Travel Between Worlds

By
Michael McCollum

We began this series on building an interplanetary civilization with a tour of the solar system. The jumping off place for our imaginary journey was Father Sol and we worked our way outbound in planetary order. From furnace-hot Mercury we sailed our virtual spaceship close to cloud-enshrouded (and even hotter) Venus, past Mother Earth and barren Luna, then headed outbound for red Mars, mighty Jupiter, and lovely Saturn. After a tour of the Jovian and Saturnian moon systems, we set out for the farthest reaches of the solar system, visiting cold Uranus, frigid Neptune, and finally, tiny frozen Pluto. In our tour we discovered that humanity's potential real estate holdings are vast beyond imagining. All that is needed to claim our heritage is to develop a technology capable of transporting us there.

In the last article we delved deeply into the physics of rockets in the hope of understanding how such engines work (and more importantly, understanding how they *don't* work). What we learned was that after nearly fifty years of developing ever better rockets, we really aren't much closer to the ultimate goal than Jules Verne was when he described his imaginary cannon for launching an expedition to the moon. The sad fact is that chemical rockets (our highest accomplishments to date) lack the performance — even theoretically! — to get us where we want to go. By straining every capability we have, we can send manned ships to Luna and possibly to Mars and the other planets of the inner solar system. But the technology is woefully inadequate for building a viable civilization spread throughout the solar system. To truly break free of the bonds of gravity, we must abandon the puny energy derived from manipulating the chemical bonds of atoms. To move freely through space we must harness the power of the atom, or even more fundamental powers of the universe.

There are those who despair our ever leaving this blue-white cradle of ours. They needn't worry. To every age the challenges of the next seem insurmountable, yet we have always surmounted them. So, having discovered what won't work in terms of spacecraft propulsion, let us turn to the possibilities that will. But before that, we need to comprehend the magnitude of the problem. Therefore, we must talk about the highways in the sky that bridge the gulf between worlds. In other words, we need to discuss orbits.

The Closest Distance between Two Points Is Never A Straight Line

Prior to the sixteenth century, scientific dogma held that the sun, planets, and stars all rotated about the Earth, and that they did so following paths that were perfect circles. Even the odd behavior of Mars, where the red planet appears to reverse course in part of

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its orbit, was explained by resorting to a complicated system of superimposed circular orbits. (The apparent "retrograde" motion of Mars in its orbit is an optical illusion brought about whenever Earth overtakes the smaller planet in the two worlds' perpetual race through the cosmos.)

This tidy picture was shattered in 1543 when Copernicus, building on the work of Tycho Brahe, displaced the Earth from the center of the universe and argued that all of the planets follow elliptical paths around the sun. You would think this better idea would quickly meet with wide acceptance. If so, you would think wrong. The church was not amused by his pronouncement, so much so that they didn't come around to ratifying the Copernican view of the universe for more than 300 years. Luckily, Copernicus had the good sense to publish his thesis after his own death, so there wasn't much they could do to him. Galileo wasn't so lucky. After publicly announcing that Copernicus was right, the great thinker was forced to recant and publicly embrace the Ptolemaic view that the Earth was the center of the universe, and the sun, stars, and planets all orbited about it.

It is easy to understand why the church would be upset with the main thesis of Copernicus's argument, namely that far from being the central point in the universe, the Earth was merely a small planet orbiting a minor star. What is less clear is why they were so outraged at his suggestion that planetary orbits were elliptical rather than circular. The problem was that the church adopted the Greek astronomer Ptolemy's views early on, and to change any portion of their doctrine would be to admit fallibility. Being fallible is not something churches – any churches! — admit willingly.

I can hear a number of people asking themselves, "Just what the hell is an elliptical orbit?"

An ellipse is an elongated circle, a rounded shape that is longer than it is wide, and an ellipse is one of four basic orbit shapes. The shapes in order are circle, ellipse, parabola and hyperbola.

Orbital Mechanics

Figure 1 shows the four types of possible orbits. The circle and ellipse are recurring orbits. That is, a planet, moon, or spaceship following one of these orbits retraces its path periodically. The Earth follows an elliptical orbit that is 152 million kilometers (94 million miles) in one dimension and 147 million kilometers (92 million miles) in the other. In other words, while elliptical, the Earth's orbit is within 2% of being circular, which as we say in the aerospace business, is "close enough for government work."

