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The Future of Space Exploration

History and motivations

Mankind's fascination with the cosmos is one that without doubt reaches back to the beginning of known history. The astronomers of ancient Babylon, Greece, and other cultures studied with great curiosity the night sky, dreaming of what laid beyond the outer reaches of our homeworld. Indeed, so much of our mythology and religion is inextricably tied to what once and still is mystery of space. From some of the earliest literature, among it the Sanskrit epic of Ramayana and the legend of Icarus, the yearning of man to journey beyond its home world and into space has manifested itself.

Over the centuries our spiritual and mythological understanding of space and the universe has ultimately developed into an advanced scientific one – yet its effect on our imagination has hardly diminished. In more recent times, the concept of space flight and exploration has been treated rather more scientifically and realistically, in both fiction and research. The German astronomer Johannes Kepler, renowned for his three laws of planetary motion, wrote what is considered by many to be the first true work of science fiction, *Somniun*, detailing the experiences of a man transported to the Moon. Although still within the realm of fantasy, authors such as Jules Verne and H. G. Wells treated the idea of space flight much more seriously than at any time before, considering the idea of humans travelling into space feasible.

In fact, it was during the last years of H. G. Wells' life that humanity finally realised the goal of sending a man-made object beyond the confines of our atmosphere. The V-2 rocket was initially developed by scientists working in Nazi Germany during the early 1940s (led by Wernher von Braun), though it later served as the basis for rockets designed in the USA and USSR, leading at least in part to their space programs. Over the years or the Cold War, space flight rapidly progressed from a mere to dream to one of the most extraordinary achievements in the history of science and technology. By the end of the 1960s, besides a number of unmanned satellites and probes having been launched, humanity had already sent humans into Earth orbit and ultimately to land safely on the Moon – undoubtedly the pinnacle in our brief history of space exploration.

If our inquisitiveness is not reason enough for the exploration of space, then there are certainly many more practical ones. Indeed, the so-called “Space Race” was born not of a grand vision to venture forth for the advancement of human civilisation or science, but rather as a military and political competition between two great superpowers. Somewhat perversely, it is thanks to the events of the Second World War and the ensuing US-Soviet rivalry that humanity has even achieved the rather more noble result of space flight. Unmistakably, the scientific community has long desired to explore the wonder that is space, from the outer reaches of Earth, to the Moon, Sun, asteroids, planets, and beyond. The problem, however, is the patent fact that exploration of space, whether using satellites or manned missions, is a costly affair, and requires the support of those with the financial capability – namely, government and multi-national organisations. As it were, this worked well up to the point where politics lost the interest near the end of the Cold War. By that time, beginning around the mid-1970s, much had already been achieved; the Soviet Sputnik 1 became the first orbiting satellite in 1957, and within only 12 years, the Americans had successfully landed humans on the Moon and returned them safely. Five successive Apollo missions, following the lead of Apollo 11, landed additional people on the moon in order to carry out basic scientific research, yet enthusiasm for the space program in the US was quickly collapsing following the initial Moon landing, and the Soviets were lagging far behind by then, no other nations even having a space program at that point.

Many of these early missions, in particular the Apollo program, along with the Mariner probes, did much to enlighten our view of the solar system and its formation. Many more objects have since been sent into space, including probes, satellites, and notably the International Space Station. The Voyager craft has even hinted that our theories regarding the vacuum of space (perhaps even general relativity) are incomplete, while the recent LCROSS probe has confirmed the existence of lunar water. Do such pursuits truly represent the goals of space exploration, however? Developing our knowledge and understanding of the universe will satisfy most scientists, yet without direct practical benefits, the means will not exist. Is it therefore not time to focus on returning man to the Moon, to planets beyond, and even settling them? Indeed, recent years have shown a renewed interest by several countries and organisations to take further space exploration, though success is no forgone conclusion.

