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Introduction to Spacesuit Design

By
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We have discussed many aspects of the science fiction writer's art in this series. We've explored the Solar System, delved into what it is that makes a rocket work, and spent some time out among the stars. We've assaulted Einstein's universal speed limit and frolicked in the great river that is Time. We've even crossed over the time barrier into alternate universes, to explore the wonders they hold for the writers and readers of speculative fiction.

To the uninitiated, the universe looks to be a complicated place, one well beyond our level of understanding. Everything about the universe is stupendous. It is a void so wide that it takes light traveling at 300,000 kilometers per second (186,000 miles per second) more than 30 billion years to cross from one side to the other. In addition to vacuum, this vast void is littered with galaxies, stars, planets, moons, gas, dust, and hordes of subatomic particles. The galaxies alone are more numerous than the grains of sand on a beach, and the population of stars exceeds that of all the fish who have ever been bathed by the life-giving waters of Earth's oceans.

Despite the fact that we live in an age when scientific education leaves a lot to be desired, even the common person is sufficiently educated about the universe to be daunted by its size and complexity. Yet, the cosmologists who study the vast black void above our heads are mystified for another reason. Rather than be intimidated by the universe's inherent complexity, they continue to ask a question as fundamental as it is non-intuitive. "Why," they ask, "is this giant machine so damned simple?"

"Simple!" you exclaim. "How can they call 10^{32} cubic light-years worth of stars and galaxies simple?"

It all depends on how you look at it. Consider the following: One of the most basic of all the universe's laws is Einstein's equation relating the equivalence of matter and energy, the famous $E=MC^2$. Virtually everyone knows this equation even if they don't understand its implications. For the record, $E=MC^2$ states that mass can be changed directly into energy (and vice versa), and the multiplier between the two is the speed of light squared. If this seems needlessly esoteric to you, consider that this is the principle that causes the stars to shine at night and atom bombs to explode.

But we aren't interested in uranium fission or hydrogen fusion at the moment. Don't worry about what the equation means. Rather, look at its form. It is an equation consisting solely of three letters and a single superscript, an equation so simple that even my wife has memorized it. Yet, it is also one of the most basic operating principles of the universe. You would think that one of the operating principles of the giant, complex engine that is the universe would at least run to a few hundred pages of symbolic logic in small type.

Yet it doesn't. It consists of three letters and a superscript. Nor is this the only occurrence of this sort of observation. Virtually all of the more basic universal principles are defined by short, simple equations ($F=MA$, $F=GM_1M_2/R^2$, $E=IR$). In fact, the situation is so bizarre that you can almost determine how basic an equation is by looking at its complexity. If it's big and complicated, then it isn't basic. That then is what the physicists are talking about when they wonder at the simplicity of the universe. The more we learn, the simpler things appear to be.

Over the past five hundred years, we have progressed from the idea that the universe is too complicated for mere mortals to ever understand God's handiwork, to the idea that the universe may be defined by a single simple equation. And, in fact, the deepest of the deep thinkers among us seem to believe that they have discovered that equation. The equation and its variants go under the name of Superstring Theory, so called because we recognize the form of the equation as that of a vibrating string in 10 dimensions. That's right, folks! As we have discussed before, the universe has nine spatial dimensions and one time dimension, and where the other six space dimensions have gone, we do not know. When we find out, life could get very interesting for science fiction enthusiasts!

What has all of this got to do with spacesuit design? Simply this. Many of you read the title of this chapter and decided that you could never understand anything as complicated as a spacesuit. Yet, you have just read several hundred words dealing with the frontiers of cosmology and probably didn't blink an eye. So if you think building a spacesuit is complicated, disabuse yourself of that opinion. It is certainly easier to understand than subjects like Philosophy or Art Appreciation! As they teach us in engineering school, any problem can be solved by first breaking it into smaller problems, and then solving these sub-problems one at a time.

So, if you have any doubts about your ability to follow along with this month's topic, take heart. Spacesuits are relatively simple devices — in principle, at least. Nor is it required that you, an author, actually build one. All you need is to have sufficient understanding to describe a spacesuit convincingly. Like everything else in science fiction writing, you need only avoid unintentional comedy. Stick with me for the next few pages and you, too, can pretend you are an expert.