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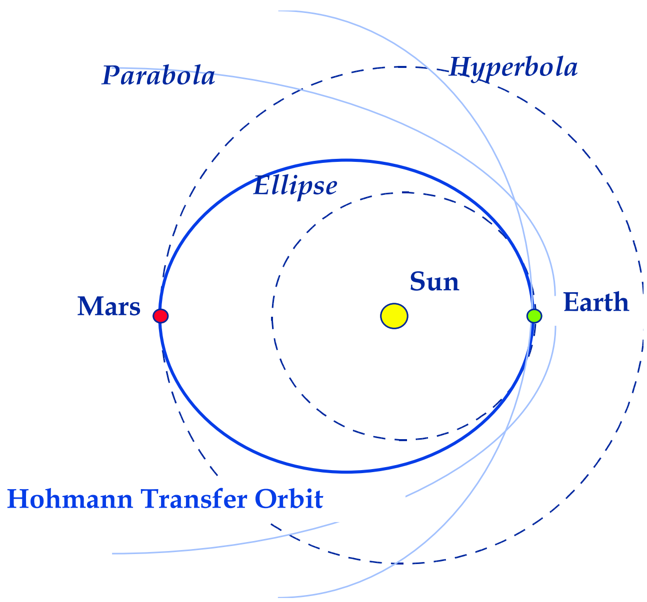

Figure 1: Orbit Types

The Earth has followed this path around the sun some four and a half billion times, taking the same length of time to complete each circuit. In fact, we have a special name for the time it takes the Earth to complete one circuit around the sun. We call it a "year." The other planets also follow elliptical orbits around the sun, all of which approximate a circle to a greater or lesser degree. Thus, they each have "years" as well, although a planetary year is different from an Earth year. Mars, for instance, circles the sun once every 1.9 Earth years; Jupiter, once every 11.8 Earth years; and Pluto, once ever 248 Earth years.

The other two classes of orbits – parabolas and hyperbolas — are "open" orbits. Anything following a parabolic or hyperbolic orbit will sweep around the sun once and then head off into space, never to return again. Comets follow highly elongated elliptical orbits which approximate the parabolic shape (at least in that section of the orbit where we can observe them), and the hyperbola is merely a more extreme example, a "flattened" parabola.

What has this to do with space travel? Everything under the influence of the sun's gravity moves in one of these four types of orbits. That includes planets, comets, and spaceships. So, if you want to take a trip from Earth to Mars, you must do so along an orbital path that is either an ellipse, a parabola, or a hyperbola. Historically, there has been one orbit that we have used consistently to send our instruments to other planets. That is the Hohmann transfer orbit.

Hohmann Transfer Orbit

The distances of the various planets from the sun are shown in Table 1. *Note: The easy way to measure planetary distance is using Astronomical Units (AU). One AU is the distance of Earth from the sun.*

There are an infinite number of orbital paths a spaceship can follow to get from one planet to another. But only one of these involves expending the minimum amount of energy. That is the Hohmann transfer orbit shown in Figure 1. Since our rockets lack performance, this is the orbit we send most of our space probes out on, (although gravity assist orbits have also been popular lately).

Table 1: The Distances To The Planets

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Planet	Distance (MegaKm)	Distance (A.U.)
Mercury	58	0.39
Venus	108	0.72
Earth	149	1.00
Mars	228	1.52
Jupiter	778	5.20
Saturn	1426	9.54
Uranus	2869	19.19
Neptune	4459	30.07
Pluto	5900	39.45

While cheap, the Hohmann transfer orbit has a disadvantage. It is also the "slowest" orbit. It takes 259 days to reach Mars in a Hohmann transfer orbit. That isn't a matter of concern for a space probe or unmanned rocket, but when you have people onboard, they aren't likely to spend the better part of a year getting somewhere and an equal time coming back. Nor is Mars the worst travel time problem. Jupiter is three years off via Hohmann transfer orbit. (Figure 2 shows the Hohmann orbit times for journeys from Earth to the planets.)

To make this stuff seem real, let's do a little thought experiment. First, look at the Hohmann transfer time for Neptune: 31 years. You are writing a novel where your buxom, 17 year old blonde heroine is exploring the ice caves of Triton, the largest of Neptune's moons. While inside the cave she is attacked by the dreaded man-eating frogs of Neptune. She beats off their attack, runs to her spaceship, and calls her boyfriend on Earth for help. Being a proper macho hero, the boyfriend immediately hops in his ship and races to the rescue, arriving a mere 31 years late! You may not realize it, but you have just developed two very serious plot problems with this novel. The first problem concerns dramatic tension; namely, what are you going to do to hold the reader's interest for the 31 years the rescue ship is in transit? The second problem is psychological, and therefore, the more difficult of the two to resolve. By the time rescue arrives, your 17 year old heroine will be age 48. And while people get excited about 17 year old blondes being in danger, by the time they get to be grandmother age, women are supposed to be able to take care of themselves.