Current plans and technologies

Despite a number of advancements, the fundamental science and technology behind space flight has not changed considerably since the first V-2 rockets. It has often been asserted that nothing more than Newton's laws of motion has been required for man to set foot on the Moon. To this day, the only successful of space flight has been based on chemical-reaction rockets, with space shuttles only representing a re-usable variety of this same fundamental technology. In fact, with the upcoming decommissioning of the Space Shuttle fleet, it may feel that we are almost moving backwards – the successor Orion craft has an uncanny resemblance to the Apollo 11 lunar module.

Chemical propulsion is still the simplest and most effective form of rocket engine available today, and it is frankly not likely to be replaced any time soon. The basic principle is that the propellants, either liquid or solid substances of high energy content (density), react chemically inside a combustion chamber to produce gas at an extremely high temperature. This gas is then directed through a nozzle, thus converting the huge amount of generated thermal energy into largely kinetic energy, ejecting the gas from the tail of the rocket at many times the speed of sound. It is simply by Newton's Third Law of Motion ("for every action, there is an equal and opposite reaction"), that the rocket is accelerated forwards with great force.

There are, however, several other methods of propulsion that are quite feasible given today's understanding of physics and level of technology. Among one of the most commonly discussed is solar sails. This technique, as with all, has both great advantages and severe issues at present. It is appealing mainly because it requires no internal source of fuel – acceleration is produced purely by the effect of photons colliding into a large, lightweight, material in the form of a sail. As we know from Einstein's pioneering work on quantum mechanics during the early 20th century, each photon has a minute amount of momentum proportional to its frequency; given a sail of large enough area, however, the vast number of photons could amount to a significant acceleration. Of course, the acceleration is nothing as great as that produced by chemical propulsion, thus solar sails have no use in escaping Earth's gravity, but rather only in navigating free space, and would thus seem to find their best application in interplanetary and perhaps interstellar travel. (Using a high-intensity beam on/orbiting Earth to illuminate the sail and thus control the spacecraft has also been proposed.) Similar to solar sails, in that it could be used as an efficient method of manoeuvring in outer space, is the ion thruster (and the related Hall Effect thruster), which operates by accelerating ionised atoms by an electric potential. Unfortunately, that advantages of this form are not outstanding, and thus its main application to date has been attitude control of satellites.

The main other possible technology is one of nuclear fission. Nuclear fuels (most commonly deuterium and tritium) are well known to have considerably higher energy contents (per unit mass) than chemical fuels, yet they present their own unique challenges. Nuclear propulsion is split into two main categories, namely electrical and thermal. The former involves using a nuclear reactor to power an electricity generator, which in turns ejects plasma to accelerate the craft. Thermal nuclear propulsion, on the other hand, is simply concerned with heating a substance (typically liquid hydrogen) directly from the reactor and ejecting it through a nozzle, in a similar way to chemical propulsion, except with greater efficiency. Much laboratory research has been conducted in the past by the USSR and US on this technique of propulsion, yet it has never been used on practice, the main obstacles being the complexity of the required engine and its relatively large mass (not to mention the possibility of nuclear fallout aboard a spacecraft).

All missions planned for the near future are essentially based on chemical propulsion engines. Besides a number of probes to be sent to Mars and the moons of Saturn and Jupiter, the next major milestones are likely to be the return of humans to the Moon. Although a number of the more technologically advanced and wealthy nations have intentions to land men on the Moon, it is likely to be the United States or perhaps European Union that do so first. Both NASA, with the Orion programme, and the ESA (European Space Agency), with the Aurora programme, aim to accomplish this feat by around the year 2020, followed by a (possibly joint) effort to land a man on Mars in the 2030s.

Private space ventures are also gaining popularity. Several companies are already planning to offer brief tourist journeys into space (initially just the sub-orbital region), the precedent having already been set recently by sending a handful of well-known wealthy persons to the international space station. Both private space flight as well as unmanned exploration has been encouraged by the X Prize foundation. Nonetheless, when looking at these efforts in light of our ultimate goals, it becomes plainly obvious that humanity’s advancements will not come through private ventures (at least for the time being).