After all, *pretend* expertise is so much easier to acquire than *real* expertise. So let us consider what we must do when we venture beyond the confining walls of our spaceship. Just exactly how do you go bounding across that brightly-lit lunar plain without your eyes popping out of your head or your blood boiling? Or perhaps we should consider a more mundane problem first. After spending nearly an hour bolting yourself into your brand new spacesuit, just what do you do when the call of nature comes?

Answers to these problems and more in the next couple of articles. But first, a short history.

A History of Spacesuits

The first spacesuits weren't spacesuits at all. They were "hard hat" deep-sea diving suits. You've all seen them in movies. A diver puts on a canvas suit, sits down in a chair on the back of a rocking boat, and then his assistants drop a big bowl with round portholes over his head.

In a hard hat diving suit, the diver wears a heavy helmet attached to a broad yoke that sits on his shoulders. The yoke is attached to a watertight canvas suit. Air is pumped through a long hose into the helmet, and then exhausts to seawater through an exhaust valve where it bubbles back to the surface. The valve keeps the air pressure inside the suit at the same pressure as the water around the diver, allowing the diver to breathe regardless of depth.

Hard Hat Diving Suit

Like a spacesuit, the diving suit is intended to protect the wearer from the outside environment, which is sufficiently hostile to kill him in a few minutes. And like a spacesuit, there are innumerable things that can go wrong in hard hat diving, most of them fatal. There are the obvious failure modes that a diver must guard against. The air pump on the surface can stop working, or the hose delivering life-saving air can become snagged or broken. In either case, the helmet quickly fills with water and the diver drowns.

I'm sure that the 18th Century inventor of the diving suit was well aware of these dangers when he first lowered some brave soul into the deep with his head stuck in a big copper bowl. These were not the only dangers, however. As early divers quickly discovered the hard way, there are things that go wrong beneath the sea that are just as fatal as drowning. The most common problem is "the bends," which occurs when pressure is released from blood saturated with nitrogen. Just as a coke bottle fizzes when you take the cap off, so too does human blood after the pressure is relieved following long periods under compression. There are few things worse for a human being than to have little gas bubbles floating around in the circulatory system. As soon as a bubble reaches a capillary too small for it to pass through, it sticks there, shutting off the flow of blood to that part of the body.

Another problem that caught the early divers by surprise involved the failure of the air delivery system. A hard hat diving suit has a non-return valve (what is known as a check valve) at the point where air enters the suit. The purpose of this valve is to ensure that air can only go in one direction – into the helmet. If this check valve did not perform its function and the pump failed, then the pressure in the diver's helmet quickly equalized to the pressure on the surface. Unfortunately, the pressure on the rest of the diver's body remained that of the surrounding water. Even small pressure differentials can be deadly when applied across large areas — say the area of a diver's head and shoulders. The effect on the human body of losing helmet pressure is much the same as that on toothpaste when you squeeze the tube in the middle. Suddenly, several tons of force are generated which tends to jam the diver's body up into his helmet.

We've come a long way since those days when men were lowered into the sea in a couple of hundred kilograms (400 pounds) of diving apparatus. Modern commercial divers still work at the end of a long hose because surface-supported diving allows them to stay down much longer than does SCUBA diving. Still, the modern equipment is dramatically improved over the traditional diving suit.

Nor is our "diving" limited to water. Other men have cavorted on the surface of the moon, or floated about in space. However, the undersea lessons of that long ago time still apply. They apply because all of the dangers inherent in deep sea diving are also inherent in spacesuit design. The spacesuit occupant can drown (at its most basic, "drowning" is death by oxygen deprivation), develop a bad case of the bends, or be torn asunder by unbalanced pressure differentials. We will discuss the hazards inherent in the space environment shortly. For now, however, on with the history lesson.