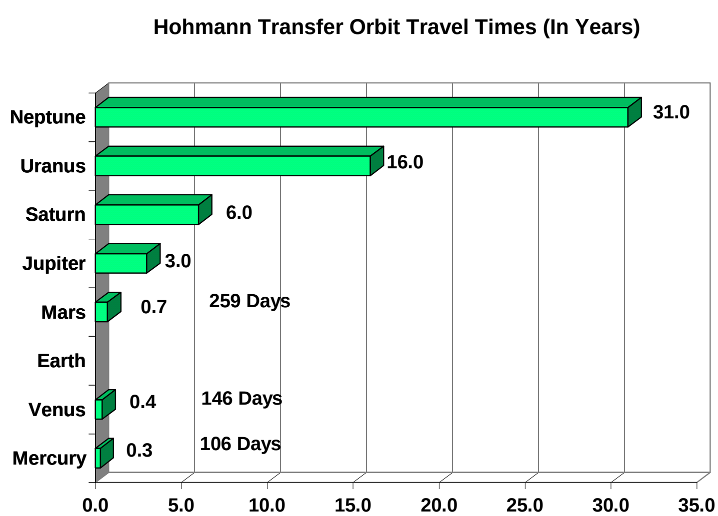

Figure 2: Minimum Energy Orbit Travel Times

So what is the solution? Obviously, we

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need a better spaceship that doesn't take so long to get there and that means that we will have to expend more energy in all phases of our journey. We will also have to radically change our orbit!

Hyperbolic Orbits, The Only Way To Go

There is only one *fast* way to get anywhere in the solar system. That involves jumping in your spaceship and *hauling ass* toward your destination. (For our foreign readers, to haul ass is an American colloquialism. It means to rush enthusiastically!) And as soon as your speed is 42% higher than the orbital speed of the planet you just left, you have entered the realm of the hyperbolic orbit. Refer back to Figure 1 if you aren't sure what I am talking about.

You can think of the planets as orbiting the sun like stately ocean liners, forever plowing their circular courses through a vast sea of vacuum. A spaceship on a hyperbolic orbit is like a speedboat cutting directly across the wakes of the great ships, heedless of other traffic in its headlong rush to get where it is going. When the speedboat reaches the ocean liner it seeks, it performs a power turn to come along side the larger ship to offload passengers.

The analogy breaks down in one respect. A speedboat that loses engine power will quickly slow down and then bob quietly among the waves until someone either comes to rescue it, or else one of the ocean liners runs it down. A spaceship in a hyperbolic orbit that loses its engines will not stop ... ever! If the engines aren't available to slow the ship at the end of its journey, it will zoom completely out of the solar system, never to return. Next stop: the stars. Estimated time of arrival: one to ten million years in the future. Condition of the crew on arrival: Very, *very* DEAD!

So, if we are to build an interplanetary civilization in our books, we need to use ships that fly hyperbolic orbits between planets. This brings us back to the problem we discovered last month, namely that our spaceships are woefully inadequate for the task. Luckily, that problem is much easier to solve if you are a science fiction writer than if you are an engineer. Remember that we don't have to build the damned things, merely describe them.

Just what sort of ships can we use to build our civilization?

Advanced Spacecraft Propulsion

We learned last month that the best spaceship is one that spews super hot hydrogen plasma from its exhaust nozzle. Hydrogen is the best rocket fuel because it is the lightest of all elements, especially if heated to the point where the diatomic hydrogen molecule (H_2) breaks down into its monatomic form (just plain H). With monatomic hydrogen and an exhaust temperature of a million degrees C, our fictional spaceship engines are 40 times more efficient than those that power the Space Shuttle.

That is a pretty good spaceship!

The problem, of course, is how one goes about heating liquid hydrogen up to a million degrees. Simple, really. All you need do is add energy. Which is like saying that all you need to be a millionaire is to make sure that you get born a Kennedy. The solution is easy to describe, but difficulties accrue in practice.

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Nuclear Rockets

The most obvious way to heat hydrogen to astounding temperatures is to use a nuclear reactor, either fission (near future technology) or fusion (a technology we have yet to master). Back in the 1950s and 1960s, fission rockets were a standard feature in science fiction, the obvious next step. That was before our society turned anti-nuclear.

There were experiments with nuclear rockets in the 1960s. The NERVA project was one such experiment. Basically, the NERVA was a fission reactor about the size of a desk that put out the power of Hoover Dam. To keep it cool, engineers pumped several thousands of gallons of liquid hydrogen through the reactor each minute. At nearly absolute zero when it went into the reactor, the hydrogen came out as a superheated cloud of hydrogen gas.