Missions for the unforeseeable future

If our current designs to set Man on the Moon and Mars (and even to create permanent bases on these terrestrial bodies) are fulfilled, where then can we go? Certainly, it will require great dedication, funds, and even good fortune to succeed in these endeavours, but whenever it is achieved, humanity will undoubtedly want to push the limits further still. Though we may be achieve as much as colonising parts of the Moon and even Mars with little more than current technology, anything further such as interstellar travel would likely require major breakthroughs.

Although still far from being ready for use, a fusion-powered rocket is perhaps the most feasible of all potential propulsion methods of the future. Harnessing nuclear fusion is something we are only just starting to do in the laboratory on Earth, yet there has recently been some optimism for at least achieving ground-based fusion reactions in order to generate power. An experimental nuclear fusion reactor is currently being constructed in France (under the ITER project), which hopes to provide sustainable power generation for as long as 1,000 seconds. The problems here are even greater than those presented by nuclear fission propulsion; firstly, strong magnetic fields and extremely high temperatures are required to contain and sustain fusion reactions; secondly, the mass of the reactor must be low enough to be flown aboard a space craft. In summary, it is likely to be on the order of a century before this method may be realised.

Entering deeper into the realm of science fiction, we encounter antimatter drives. Having the enormous potential of being able to entirely convert the mass of fuel into purely radiative energy (due to the mass-energy equivalence discovered by Einstein in 1905), the impulse generated by the engine could be enormous – up to 10 billion times greater than that of a chemical engine. Here, the challenge is not so much a scientific or technical one (though they certainly are significant), but rather one of resources. We can generate relatively small numbers of antiparticles in the high-energy particle accelerators of today, yet this is hardly a ready supply of antimatter. To accumulate enough mass of antimatter to reach even the Moon, current generators would have to run for endless years and consume many times the amount of energy the antimatter could eventually generate in a rocket engine. The idea of only requiring 10 grams of antimatter to reach Mars in a single month, is however a wonderfully attractive one, yet 10 grams in far beyond the amounts we could feasibly generate today.

Beyond antimatter drives, there are purely theoretical and highly speculative forms of propulsion. Among the most commonly discussed is a reactionless drive (also known as an inertia drive). Any conceivable method of space flight, from chemical and nuclear drives to solar sails, requires at its core the principle of conservation of momentum. This is a law that has been widely accepted in physics for the past few hundred years; it is inextricably tied to Newton's Third Law of Motion, and for this reason highly unlikely to be overturned with any ease. If that is not enough cause for doubt, this violation of conservation of momentum also implicitly leads to the breaking of conservation of energy. It is therefore not too surprising that most scientists nowadays have grave doubts about such a drive even being theoretically, let alone practically possible. There are nevertheless a number of theoreticians at the fringe working on such concepts, some based purely on mechanics (such as the “stiction drive”), while others are based on strange configurations of electrostatic fields. Perhaps the least straightforward to dismiss is one based on antigravity, or some quirk of general relativity, given that modern research has pointed towards the theory of gravity being either incomplete or not fully understood.

All the methods proposed so far, though not necessarily attainable, obey the laws of special relativity; specifically, although they may allow a spacecraft to accelerate arbitrarily close to the speed of light, they cannot in fact reach or surpass the universe's ultimate “speed limit”. The problem is due to the fact that the apparent mass of any object tends towards infinity as the velocity approaches the speed of light, thus by Newton's Second Law requiring a larger and larger force to accelerate the thing as the speed approaches that of light. Nevertheless, several rather inventive theories have been proposed as a way of circumventing this limitation, commonly known as “warp drives” (named after the devices in the famous *Star Trek* series). The term “warp” here refers to the act of warping (or bending) the fabric of spacetime in such a way that faster-than-light travel is permitted. It may seem quite surprising at first to discover that Einstein’s equations of general relativity do in fact permit what *appears* to be faster than light travel in curved space, but by a quirk of nature that is precisely what they do. Among the variety of suggestions, there are proposals that deal with the manipulation of higher dimensions of space-time (theorised by string theory), as well as creating waves in its very fabric such as to create a “warp bubble”. The latter, known as the “Alcubierre drive” (named after the physicist who proposed it in 1994), is perhaps the most notable. The Alcubierre drive, though still enormously speculative, does not require quite so many radical changes to the current models of physics, as it primarily relies only on the possibility of stretching and contracting the areas of space-time ahead and behind a spacecraft.