Early Altitude Suits

The next development in the "spacesuit" (a more proper name would be the "artificial environment suit"), was in the field of aviation. By the 1930s, the early box-kite airplane designs had begun to mature to the point where pilots could fly to altitudes where they would be incapacitated by anoxia (lack of oxygen to the brain). One of the most intrepid of the early flyers, Wiley Post, decided to set a world altitude record in his supercharged Lockheed Vega. Since pressurized aircraft cabins were unknown at the time, Post designed a high altitude suit that ran off his aircraft engine's turbocharger. (Despite his many aviation firsts, Post is mostly remembered for a trip he took to Alaska with humorist Will Rogers in 1935. It was his last. His aircraft crashed, killing both Post and Rogers.)

Photographs of Post in his altitude suit always show him sitting down. The reason for this is that his suit was constructed in a sitting position and he couldn't stand in it. He had tried a conventional suit, but when pressurized, Post discovered that he couldn't sit down, or move his arms and legs sufficiently to control the airplane. By fabricating the suit in a sitting position, he was able to operate the aircraft controls, although his movements were still terribly restricted by the force required to flex the pressure suit.

Mercury Astronauts

This is a problem that haunts spacesuit designers to this day. The problem was that Post's suit was merely an inflated balloon and when he moved his arms or legs, the volume of the balloon decreased, causing the pressure inside to increase. This, in turn, generated considerable resistance to the movement of his limbs. To combat this problem, modern spacesuit designers use various complex schemes in constructing such joints as elbows and knees. Most involve the use of accordion-pleated bellows in the joint. The corrugated shape of a bellows joint can be bent without changing the overall volume of the suit. When the astronaut bends his arm at the elbow, the pleats in the bellows joint compress at the inside of the bend, but extend at the outside of the bend, thereby maintaining an overall constant volume. Since moving an arm no longer involves pumping up the pressure in the suit, movement becomes much easier – which is not to say easy.

Gemini Astronauts

The Evolution of Space Suits

With the arrival of the space race in the 1960s, there came a strong impetus to improve environment suits. The first such suits were adaptations of Air Force high- altitude suits where the wearer was corseted into a skin-tight body suit and then had a combination oxygen mask and helmet attached. While this approach appears primitive today, the idea has considerable merit for a very advanced spacesuit – see the section on Advanced Spacesuits in next month's article.

Apollo Astronaut

The first true spacesuits were those worn by the Mercury astronauts, although they were also modifications of military high altitude suits. The Mercury suit had a layer of neoprene rubber (the impermeable barrier that contained the gas) under a nylon layer that supported the rubber and kept it from blowing out under pressure. The Mercury suit wasn't a very good spacesuit, but then, it wasn't intended to be. Its primary purpose was to act as a safety device in the event the Mercury capsule lost pressure (which none of them ever did). Thus, the Mercury suits were never called upon to perform their function.

In Gemini, the suits had to be improved because the astronauts actually intended to go outside in them. However, the range of motion required during a Gemini extravehicular activity (EVA) was limited. Most such spacewalks involved the astronauts merely standing up in their seats. Thus, while the arms had to work in a Gemini spacesuit, mobility of the feet was not a major consideration. So the engineers spent a lot of time working on the arms, but it was difficult to walk in an inflated Gemini spacesuit.

This changed in Apollo, where the astronauts required full mobility. Not only did they have to manipulate things with their hands; they had to walk around the lunar surface. The Apollo moon suits were very sophisticated devices. These suits were improved again for the Space Shuttle program.

Shuttle Astronaut

Spacesuits are designed to keep a bubble of earthlike environment surrounding the astronaut, while keeping the cold vacuum of space outside. As such, they must all contend with one of the harshest environments ever encountered by human beings. What then are the characteristics of this environment?

The Space Environment

We who live on the surface of the Earth have certain subconscious expectations of what our environment will be like. We expect the air pressure to be on the order of 101 KiloPascals (14.7 LB per sq. inch), the temperature to be above 0°C (32°F) most of the time and well below 100°C (212°F) all of the time. We expect gravity to pull down on us with an acceleration of 9.8 m/sec^2 (32.2 ft/sec^2) and for the ground beneath our feet to be relatively stable.