NERVA was a good first step, and had we continued the development of nuclear rockets, we might have something approaching the capability needed to send people to the planets by now. Amazingly, despite the fact that we haven't yet built a practical fission nuclear rocket, somehow the technology seems dated. It's almost as though in the public's eye, fission rockets are a technology we have advanced beyond. In reality, of course, we never got that far. Then there is everyone's favorite bugaboo, radiation. Fission rockets would have some tendency to spew radioactive particles out the exhaust along with the hydrogen reaction mass. In space this isn't the problem that it would be on Earth because the vacuum of space is awash in radiation already. Except we don't call it "radiation." That would make it seem scary. We refer to it as the "solar wind."

So, if you don't want to immediately date yourself, you power your nuclear rocket with a fusion reactor rather than a fission one. That technology has a lot of promise to it, and unlike a fission rocket, would produce little if any radiation. In fact, fusion rockets are to be preferred over fission any day. They have only one drawback. We can't build one. To date we have managed to sustain a controlled fusion reaction for less than a second, not very promising if you want to send a spaceship hurtling on a hyperbolic orbit toward Mars.

How does a fusion rocket work? The simplified explanation is that you inject hydrogen atoms into a combustion chamber, somehow get a small fraction of the atoms to fuse together to form helium, and use the resulting energy to heat the rest of the reaction mass and send it hurtling into space through some sort of nozzle (preferably electromagnetic so that you don't melt something).

Are fission and fusion the only choices when it comes to nuclear powered rockets? Well, yes and no. There is another nuclear-type technology that might be used to power a spaceship, one that has the greatest potential of all. That is the antimatter rocket.

Antimatter Rockets

The first reaction most people have when they learn of antimatter is to deny that any such a thing exists. Let me assure you that what follows is very conventional science. We know that antimatter is real because we create it in our particle accelerators

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(like the one at CERN in Switzerland). So, to familiarize you with the concept, a quick lesson in elementary particle physics.

Matter in the universe is made up of atoms, which are themselves constructed of subatomic particles. An atom of hydrogen has one positively charged proton in the nucleus and one negatively charged electron in orbit. Physicists have long known that each particle in the universe has an antiparticle counterpart. These antiparticles have all the properties of a subatomic particle, save one. Each antiparticle has an opposite electrical charge to its normal matter cousin. Thus, the negatively charged electron has a positively charged twin called the anti-electron (or often in science fiction, the positron). The positively charged proton's antimatter twin is the negatively charged antiproton. There are a lot more particles and antiparticles, but those will do for now. Theoretically, you could produce an atom of anti-hydrogen by getting a positron to orbit an antiproton just as you produce hydrogen by orbiting a proton with an electron.

The thing that makes antimatter interesting to the spacecraft designer is what happens when antimatter and normal matter come into contact with one another. At the instant of contact, the two annihilate one another in a burst of pure energy. Thus, a kilogram of antimatter mixed with a kilogram of normal matter will release two kilograms worth of pure energy, and that is one hell of a lot of energy! (Remember $E=mc^2$? Two kilos worth of energy is sufficient to blow a very large hole in this planet.) Since you get normal matter for free (you could use dirt as the normal matter component of the reaction), you can think of the antimatter reaction as being 200% efficient.

"Great," you say, "so where can I get some of this stuff?" It may surprise you to learn that we manufacture billions of antiprotons every second in our big particle accelerators. The problem is that antiprotons, once created, are devilishly hard to catch. Still, improving collection efficiency is a mere technical detail, and one thing human beings are good at is resolving the technical details of a problem.

How would an antimatter production facility operate? An antimatter "factory" would be a big particle accelerator optimized for the production of antiprotons. A beam of protons would slam into a target, creating a beam of antiprotons, which would then be slowed down and captured magnetically. This would all have to take place in pure vacuum of course, since any antiproton that encountered an air molecule would disintegrate in a burst of high-energy gamma radiation. In fact, the antiproton beam would ensure that there is no air anywhere in the particle accelerator.

The end product of the whole process would be a small magnetic containment torus about the size and shape of a glazed, chocolate doughnut. Only this "doughnut" would have a cloud of charged antiprotons forever circling inside, trapped in a magnetic field, just waiting to be released.

The beauty of the antimatter rocket is the fact that the antimatter production machine (a million tons of factory) could be left behind. All that would be needed to power the spaceship is the little torus filled with antimatter. Whenever the ship needed to use its engines, the magnetic containment field would be adjusted to let a little antimatter escape into the reaction chamber. Once there the antimatter would encounter normal matter in the form of liquid hydrogen. Antiprotons would annihilate normal protons and all hell would break loose! The pure energy released by the matter-antimatter reaction would then be absorbed by the hydrogen reaction mass and the whole cloud would be

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heated to a million degrees in a few microseconds. This super hot hydrogen plasma would then drive the ship anywhere you wanted it to go.

