

Because of this, some scientists have argued that velocities approaching that of light can never be attained, no matter how far present or foreseeable methods of propulsion are improved. This conclusion is probably correct — but it is about as useful and relevant as a demonstration that no wooden, coal-burning airplane can ever make a supersonic crossing of the Atlantic.

It is absurd to imagine that the energy sources, and the methods of employing them, which we can envisage here at the very dawn of the Neotechnic Age are those that will still be employed a thousand years from now. Even at the beginning of *this* century, who would have dreamed of the two hundred million horsepower that lift the Saturn V? It is doubtful, in fact, if so much power was then available to the entire human race.

To state that the energy of a whole sun would be needed to drive a star ship does not prove the impossibility of such a vehicle. It merely means that we may have to wait a few centuries before we can build one — which, perhaps, is desirable for a number of excellent reasons.

Nor should we be discouraged by the undoubted fact that nuclear energy — the most concentrated source of power now known — is wholly inadequate for high-speed star faring. Recent astronomical discoveries strongly suggest that nuclear power is pretty feeble stuff, compared to some of the forces being let loose in the cosmos. When we observe "quasars" or radio galaxies liberating energies equivalent to the simultaneous explosion of a billion stars, we may well wonder if we are glimpsing some new order of creation. Fifty years ago, studies of the sun gave us our first hint of the powers locked in the hydrogen atom, which we have now released — though not yet tamed — here on earth. One day we may likewise learn the secrets of the quasars; and if we survive that knowledge, we will be on our way to the stars.

Whether we shall be setting forth into a universe which is still unbearably empty, or one which is already full of life, is a riddle which the coming centuries will unfold. Those who described the first landing on the moon as man's greatest adventure are right; but how great that adventure will really be we may not know for a thousand years.

It is not merely an adventure of the body, but of the mind and spirit, and no one can say where it will end. We may discover that our place in the universe is humble indeed; we should not shrink from the knowledge, if it turns out that we are far nearer the apes than the angels.

Even if this is true, a future of infinite promise lies ahead. We may yet have a splendid and inspiring role to play, on a stage wider and more marvelous than ever dreamed of by any poet or dramatist of the past. For it may be that the old astrologers had the truth exactly reversed, when they believed that the stars controlled the destinies of men.

The time may come when men control the destinies of stars.