Interplanetary Space War

By
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"Nature abhors a vacuum!" — Anonymous Natural Philosopher, circa 1600 AD.

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If nature abhors a vacuum, why is there so damned much of it in the universe? When measured by volume, the universe is 99.99999999999999%-plus vacuum. Indeed, if you were to sample a trillion separate points at random across the whole 30 billion light-year expanse of the known universe, you could easily convince yourself that those points that are *not* pure vacuum are statistically meaningless. Except, of course, for the obvious fact that we human beings just happen to inhabit one such anomalous point.

No, the 17th Century sage who first noted that "nature abhors a vacuum" was suffering from a peculiarly human failing. The observation is true so far as it goes, which of course, is no farther than the philosopher's immediate surroundings. Having no flying machine to carry him aloft, he had no concept that atmospheric pressure diminishes with altitude, and by extension, must fall to zero somewhere not too far overhead. Nor did he understand that the movement of water up a straw is due not to nature filling a vacuum, but rather, to atmospheric pressure pushing it up from the bottom. Had the Renaissance possessed rudimentary space travel, our unknown natural philosopher could have discovered that air doesn't necessarily rush into a vacuum-filled flask as soon as the stopper is removed. Having none of these capabilities, he postulated the principle of *Horror vacuui*, and made the wild leap of faith that it must apply everywhere else in the universe. In other words, he was being provincial.

That is the problem with living our lives under the very special conditions that exist at the bottom of Earth's 100-kilometer thick sea of air. It tends to give us a skewed view of what the rest of the universe is like. We sit in our 1.0 gee gravity field, suck in air at 780 millibars of pressure and 20 degrees C, and then act as though these conditions exist for as far as the eye can see — and the eye can see surprisingly far, especially at night when looking straight up! Oh, we don't really believe that everywhere is just like here, at least not *intellectually*. We are sufficiently advanced to know that the universe over our heads is the hardest of vacuums. Emotionally, however, we aren't really convinced. Deep down where that small, six-year-old child lives in each of us, we are still utterly sure that we are immortal and nothing will ever really change. It is this subconscious belief in an unchanging, benign universe that causes that look of utter surprise whenever we step forward to discover our foot planted firmly in midair.

We explored this tendency to view things through the rose-colored glasses of our experience last month when we looked at the way space battles are portrayed in the movies. On the silver screen, spacecraft resemble nothing so much as sleek jet airplanes, and even those that don't outwardly resemble airplanes continue to maneuver as though they had wings. The larger warships — the star destroyers and cruisers of the Empire, or the long motley collections of geometric shapes of the Alliance — all move ponderously about as though they were so many battleships of yore. Paratroopers still descend from the sky and spacesuited Marines still dig foxholes with their short handled shovels. Cinematic future war has changed little from cinematic past war.

Of course, there is a reason why science fiction writers construct space battles that resemble the great naval slugfests at Jutland and Midway. We write these scenes because they relieve us of having to introduce our readers to something new. We make our own jobs easier by tapping into this storehouse of pre-existing myth and making off with the gold bars long stored there. So long as we can use this dodge to keep from working, there will be no shortage of dogfights in vacuum.

Our current level of technology limits what we can do to harass our enemies above the atmosphere. Oh, we might be able to shoot down a low-flying satellite or two, but general combat in vacuum is clearly beyond us. Nor are we liable to become much more sophisticated in the near future. Our rocket engines, the only method we have so far invented to maneuver in space, just aren't up to the task.

For would-be science fiction writers, these limitations on what we can do may seem discouraging. Don't worry. Our level of technology at the beginning of the twenty-first century is nowhere near the theoretical limits of what is possible. True, we currently strain everything merely to climb above our thin layer of air, but someday we will win through to the freedom of space as easily as we now fly halfway around the world.

Real space war will become possible on the day our technology reaches that level of sophistication, and on that day, the human race will enter its period of greatest danger. For if the military imperative to "take the high ground" remains as true as it has always been, then the society that rules space will have the capability to rule humanity. There is no "higher" high ground than space, and the energies involved in getting there make delivering death and destruction onto the heads of one's enemies nearly an afterthought.