Think of it as Energizer batteries for rocket ships!

How Far In The Future Is Antimatter Propulsion?

I first learned about antimatter rockets in 1987. At the time I was writing *Thunderstrike!* in which a comet threatens the Earth. For reasons of plot I needed my protagonists to make it from Earth to Jupiter in six months. If you remember Figure 1, the normal time via Hohmann transfer orbit is six years.

I decided to power my ship with antimatter, and to impress my fellow hi-tech science fiction writers by being as technically accurate as possible. You can see the result in Figure 3. *I.S.F. Admiral Farragut* is a freighter with eighteen 4000-cubic meter liquid hydrogen tanks powered by 1 kilogram of antimatter. The ship has a reaction temperature of 100,000 degrees. She is, by contemporary standards, a very impressive craft.

I was approximately 50% through *Thunderstrike!* when I received a copy of *Aviation Week* in the mail. I opened the magazine and discovered a two-page story on the Air Force's proposal for a space fighter in conjunction with the Strategic Defense Initiative. Basically, the Air Force was proposing to research the problem of antimatter production to build an orbital "fighter" vehicle. The problem statement was simple. The space fighter was to be capable of making a U-turn in orbit. In other words, while going 30,000 kph (18,000 mph) one way, it would be able to reverse course, accelerating to 30,000-kph orbital speed – but in the opposite direction! The Air Force estimate was that they would need 20-30 billion dollars and two decades to finish the project.

It's a shame they didn't get the money. We would be well on our way to a working antimatter powered spaceship by now.

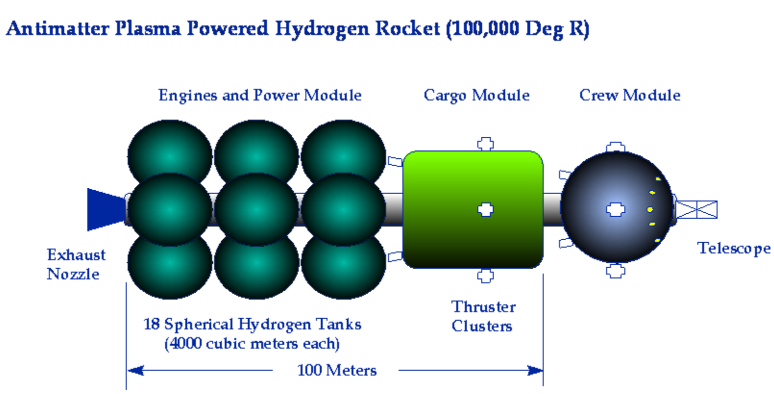

Figure 3: ISF Admiral Farragut

Other Possibilities for Spaceship Design

What other possibilities exist for spacecraft design? You may be surprised to learn that we have quite a lot of them. I will mention a few of the leading candidates.

Ion Drives

Electric rockets, or ion drives, have been around a long time. They basically work on the same principle as the old vacuum tube, which is undoubtedly where the idea first came from. Figure 4 shows a diagram of an ion drive. An ion drive operates by heating a metallic propellant such as cesium to a high temperature. The metal vaporizes at high temperature, and the resulting ionized vapor passes through a grid where the electrons are stripped away to produce a positively charged plasma gas. This gas is then accelerated through a second, negatively charged grid until the plasma is traveling at a goodly percentage of the speed of light. Just before the plasma leaves the ship, the electrons are put back into the plasma, and the ion stream drives the ship with amazing efficiency.

We learned about specific impulse, the measure of rocket efficiency, in the last chapter. To date the space shuttle engine is the best rocket we have built, and its specific impulse (I_{sp}) is 450 seconds. Ion engines built in the 1960s demonstrated specific impulses of 30,000 seconds, a quantum leap in performance by any standard!

So why don't we use them to run our rockets? Because although an ion drive is highly efficient, it suffers from one major drawback. The thrust of the ion stream is extremely low. I believe the most thrust we have ever gotten out of one of these devices is less than 50 pounds. Obviously, a 50-pound thruster is not going to lift a million pounds of spaceship off the Earth, making the applicability of ion engines somewhat limited.