In space, none of these expectations are met. Air pressure is precisely 0.0 KPa, temperature varies widely depending on whether you are in sunlight or shade, and gravity is non-existent. Since the organic machine known as a human being is designed to operate in the environment that exists on the surface of the Earth, the fact that space lacks air, a controlled temperature, and gravity presents problems for the intrepid space traveler. In fact, exposure to the vacuum of space is quickly fatal, making it something you don't want to do, not even once.

Chief among the hazards of space is the lack of air. I don't mean that space lacks oxygen. It is devoid of gas molecules of any kind, at least in the quantity that we take for granted on Earth. This lack can have serious deleterious effects on an organism that evolved at the bottom of a sea of air more than 100 kilometers (60 miles) deep.

The Vacuum of Space

Pilot Boiling Water

Let us begin simply. Vacuum is volume without substance. Vacuum doesn't merely lack the chemical oxygen that the human body needs to support combustion. It is the lack of all gasses and liquids. Vacuum *looks* like air because both are colorless, but it *isn't* air. It isn't anything! It's a place where the wind never blows, where you can rocket at a thousand kilometers per second without feeling the slightest breeze, and where you can push down on the handle of a tire pump a million times without inflating the inner tube of your moon rover even a little bit.

It is common knowledge that vacuum is hazardous to human beings and other living things. Those of us who read science fiction novels or watch SF movies have encountered numerous gory descriptions of what happens to the human body when it is exposed to vacuum. The victim's eyes pop out of his face and his head explodes, followed by the rest of his body in a gruesome spray of boiling, red liquid.

The only problem with this image is that it isn't true. Vacuum will kill you, all right, but it won't explode you. You die because your lungs are starved for oxygen, and shortly thereafter, so is your brain. Like drowning, which is a similar death, human beings exposed to vacuum don't die instantly. First they lose consciousness and then they are asphyxiated. If help arrives quickly enough, the victim may even survive. I remember seeing a news report of a NASA technician testing a spacesuit in a vacuum chamber. His glove came off and his suit lost pressure. He lost consciousness immediately, but was saved when the test director ordered an emergency re-pressurization of the chamber. So far as I know, he survived with no long-term effects.

In Stanley Kubrick's *2001, A Space Odyssey*, there is a scene where the surviving astronaut ("Dave," played by Keir Dullea) is marooned in his small orbital scooter without his helmet. The problem is that *Hal*, the crazy computer, won't let him back in the ship. So he blows the hatch on his scooter, vaults through vacuum to the open airlock of his ship, then re-pressurizes the lock before he loses consciousness. While dramatic, the scene is scientifically accurate. People can "breathe" vacuum for a limited period. Typically you lose consciousness in about 15 seconds, although flooding the body with oxygen should increase that time. Fifteen seconds can be an eternity when your life depends on it.

So how did we all get the idea that the human body explodes in vacuum? Like many of our loonier concepts, it comes from a basic scientific principle that is well understood, but misapplied. One of the things that Air Force pilots have long demonstrated is that water boils at room temperature when one reaches the stratosphere. Typically they demonstrate the principle by holding an open container of water in an altitude chamber. Obviously, if water boils in vacuum, then blood does also. So why doesn't it boil in an astronaut's veins when he is exposed to vacuum?

To answer that question, think about the differences between a human body and a length of sausage hanging in the display window of your local butcher shop. In fact, there is very little difference between the two. Both are meat filled tubes covered by an impermeable membrane. And just as the sausage casing prevents its insides from spraying outward when it is exposed to vacuum, so it is with the "casing" of a human being. A person's blood doesn't boil when he is exposed to vacuum because the internal blood supply is still under pressure. It takes a long time for that mass of meat and capillaries that we call our bodies to lose their internal pressure. Long before the pressure drops to where the blood begins to boil in our veins, we will have been exposed to other highly fatal effects of vacuum.