Advanced Warfare Requires Advanced Propulsion Systems

As noted above, the current limitations on our ability to do combat in space are the result of the limitations of our chemically powered rockets. Luckily, manipulating the energy to be found in the outer shells of atoms is not the only game in town. It's just the easiest (and least efficient) method for breaking into the universe's great storehouse of available energy. There are other sources of energy that are much more efficient than chemical combustion, much more efficient and inherently far more dangerous in the hands of an adversary. We discussed propulsion systems at some length earlier in this series and I have no desire to repeat the gory details here. However, more than anything else, the ability to make war in space depends on the propulsive efficiency of the spaceships involved. What follows is a refresher course on the possible engines — both real and imagined — that may someday power our space navies.

<u>Nuclear Rockets</u>

The basis for chemical rockets is chemical combustion. For really high energy levels, you have to crack the atomic nucleus – literally! That there is energy to be had in the nucleus of an atom has been obvious since the morning of August 6, 1945, when a single B-29 Bomber destroyed the city of Hiroshima with a single bomb. With the birth of the atom bomb came humanity's first real hope of breaking free of the bonds of Earth. That hope was short lived. It died a little more than a decade later, crucified on a cross of anti-nuclear sentiment.

For decades now, we have been trained to think of nuclear energy in any form as a bad thing. This attitude, while understandable, is the mark of a society that has failed in its duty to teach its citizenry to cope with the inevitable march of technology. The problem with nuclear power is that, when placed in the wrong hands, it provides energy in doses sufficiently concentrated as to endanger the very existence of the human race. Well, I have news for you, friend. The same can be said of just about every other technology on which a space-based civilization must be built!

The reason for this is that an adversary in space has an inherent advantage over one on the ground. That advantage comes from position and velocity. The energy to achieve orbit is roughly equivalent to that required to fly once around the world. All of that energy becomes available to a spacefarer, whether his mission is to fly to the moon or destroy a target in an enemy land.

Nor is wholesale nuclear destruction the only option once you achieve orbit. Jerry Pournelle once championed a scheme to orbit several thousand 2-meter-long rods of depleted uranium. Each of these "flying crowbars" would have its own retro-rocket and guidance system, allowing the rods to be called down on targets anywhere on Earth at the punch of a button. The crowbar would arrive at its target moving in excess of 10,000 kilometers per hour. The resulting explosion would be something to behold. Basically, you merely wait until Mohammar Khadafy gets to the part of his speech where he says, "May Allah strike me dead if this isn't true…"

But I digress. The subject is nuclear powered spacecraft and what you can do with them.

We learned in "Spacecraft Propulsion" that the best reaction mass (in terms of efficiency) is the lightest reaction mass. The very best stuff to throw out the back of your rocket is monatomic hydrogen (molecular weight equal to 1). Unfortunately, to get things to burn, you have to combine the fuel with an oxidizer. In the Space Shuttle, hydrogen combines with oxygen to form water (molecular weight 18). This inherently decreases the rocket's efficiency; i.e., its ability to deliver the maximum change in velocity for the minimum mass of fuel.

A nuclear rocket doesn't have this problem. Its fuel source, uranium, never leaves the ship. Thus, instead of pumping a heavy mixture of fuel and oxidizer through the reactor, you pump pure, lightweight hydrogen. Energy from the fission reaction heats the hydrogen to the point where H_2 disassociates into simple H. Because efficiency is inversely proportional to the square root of the molecular weight of the reaction mass, all other things being equal, nuclear rockets are inherently 400% more efficient than hydrogen-oxygen rockets, the best we currently have.

If you happen to be someone who loves the space program and hates nuclear power, I have bad news for you. You're going to have to choose which of these two mutually exclusive ideals you are going to support. True space travel requires nuclear powered rockets. Without the energy of the atom, we will never seriously venture beyond our own atmosphere.

Antimatter Powered Rockets

As I have noted before in this series, my personal favorite rocket is one powered by antimatter. Antimatter particles have the same characteristics as their normal matter cousins except their electrical charges are reversed. One of my compatriots in the science fiction game suggested that it would make more sense to call the stuff "mirror matter."