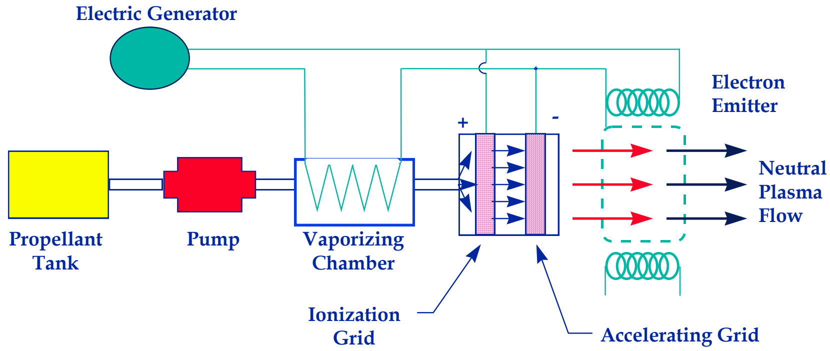

Figure 4: Ion Engine

While ion engines are too weak to lift a ship off the ground, once in orbit this limitation no longer applies. Ion thrusters are used to position communications satellites, and a spaceship with ion engines is feasible so long as it is an orbit-to-orbit design. Such a ship would turn on its thrusters and slowly build its velocity over a period of weeks. At first the engines would appear to have no effect, but slowly, the ship's orbit would widen in a spiral until the ship broke free of Earth. It might take a solid month of operation to reach cruising speed, but once there, an ion ship could outrun anything else in the Solar System.

Nuclear Pulse Engines

Figure 5 shows a diagram of an actual rocket concept that was under development in the 1950s. Called Project Orion, the idea was simplicity in itself. Want to fly in space? Just get yourself a really big metal plate, mount your ship on shock springs attached to the plate, then once each second, throw an atom bomb out the back and set it off!

Project Orion wasn't a puny little rocket; it was a ship capable of lifting city blocks. Unfortunately, it ran into two difficulties. The first was that it didn't exactly adhere to the spirit of the nuclear test ban treaty of 1962, and therefore, had to be cancelled. The second problem was that they were having a devil of a time finding a test pilot to ride it.

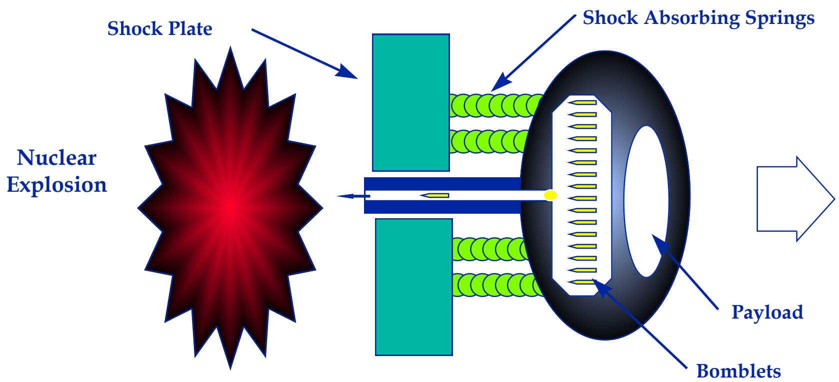

Figure 5: Nuclear Pulse Drive

Still, if you want to move something big, say an asteroid, nuclear pulse is the way to go.

Solar Sail

Another concept for moving things in space is the solar sail. A solar sail is just a big piece of aluminized plastic spread out to collect the rays of the sun. Since photons have momentum, when they bounce off the surface of the sail, they impart a force to the ship and by tilting the sail in the proper direction, you can make the ship go wherever you want. Like the ion drive, solar sailing is a slow process that is better suited to moving bulk cargo than it is people, but it has the advantage that the fuel (sunlight) is free. The disadvantage, of course, is that the farther away from the sun you move, the more sail area is required to drive the ship. The law of diminishing returns sets in before you get to the outer solar system. Figure 6 is a diagram of a solar sail.

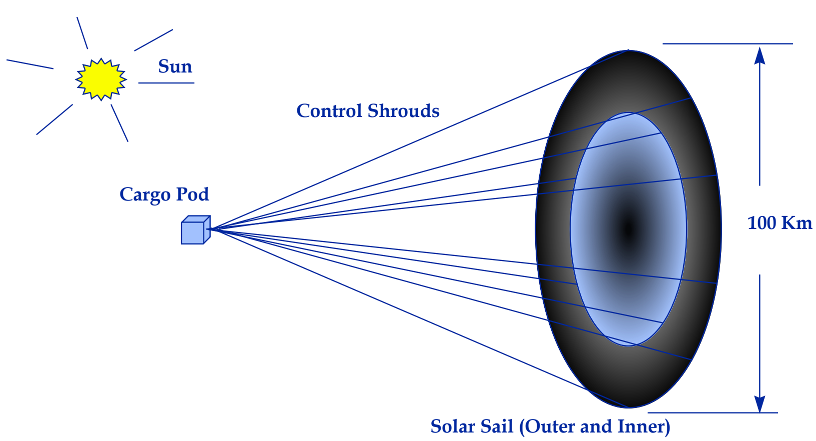

Figure 6: Solar Sail

Photon Drive

I stated earlier that the lighter the exhaust product of a rocket engine, the more efficient that engine is in driving a spaceship. That is why nuclear powered hydrogen rockets are better than chemical rockets, and why ion drives are better yet. The ultimate

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reaction mass, however, is not cesium ions. It's light! Photons have no mass at all, yet they possess energy that can drive a spaceship. In fact, a photon drive is the most efficient that is theoretically possibly. While the Space Shuttle has to limp along at 450 seconds I_{sp}, a photon drive has a specific impulse of *30 million seconds!* You can't do any better than that.