It is the differential between internal and external pressure that causes most of the damage to the human body in vacuum. The loss of oxygen in our lungs is worst, of course. Other damage is caused by the fact that our skin is both watertight and gas tight. In fact, it makes a pretty good balloon covering. The problem is that the skin lacks strength, especially when placed in tension by an interior-to-exterior pressure differential. If a human body were hollow inside our epidermal layer, it might well explode when exposed to vacuum. But, of course, the skin isn't merely inflated by pressure. It is anchored to the underlying meat all over our bodies, which gives it sufficient strength not to burst.

As soon as one is exposed to vacuum, those blood vessels that are closest to the surface and weakest begin to rupture. The blood vessels in the eyes are especially sensitive to this sort of thing, as are the veins just beneath the skin. A "vacuum breather" who survives the experience is likely to have bloodshot eyes and varicose veins.

The other problem is the one the divers first encountered – nitrogen bubbles coming out of solution in the blood and stopping up various capillaries in the circulatory system. In other words, the bends. A human body in zero pressure will eventually tend to fizz like an open coke bottle, and that is bad news as soon as one of those gas bubbles reaches the brain and shuts off the flow of blood to the brain cells.

So if exposure to vacuum is so hazardous, all a space traveler need do is seal themselves up in a man-shaped balloon and fill it with life-giving oxygen, right? Well, it's a start, but it isn't sufficient for long term survival. Once you have oxygen to breathe at sufficient pressure to keep your brain alive, your next problem involves heat. For as the Thermos Company discovered many decades ago, the thermal characteristics of vacuum can be quite useful – and also, quite deadly!

The Thermal Properties of Vacuum

Most people are surprised to learn that the human body is a fairly efficient heat engine. In fact, human beings are some of the most efficient space heaters around. If you don't believe me, just remember the last time you had to stand in a crowded auditorium or bus without air conditioning for any length of time. No matter the temperature when you entered, it was undoubtedly sweltering within a few minutes. A human being working "vigorously" can generate up to 2 million joules of heat per hour. Somehow that heat must be dissipated if the astronaut is not going to slowly broil in his own juices.

There are various mechanisms for heat transfer. The three most important are conduction, convection, and radiation. The problem people in space have with heat is that in a vacuum, there is essentially only one heat transfer mechanism – radiation. And since radiation isn't very efficient at the temperatures human beings find comfortable, it is very easy for someone in a spacesuit to overheat. In fact, next to supplying the body with oxygen, getting rid of waste heat is one of the more important functions a spacesuit needs to perform.

To understand why this is, it is necessary to review a bit of high school physics. Conduction is the transmission of heat through a substance. Convection is the transfer of heat from one substance to another via a flowing gas or liquid. Your car has a mechanism in front of the engine called a "radiator." The name is a misnomer. An automotive radiator actually cools by convection. Hot water carries the heat from the engine (a form of convection), and then the heat is transferred to the moving air molecules generated by the vehicle's forward motion or a fan. It would be more correct to call the mechanism a "convector."

Radiation is just what it sounds like. Things that are hot emit photons of a distinct wavelength, and these photons carry away the heat. Everything above absolute zero radiates heat. The amount of heat radiated is determined by the fourth power of the absolute temperature. In other words, double the absolute temperature of an object, and you increase the level of heat energy being radiated by a factor of 16.

The problem with wrapping oneself up in a spacesuit is that human beings are designed to cool primarily by convection, and by a related phenomenon, evaporation. That is, the heat required to boil the water in our perspiration is carried away when that perspiration is vaporized, causing a significant cooling effect.

Objects in the vacuum of space can cool themselves only by radiation. Since space lacks air, there is no wind to carry off the waste heat or to evaporate the sweat beads on the skin. Nowhere is it written that you can't cool a human being by radiation, but at the temperatures human beings find comfortable, radiation is a much less efficient heat transfer mechanism than either convection or evaporation. This makes cooling an astronaut in a spacesuit a non-trivial exercise.

Microgravity and Frictionless Movement

One of the biggest worries about the space environment before the age of space was weightlessness. Actually, space is almost never absolutely "weightless," so scientists prefer to use the more precise term "microgravity." On Earth we are subjected to gravitational acceleration of 1.0 standard gee, whereas in orbit, the accelerations to which the human body are subjected are less than a thousandth as much. The fear was that when subjected to weightlessness for long periods of time, the human body would undergo physiological changes that would make returning to the Earth's gravity hazardous.