The thing that makes antimatter such an attractive power source for rockets is that when a particle (electron, proton, neutron) and its antiparticle (positron, antiproton, antineutron) come into contact, they annihilate one another. One instant you have two particles, then the next, you have two equivalent bundles of energy. And since the "C" in Einstein's $E=MC^2$ stands for the speed of light — 300,000 kps — that's a lot of energy. Even more interesting, for each gram of antimatter expended, you get two grams of equivalent energy — a reaction that is 200% efficient! (You don't *really* get twice the energy from the reaction, of course. Two grams of matter and antimatter were annihilated. But normal matter is essentially free (dirt works just as well as gold in sustaining the reaction), so it seems like you are getting something for nothing.

Total energy conversion is thousands of times more efficient than nuclear energy. Thus, if we had a ready source of antimatter, we could build spaceships that could fly to the farthest planet in the Solar System within a month.

Most people are surprised to learn that manufacturing anti-matter is one thing we are quite good at. Indeed, we generate billions of antiprotons every second in our high-energy particle accelerators like the one at CERN. The problem isn't creating the antimatter, but rather, catching it once it's been created. Antiprotons born of catastrophic collisions between subatomic particles are generally traveling at nearly the speed of light as they leave the scene of the catastrophe.

For the process to be useful, we must somehow slow down the antimatter particles and then capture them, all without ever allowing them to come into contact with normal matter. How do you store antimatter? You contain it with a magnetic field and force it to circle around a vacuum-filled torus until such time as you need it. (This is one case where nature *loves* a vacuum.)

So why is antimatter so suited to spaceship propulsion? Because, even though the factory that produces the stuff weighs millions of tons, the factory never leaves the ground. The only thing you transport into space is the small doughnut shaped storage vessel stuffed full of antimatter, the most concentrated form of energy we can imagine. A few milligrams of antimatter contain sufficient energy to turn thousands of tons of liquid hydrogen to incandescent plasma.

Virtual Particle Rockets

Possibly the dumbest theory I have ever heard in physics involves something called “virtual particles.” For very esoteric reasons, physicists postulated a theory stating that far from being empty, the vacuum of space is a seething cauldron of subatomic particles. That is, particles like electrons and positrons appear out of nowhere (in pairs), and then disappear again too quickly for the pair to annihilate one another. And this doesn’t happen occasionally. It happens everywhere in the universe, trillions of times per second per cubic meter of space.

The theory is dumb because it basically postulates that the vacuum of space is actually a volume of super-high energy. If true, all matter is merely a transient wave on the surface of this underlying bubbling sea of particles, much as a television picture is a pattern of glowing phosphors on a picture tube. If virtual particles exist, then the total energy of the universe is far higher than we can see in all the stars in the sky. In fact, the theory is so dumb that it should have been discarded about two minutes after someone thought it up. There is only one reason why we keep the theory of virtual particles around — someone proved that the damned things actually exist in the mid-1950s!

What this means is that there is one more energy source that can be used to power a rocket, assuming we can find a way of “tapping” into it. That is the inherent bulk energy of free space. So far, our science has not come up with even a theory of how we might be able to do such a thing. If we ever do come up with the technology, however, our troubles with regard to interstellar travel may be solved.

Of course, like every energy source, “virtual particle power” would have its drawbacks. With the invention of the atom bomb, people worried about “blowing up the world.” In reality, of course, even if we exploded all of the nuclear weapons ever built, there would not be any serious damage to the planet. We human beings might not exist any longer, but ten thousand years after the event; it’s unlikely that you would be able to detect the effects of the war on the structure of the Earth itself.

Virtual particle energy would be of a totally different scale altogether. If we are ever able to tap into that sea of bubbling subatomic particles, we just might be able to turn the whole planet into an incandescent cloud of gas!

Antigravity

So far, we’ve spent a great deal of time talking about rockets. Are there no propulsion system concepts other than those that require us to throw valuable reaction mass overboard? Actually, there is one that might actually come to pass someday. I refer to that old science fiction standby, the antigravity generator.

People have been aware of gravity since the first caveman tried climbing a tree to rob a bird’s nest and fell out. Our understanding of gravity was much improved in 1687 when Sir Isaac Newton published his *Philosophiae Naturalis Principia Mathematica*, in which he included his Theory of Universal Gravitation. Basically, he stated that gravity is the force exerted on one mass by another, and that the force is directly proportional to the product of the two masses, and inversely proportional to the square of the distance between them. For the more scientific among you, his formula was $F=Gm_1m_2/r^2$.