What would a photon powered ship look like? It would look a lot like a flashlight, but what a beam of light it would shed! Think of a laser beaming out the back of a ship and you'll have some idea. But if you build a photon-powered spaceship, watch where you point that beam! You could use it for drilling holes through things like moons and planets. You wouldn't want to vaporize some small town on Earth while rendezvousing with Mars, now would you?

Conclusion

Those, then, are the possibilities for building a ship that can support your interplanetary civilization. The good news is that there are sufficient options that some solution to the problem of an economically viable spaceship will eventually be found. And remember, those are merely the ideas that we know will work given sufficient development. There are a great many other propulsion systems that we don't know are possible … yet. All that may be required is some unforeseen breakthrough. What if you wake up tomorrow morning to discover someone has invented antigravity, or a reactionless thruster, or any of a hundred other things that science fiction writers have been talking about for years? And then there are the ideas that no one has thought up yet. Perhaps traveling to another planet is as simple as changing your space coordinates and finding yourself there. That would certainly be easier than spewing a column of flame out your butt every time you wanted to change course, now wouldn't it?

And then there is a way of describing your spaceship that always works. "Biff Spacer jumped in his ship and took off, arriving at Mars some thirty hours later. He buzzed Phobos on the way in, then set down on a pillar of flame and a cloud of rust-red dust." You don't have to know anything about spacecraft propulsion in order to write science fiction stories. However, I maintain that the quality of your writing will be better if you at least pay lip service to real science.

After all, at least some readers will know the difference!

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The End

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3. Antares Dawn - US$5.00

When the super giant star Antares exploded in 2512, the human colony on Alta found their pathway to the stars gone, isolating them from the rest of human space for more than a century. Then one day, a powerful warship materialized in the system without warning. Alarmed by the sudden appearance of such a behemoth, the commanders of the Altan Space Navy dispatched one of their most powerful ships to investigate. What ASNS Discovery finds when they finally catch the intruder is a battered hulk manned by a dead crew.

That is disturbing news for the Altans. For the dead battleship could easily have defeated the whole of the Altan navy. If it could find Alta, then so could whomever it was that beat it. Something must be done…

4. Antares Passage - US$5.00

After more than a century of isolation, the paths between stars are again open and the people of Alta in contact with their sister colony on Sandar. The opening of the foldlines has not been the unmixed blessing the Altans had supposed, however.

For the reestablishment of interstellar travel has brought with it news of the Ryall, an alien race whose goal is the extermination of humanity. If they are to avoid defeat at the hands of the aliens, Alta must seek out the military might of Earth. However, to reach Earth requires them to dive into the heart of a supernova.

5. Antares Victory – First Time in Print – US$7.00

After a century of warfare, humanity finally discovered the Achilles heel of the Ryall, their xenophobic reptilian foe. Spica – Alpha Virginis – is the key star system in enemy space. It is the hub through which all Ryall starships must pass, and if humanity can only capture and hold it, they will strangle the Ryall war machine and end their threat to humankind forever.

It all seemed so simple in the computer simulations: Advance by stealth, attack without warning, strike swiftly with overwhelming power. Unfortunately, conquering the Ryall proves the easy part. With the key to victory in hand, Richard and Bethany Drake discover that they must also conquer human nature if they are to bring down the alien foe …

6. Thunderstrike! - US$6.00

The new comet found near Jupiter was an incredible treasure trove of water ice and rock. Immediately, the water-starved Luna Republic and the Sierra Corporation, a leader in asteroid mining, were squabbling over rights to the new resource. However, all thoughts of profit and fame were abandoned when a scientific expedition discovered that the comet's trajectory placed it on a collision course with Earth!