Inventing these extraordinary methods of space propulsion is not the only route to progression in our exploration of space, however. The concept of the “space elevator” was proposed by the Russian scientist Konstantin Tsiolkovsky in the late 19th century, and does not really on any exotic theories of physics. The name summarises the idea quite well: to construct a tower of exceptional strength that would reach upwards to the height of geostationary orbit. (The geostationary point is where satellites above the equator orbit the Earth with the period of a day, thus remaining over a fixed point on the surface). More recent ideas focus on tethering a cable of extremely high tensile strength (perhaps of a carbon nanotube material) from a geostationary satellite, which greatly reduces the challenges compared to constructing a tower from the ground up. If such an idea does become practical – perhaps even in the medium-term future – it will open up many doors to further space exploration. The great hurdle of designing a powerful and light enough engine for a spacecraft is wholly overcome, as the ascension of an object into space (thus reaching escape velocity) can be done from a power source based on Earth's surface. The consequences of a space elevator would additionally include the ability to construct and even launch spacecraft from outer space. It may be that this will enable us to travel to nearby stars in some sort of self-sustaining "space habitat", in which successive generations of people would live and maintain the environment of the ship until the final destination is reached.

Putting aside for the time being the feasibility of these various methods of futuristic space flight, the question still remains of why would want (or potentially need?) to develop such technology. Besides our desire to better comprehend the nature of the cosmos, human colonisation of other planets and moons, in our solar system and across the galaxy, has often been. The greatest motivation, as seen by many prominent scientists, is to ensure the very survival of our species. Though it may seem far-fetched at present, the possibility of Earth's population being destroyed is remote but non-negligible. Among the potential causes could the impact of a massive asteroid (the technology at present to deflect such objects is dubious), or global nuclear/biological warfare. The most prominent advocates of the expansion of humans beyond our home world are the late science fiction author Arthur C. Clarke and theoretical physicist Stephen Hawking, who once said "I don't think the human race will survive the next thousand years, unless we spread into space. There are too many accidents that can befall life on a single planet. But I'm an optimist. We will reach out to the stars." Numerous other scientists, philosophers, and writers have explorer the same possibility. The renowned author of the *Dune* series, Frank Herbert, concentrated much on the theme of a great "Scattering" in his works, where various populations of humans resettle in the outer regions of the galaxy, where they loose contact with the rest of humanity, thus insuring the survival of at least some groups, as well promoting evolution and biodiversity of humanity. Certainly, expansion other planets and moons, even within our own star system, will initially force us to accept some significant differences to live on Earth (lower/higher gravitational strength, not being able to exist in the bare atmosphere, and potentially sever climate and terrain). Our future ability to terraform such celestial bodies to suit the needs and comforts of humans will likely determine how successful colonisation of space will be, and is a subject of vastly complexity in itself.

Whether the politics and economics of such ventures will permit such efforts any time soon is questionable, though many believe it is an inevitable course of our species if we are to survive and prosper in the coming millennia. The over-optimism displayed during the Cold War, which anticipated humans living on the Moon by the end of the 20th century is long gone, yet the desire has surely not vanished. Is it not after all the primordial urge of the human race to explore, however far it takes us?

What does the future hold for us?

The future of space exploration is a matter of much speculation, and could take one of many courses in the centuries ahead. Further exploration of your solar system using space probes, and manned missions to the Moon, Mars, and perhaps other bodies, will with little doubt occur some time over the next century, yet what we choose to make of any such success is the guess of anyone. It will undoubtedly take greater far-sightedness, or worse, an impending disaster of huge magnitude, to start any serious effort to venture beyond our homeworld. It is not however, in considering our enormous advancements in technology of the past century, difficult to conceive that we will do so and thus thrive.

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