Albert Einstein pointed out in 1915, that Newton’s gravitational law is wrong in one important respect. Gravity, it seems, is not a force of any kind! Light does not have mass, so it can’t be affected by a force. Yet, Einstein’s General Theory of Relativity predicted that light rays are bent in a gravitational field. This was only a theory until a solar eclipse in 1919 when scientists noted that stars near the blacked-out sun appeared to have shifted their positions slightly.

With the launch of the Hubble Space Telescope, we have been getting spectacular confirmation of gravity's ability to bend light. One of my favorite web sites is NASA's Astronomical Picture of the Day (APOD), which can be found at http://antwrp.gsfc.nasa.gov/apod/astropix.html. If you look at the APOD picture for June 14, 1998, you will see the best example of a gravity lens yet photographed. In this picture, there is a large galactic cluster interposed between us and a very distant blue-white galaxy. The cluster's gravity field bends the light rays from the blue-white galaxy just as though we were seeing it through a lens. There are at least four distorted views of the galaxy in the photograph. Don't trust me. Look it up. You'll be impressed.

So if gravity isn't a force, just what the heck is it? According to Einstein, gravity is a "curvature of the space-time continuum caused by the presence of mass." If we can ever figure out precisely what that means, we may be onto something useful. What if we were to discover some artificial way to reduce the "curvature" of the space time continuum locally through the application of energy? In theory, anything included in the volume of "lesser curvature" would naturally tend to float upward until the external space-time curvature matched that inside the antigravity generator's field. On the day when we can perform this trick, we will have reached a major milestone in the history of the human race. We will make the rocket and all other reaction engines obsolete. Effectively, we will have discovered a method for pulling ourselves up by our bootstraps!

Space Combat Tactics

Once we have built a better spaceship, say one that is able to change its velocity by at least 100 kilometers per second, then we will be free to make war virtually anywhere in the solar system. But having the propulsive power to seek out an enemy and engage him in combat is only half the problem.

For a science fiction writer it isn't enough to say "the ships lunged at one another like two fighting terriers." If we are going to write convincingly about combat in space, we need to know something about how ships maneuver in vacuum. Basically, there are only two venues for a battle in interplanetary space. Either the ships are in orbit about some planet (like Earth) or else they are in orbit about the sun. Depending on which situation exists, combat tactics can vary significantly.

<u>War in Orbit</u>

As one who used to get up at 4:00 O'clock in the morning to watch Mercury, Gemini, and Apollo space launches, I received an early education in practical orbital mechanics. Then, in my last semester of college, I found that I only needed five semester hours to graduate. So, not wanting to get drafted, I decided to fill out my schedule with classes that interested me. One of these was Orbital Mechanics. As a professional science fiction writer, I have found this background to be exceedingly useful.

We have discussed the fact that orbits are conic sections (circles, ellipses, parabolas, and hyperbolas) several times in this series and won't go into that again here.

However, the way you overtake another ship in orbit is not intuitively obvious. Let us say that you are in an armed spacecraft in a 1000-kilometer-high orbit above the Earth, and that your enemy occupies the same orbit on the opposite side of the planet. With everything remaining equal, both ships have the same orbital period, and therefore, will never see one another. So, having resolved to rid space of that ship on the other side of the world, how do you go about catching it?

Obviously, if your quarry is ahead of you and you want to catch him, you speed up, right? No, sorry. If you are in a 1000-km orbit and accelerate, what happens is that you move to a higher orbit (say 1500-km high), and since things in higher orbits tend to orbit more slowly, you will soon find your enemy coming up behind you rather than vice versa.

This situation is so counter-intuitive and important that we need to look at it more closely. When you accelerated with the intent of overtaking your enemy, what you actually did was put your ship in an elliptical orbit with a perigee of 1000 km and an apogee of 1500 km. (Perigee is the minimum altitude point and apogee is the maximum altitude point. They occur at opposite ends of an orbit.) If you take no additional action, you will move in this lopsided orbit, descending to 1000 km altitude at the same point each orbit, and then rising to 1500 km altitude on the exact opposite side of the planet. Yet, even though you are going substantially faster in terms of your linear velocity (km/sec), you keep losing ground to your enemy. It is he who is gaining on you, not vice versa. What happened?