As scientists struggled to find a way to alter the comet's course, world leaders tried desperately to restrain mass panic, and two lovers quarreled over the direction the comet was to take, all Earth waited to see if humanity had any future at all…

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7. The Clouds of Saturn - US$5.00

When the sun flared out of control and boiled Earth's oceans, humanity took refuge in a place that few would have predicted. In the greatest migration in history, the entire human race took up residence among the towering clouds and deep clear-air canyons of Saturn's upper atmosphere. Having survived the traitor star, they returned to the all-too-human tradition of internecine strife. The new city-states of Saturn began to resemble those of ancient Greece, with one group of cities taking on the role of militaristic Sparta...

8. The Sails of Tau Ceti – US$5.00

Starhopper was humanity's first interstellar probe. It was designed to search for intelligent life beyond the solar system. Before it could be launched, however, intelligent life found Earth. The discovery of an alien light sail inbound at the edge of the solar system generated considerable excitement in scientific circles. With the interstellar probe nearing completion, it gave scientists the opportunity to launch an expedition to meet the aliens while they were still in space. The second surprise came when *Starhopper's* crew boarded the alien craft. They found beings that, despite their alien physiques, were surprisingly compatible with humans. That two species so similar could have evolved a mere twelve light years from one another seemed too coincidental to be true.

One human being soon discovered that coincidence had nothing to do with it...

9. Gibraltar Earth – First Time in Print — $6.00

It is the 24th Century and humanity is just gaining a toehold out among the stars. Stellar Survey Starship *Magellan* is exploring the New Eden system when they encounter two alien spacecraft. When the encounter is over, the score is one human scout ship and one alien aggressor destroyed. In exploring the wreck of the second alien ship, spacers discover a survivor with a fantastic story.

The alien comes from a million-star Galactic Empire ruled over by a mysterious race known as the Broa. These overlords are the masters of this region of the galaxy and they allow no competitors. This news presents Earth's rulers with a problem. As yet, the Broa are ignorant of humanity's existence. Does the human race retreat to its one small world, quaking in fear that the Broa will eventually discover Earth? Or do they take a more aggressive approach?

Whatever they do, they must do it quickly! Time is running out for the human race…

10. Gibraltar Sun – First Time in Print — $7.00

The expedition to the Crab Nebula has returned to Earth and the news is not good. Out among the stars, a million systems have fallen under Broan domination, the fate awaiting Earth should the Broa ever learn of its existence. The problem would seem to allow but three responses: submit meekly to slavery, fight and risk extermination, or hide and pray the Broa remain ignorant of humankind for at least a few more generations. Are the hairless apes of Sol III finally faced with a problem for which there is no acceptable solution?

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While politicians argue, Mark Rykand and Lisa Arden risk everything to spy on the all-powerful enemy that is beginning to wonder at the appearance of mysterious bipeds in their midst…

11. Gridlock and Other Stories - US$5.00

Where would you visit if you invented a time machine, but could not steer it? What if you went out for a six-pack of beer and never came back? If you think nuclear power is dangerous, you should try black holes as an energy source — or even scarier, solar energy! Visit the many worlds of Michael McCollum. I guarantee that you will be surprised!

Non-Fiction Books

12. The Art of Writing, Volume I - US$10.00

Have you missed any of the articles in the Art of Writing Series? No problem. The first sixteen articles (October, 1996-December, 1997) have been collected into a book-length work of more than 72,000 words. Now you can learn about character, conflict, plot, pacing, dialogue, and the business of writing, all in one document.

13. The Art of Writing, Volume II - US$10.00

This collection covers the Art of Writing articles published during 1998. The book is 62,000 words in length and builds on the foundation of knowledge provided by Volume I of this popular series.

14. The Art of Science Fiction, Volume I - US$10.00

Have you missed any of the articles in the Art of Science Fiction Series? No problem. The first sixteen articles (October, 1996-December, 1997) have been collected into a book-length work of more than 70,000 words. Learn about science fiction techniques and technologies, including starships, time machines, and rocket propulsion. Tour the Solar System and learn astronomy from the science fiction writer's viewpoint. We don't care where the stars appear in the terrestrial sky. We want to know their true positions in space. If you are planning to write an interstellar romance, brushing up on your astronomy may be just what you need.

15. The Art of Science Fiction, Volume II - US$10.00

This collection covers the *Art of Science Fiction* articles published during 1998. The book is 67,000 words in length and builds on the foundation of knowledge provided by Volume I of this popular series.

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16. The Astrogator's Handbook – Expanded Edition and Deluxe Editions

The Astrogator's Handbook has been very popular on Sci Fi – Arizona. The handbook has star maps that show science fiction writers where the stars are located in space rather than where they are located in Earth's sky. Because of the popularity, we are expanding the handbook to show nine times as much space and more than ten times as many stars. The expanded handbook includes the positions of 3500 stars as viewed from Polaris on 63 maps. This handbook is a useful resource for every science fiction writer and will appeal to anyone with an interest in astronomy.

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