This belief in irreversible physical changes is one of the plot devices used in Robert Heinlein's *The Moon is a Harsh Mistress*. In that book, Luna is being used as a penal colony and people sentenced there quickly lose the ability to return easily to Earth. They can visit after long preparation in a centrifuge, but their bodies have been irreversibly changed to adapt to the lower gravity on the moon.

Luckily, that particular problem did not come to pass. There are physiological changes to the human body as a result of exposure to microgravity, but the body readapts to the Earth's gravity fairly quickly after the astronaut returns. Among the physiological changes are a gradual weakening of the bones through calcium loss and a general increase in skin oil, making pimples more than an adolescent problem.

Luckily, there is no need to equip our spacesuits with artificial gravity generators to keep their occupants healthy. I say "lucky" because we don't know how to build an artificial gravity generator. However, there is one other aspect of weightlessness that is a problem, and possibly a very major problem.

For although things possess mass in the microgravity of space, they are essentially weightless and frictionless. In other words, they can be set into motion – say rotating – with ridiculous ease, and once set in motion, experience has proven that they are difficult to get stopped again. In fact, the astronauts have had so many handling problems in the cargo bay of the Space Shuttle when attempting to retrieve malfunctioning satellites, it makes one wonder if we are really ready to begin assembling the International Space Station. [Author's Note (06/04): It turns out that we were successful in assembling the Space Station. What we seemed to have overlooked was that, from time to time, the wing will fall off the Space Shuttle. As a result, the Space Station has been getting by using Russian expendable booster technology. Is this any way to run a railroad?]

Working in space requires that we develop a whole new set of tools based on new operating principles. Take something as simple as an electric drill. On Earth we use the friction our bodies possess with respect to the ground to react the torque of the drill as it spins the bit at high speed. In space, an electric drill will send the astronaut spinning unless it is specially designed to cancel the reaction. This is only one example. There are hundreds of others that must be countered by spacesuit designers.

<u>Input and Output: The Daily Minimum Needed To Maintain Life</u>

The human body is, first and foremost, a biochemical machine. Machines, by their very nature, have a continuous need to consume energy and to exhaust waste products. Take, for instance, the 19th Century steam locomotive. To keep running, steam locomotives required fuel in the form of either wood or coal. This fuel was burned in the firebox to produce heat, which in turn boiled the water to produce the steam that drove the engine. Nor was fuel the engine's only need. Every hundred kilometers (60 miles) or so the engine would have to have its water supply replenished, to replace all of the water lost when steam that leaked from the drive cylinders and other places around the engine. Nor did the locomotive merely consume fuel and water. It also had various effluents. The acrid smoke that poured forth from the smokestack was the primary effluent, although the leaking steam was also continuously spewed forth. And periodically, it was necessary to empty the firebox of ash to make room for additional fuel.

Input and output are the characteristics of any machine, including the human body. The table below shows the inputs and outputs needed to sustain a typical human being for a full day. To continue operating, the human body needs 0.84 Kg (1.84 Lb.) of oxygen, 0.62 Kg (1.36 Lb.) of food solids, and 2.77 Kg (6.1 Lb.) of water (half in food, half as drinking water) each day. And like the belching smokestack of the locomotive, the human body belches out its own waste products that must be dealt with. There is carbon dioxide (1 Kg, 2.20 Lb.), the water in respiration and perspiration 2.28 Kg, (5.02 Lb.), urine (1.5 Kg, 3.3 Lb.), and Feces (0.13 Kg, 0.27 Lb.) Note: That last seems to understate the case dramatically, but these are official NASA figures.

For that portion of the day in which the astronaut is encased in his or her spacesuit, the suit will have to provide those needs. And while less than 1 Kg of oxygen per day doesn't seem like much, when you consider the density of oxygen, a full kilogram is actually quite a lot of breathing air. Obviously, as spacesuits become more and more capable and astronauts are able to stay in them for longer periods of time, the problem of providing the body with its needs, and disposing of its waste products becomes an ever greater concern.