The problem lies in the fact that a spaceship isn't an automobile and an orbit isn't a highway. You don't "stay in the same lane" when you increase your velocity. Since an orbit is just one giant curve, increasing your velocity causes you to move to the outside of the curve, where the distance to be traveled is greater than when you were in the inside lane. Thus, even though your speed has increased, the length of the path you must traverse has increased even more. This brings about the contradictory situation that even though your linear velocity is faster; your angular velocity (in terms of degrees of longitude traversed per unit time) has fallen.

When attempting to engage an enemy, you slow down to overtake. By slowing down, you drop to a lower altitude, and shorten the path to be traversed, thereby increasing the angular velocity of your orbit. Then when your enemy is in sight, you speed up again, returning to the original orbit and overtaking him from below and behind. That is the reason why orbital combat is counterintuitive. Slow down to overtake; speed up to fall behind!

The relative positions "ahead" and "behind" don't mean as much in space as they do in the atmosphere. Remember that the orientation of a ship in orbit is completely arbitrary. Since there is nothing to prevent you from turning around and flying ass backwards through the sky, the difference between overtaking and being overtaken is largely a matter of human prejudice. Eventually, your ship and that of your enemy come within weapons range of one another and the two of you exchange fire until one ship or the other is damaged or destroyed.

What is not obvious to the layman is that war in space requires some degree of cooperation between the combatants. Of course, that is the case for war everywhere. In air-to-air and space-to-space combat, each party usually has the option of breaking off and leaving the scene of battle. This is one of the things they teach in Air Combat

Training. If you find yourself at a disadvantage, break off and seek a tactical situation more to your liking. In the extreme, break off and run for home, saving yourself and your craft to fight another day.

Since space is large and the ships we are postulating are very capable, it will be virtually impossible to destroy an enemy who seeks to avoid engagement. The trick will be (as it is in all war) to make your enemy *want* to engage you. This is best done by attacking something your enemy cares about, or by giving him the false impression that you are ripe for the picking.

<u>Change of Plane Maneuvers</u>

As Mr. Spock noted in the climax of *Star Trek II: The Wrath of Khan*, people raised on the Earth have a tendency to think in two dimensions, whereas war in space is a three dimensional affair. Thus, when we think of orbits, we get out our paper and draw circles and ellipses, all in the same plane. The problem, of course, is that finding two ships orbiting in the same plane is wildly improbably unless both parties have a reason for being there. One such reason is that they are in geosynchronous orbit at 35,000 kilometers (22,300 miles) above the equator. Since geosynchronous orbits are *only* possible in the plane of Earth's equator, that particular orbit is getting fairly crowded with communications and weather satellites.

People often wonder why Halley's Comet hasn't hit the Earth. The reason is simple. It orbits in a different plane than we do and our paths through space do not intersect anywhere. Two orbits that do not intersect and are in different planes are referred to as "skewed." In any future conflict, it is likely that the combatants will be in skewed orbits. That is, they will occupy neither the same orbital path nor the same orbital plane.

This will make things interesting. For one thing, attacking someone in a skewed orbit means that the time you have to attack them will be very short and pursuits will be practically impossible. That is because "change of plane" is the most difficult of all orbital maneuvers.

Think of an orbital plane as a giant sheet of paper on which is inscribed an ellipse. That ellipse is centered on the large basketball shape of the Earth. Now add a second sheet of paper at an angle to the first, with an inscribed ellipse also centered on the Earth (that is, the Earth is at one of the focuses of the ellipse). For a ship on one ellipse to attack a ship on the other, it is necessary to swing the two sheets of paper around the center of the basketball until they are lying on top of one another. Swinging the plane of an orbit takes much more delta V (change in velocity) than does merely changing the shape of the ellipse while remaining in the same plane (on a single sheet of paper).

If you have trouble visualizing this situation, you understand why orbital mechanics are not totally intuitive. For a special case, consider the situation where a ship in equatorial orbit (in the plane of Earth's equator) wishes to attack a ship in polar orbit (in the plane of Earth's poles). Both ships are traveling at 30,000 kph (18,000 mph), but at right angles to one another. They pass near each other twice each orbit (assuming their orbital periods are the same and synchronized). That is, whenever the polar orbiting ship crosses the plane of the equator, the two can trade shots. But for one ship to pursue the other requires that it change is velocity by 42,000 kph (25,000 mph) and its orbital plane by 90 degrees. (The problem involves vector addition for those who want to do the math).

Compare this requirement with the need to change velocity to overtake a ship in the same orbital plane. If you wish to overtake your enemy and you don't mind how long it takes; reducing your velocity by even a single kilometer per hour will eventually cause you to overtake them. In this rather extreme example, it is 25,000 times easier to engage an enemy in the same plane than it is to engage one in a plane at 90 degrees to your own. Of course, in real life, the multiplier isn't nearly that high.

Combat In Solar Orbit

Combat between ships in orbit about the sun is simpler than the situation where the combatants are in orbit about a planet. The reason for this is that all the planets orbit in approximately the same plane. This is why the planets sometimes form a straight line in the sky. This plane is known as the ecliptic, and being very provincial, we have defined the ecliptic by Earth's orbital plane (0.0 degrees of inclination).

Since all ships are more or less in coplanar orbits, combat in solar orbit is reduced to the two-dimensional duel that is common for ships at sea. And since any solar orbit outboard of Earth takes years to complete, it will largely be possible for ship captains to forget that they are in orbit and pretend that they have full freedom to maneuver. Thus, warring ships and fleets will do battle by intentionally rendezvousing with their foes and slugging it out on intersecting orbits that are nearly coincident, but which keep sufficient differences in velocity that the loser can be assured of an escape at any time he wishes.

In solar orbit, you just point your ship at the enemy and slug it out!

Conclusion

No matter how restrictive our current technology, sooner or later we will break free of the straightjacket in which we find ourselves, and will be able to pursue our species' favorite antisocial hobby above the atmosphere. Note that his should not be considered a good thing from the standpoint of the human race. It would be better for all of us if we can live in peace with one another for the rest of eternity.

Unfortunately, eternal peace is not something that is good for the writers of escapist fiction. Fiction is about conflict, and there are few purer forms of conflict than warfare. It is against this backdrop of violence, death, and destruction that we must often set our stories; so fiction in which the race is happy and at peace does not generally sell well at the bookstore.

So what will future war in space (hopefully fictitious) be like? It may eventually come to resemble something akin to the cinematic version that we enjoy on the silver screen today. Given sufficient delta V capability, a fleet commander can concentrate on maneuver and surprise, and not have to fight with one eye on the readout telling him how much reaction mass remains in his tanks.

The U.S. Air Force has already written a specification for a "Space Fighter." The requirement is very simple. The space fighter must be able to make a U-turn in orbit. In other words, when proceeding 30,000 kph in one direction, it must have sufficient delta V capability to halt, reverse course, and end up going 30,000 kph in the exact opposite direction (16 kps of delta V).

I think you can see that a fighter or warship with that kind of maneuvering capability would essentially have the freedom of space. No longer would commanders be forced to take long, slow transfer orbits to get at their enemies, or place themselves in orbit about the planet such that they would encounter their enemy each circuit. They would be able to slash and run, maneuver and counter-maneuver. Instead of the long, slow elliptical orbits now used to get from world to world, the war fleets of the future will launch themselves in long, flattened hyperbolas that cut across the larger circular orbits of the planets at acute angles and vastly exceed local escape velocity. They will swoop down on their enemies ("down" being a figurative term in this context) with closing speeds measured in the tens of kilometers per second. Then, having struck a slashing blow, they will decelerate as quickly as their crews' bodies will withstand, reverse course, and strike again.

Space war in the future will be fought under continuous power, with crews strapped into their acceleration couches and unable to move anything but their fingers. When our ships become that powerful, space war will move from the era of the sailing ship to that of the jet airplane. At that point, things are likely to get *very interesting*.

And as the old Chinese curse states: "May you live in interesting times!"

The End

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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…

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?

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.

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.