Which brings us to the question we asked in the introduction of this article. Just what do you do after you've spent an hour putting on your spacesuit and you suddenly feel the call of nature? Current spacesuits solve the problem using a system of extra-absorbent adult diapers. Effectively, if you have to go, you either wet or poop your pants. While effective, I think it is obvious to see that this solution has limited utility for the future when people will need to be in their spacesuits for a day or more at a time. (When thinking about the problem, I am put in mind of a Jeff Foxworthy joke. Being a new father, he praises the usefulness of disposable diapers. "Yep, them labels on the Pampers boxes are right. Ten or twelve pounds is about all they will hold!")

Obviously, future spacesuits will have to come up with a much more effective waste disposal system. Urine disposal is relatively straightforward. All you need is a system

Table 1: Human Body Inputs and Outputs Per 24 Hours

Input	Mass		Effluent	Mass	
Oxygen	0.84 Kg	1.84 Lb.	Carbon Dioxide	1.00 Kg	2.20 Lb.
Food Solids	0.62 Kg	1.36 Lb.	Respiration and Perspiration Water	2.28 Kg	5.02 Lb.
Water in Food	1.15 Kg	2.54 Lb.	Urine	1.50 Kg	3.31 Lb.
Drinking Water	1.62 Kg	3.56 Lb.	Feces Water	0.091 Kg	0.20 Lb.
Metabolized Water	0.35 Kg	0.76 Lb.	Sweat Solids	0.018 Kg	0.04 Lb.
			Urine Solids	0.059 Kg	0.13 Lb.
			Feces Solids	0.032 Kg	0.07 Lb.
Totals:	**4.58 Kg**	**10.06 Lb.**	**Totals:**	**4.98 Kg**	**10.97 Lb.**

for drawing the liquid away from the astronaut, then exposing it to vacuum (without exposing the astronaut's private parts to vacuum). As noted above, liquid at room temperature boils in vacuum. Of course, first you have to collect the liquid, a problem much more difficult for female astronauts than for male. Men can use a relief tube, but women must use an uncomfortable catheter. (As evidenced by the long lines in front of the female restrooms at movie theaters and sporting events, there are some things for which male plumbing is superior to female plumbing.)

Feces disposal is obviously a much more difficult problem, one that I don't think we've got any good ideas for. So any young engineers out there that may have an idea to solve this difficult problem, here's your chance to make your mark on the world. Who knows, you may end up as famous as Thomas Crapper, an English manufacturer of … well, surely you must know what he manufactured!

One thing that science fiction writers generally ignore is what a person wears inside their spacesuit. Current astronauts wear a garment like a pair of “long john” underwear. This garment has thin-walled plastic tubing sewn into its lining, tubing through which cold water is circulated to cool the astronaut. In the future, however, this cooling system may be built into the suit itself. With all of the biological attachments required for long duration jaunts in vacuum, perhaps it will be better to climb into the suit naked. If nothing else, that would allow us to write some interesting scenes in the suiting rooms just inside the airlocks.

The End

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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. Gibraltar Stars – First Time in Print — US$7.50

The great debate is over. The human race has rejected the idea of pulling back from the stars and hiding on Earth in the hope the Broa will overlook us for a few more generations. Instead, the World Parliament, by a vote of 60-40, has decided to throw the dice and go for a win. Parliament Hall resounds with brave words as members declare victory inevitable.

With the balance of forces a million to one against *Homo sapiens Terra*, those who must turn patriotic speeches into hard-won reality have their work cut out for them. They must expand humanity's foothold in Broan space while contending with a supply line that is 7000 light-years long.

If the sheer magnitude of the task isn't enough, Mark and Lisa Rykand discover they are in a race against two very different antagonists. The Broa are beginning to wonder at the strange two-legged interlopers in their domain; while back on Earth, those who lost the great debate are eager to try again.

Whoever wins the race will determine the future of the human species… or, indeed, whether it has one.

12. 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

13. 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.

14. 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.

15. 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.

16. 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.

17. 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.

