Condition Zulu:
Weapons and Defenses in Space Combat

Soon the Skylark was again dealing out death and destruction in the thick of the enemy vessels, who again turned from the devastation of the helpless city to destroy this troublesome antagonist. But in spite of the utmost efforts of light-waves, sound-waves, and high-tension electricity, the space-car continued to take its terrible toll. As Seaton had foretold, the armor of the Skylark began to grow hot, and he turned on the full power of the refrigerating system. In spite of the cooling apparatus, however, the outer walls finally began to glow redly, and, although the interior was comfortably cool, the ends of the rifle-barrels, which were set flush with the surface of the revolving arenak globes which held them, softened, rendering the guns useless. The copper repellers melted and dripped off in flaming balls of molten metal, so that shells once more began to crash against the armor.

– *The Skylark of Space*, E. E. "Doc" Smith

Space combat has been part of the science fiction adventure genre since its inception, as this introductory passage by Smith shows. The writers of each generation put their own stamps on the concept, adapting to new knowledge about the operating environment of space, or adapting the then-current military modality to their stories for reader familiarity.

Thus, the history of military SF is strewn with analogies to everything from pre-dreadnought naval combat and the battles of Jutland, Dogger Bank, and Midway to the Normandy invasion. Space combat portrayals have gone from analogs of everything from torpedo boats and capital ships to carrier battles to remotely controlled drone warfare and AIs.

Strategic questions of how and why wars are fought get less attention in fiction, because it's hard to get readers to care about meetings between admirals and their senior staffs. Covering those questions in depth is beyond the scope of this essay, though they will be touched on.

The Problem with Analogies

Space combat by analogy falls prone to the diktat that generals and admirals prepare to fight the last war, not the next war. This is less of a problem with SF than with real-world operational planning, because the writer needs to build a sense of drama for the reader, and the reader needs to understand what's going on without a syllabus explaining all the jargon. Unlike the writers of technothrillers and conventional military fiction,' SF writers don't have an extant group of space warfare veterans to draw on as a customer base, pleased that the author "got it right."

That said, there are plenty of places in space combat SF where writers commonly "get it wrong." I've covered some of these in more detail in other places (stealth in space with "The Hot Equations," orbital travel times and orbit-to-ground interface issues in "Objects in Motion"). In this essay, I'm covering how ships take damage as well as how weapons in space are likely to work and what constraints control them.

What Kills Ships

Popular media representations and the ambient environment we live in shape our experience with what kills ships. We're used to living in an environment with a gravitational field pulling us down by 9.8 meters per second, in an atmosphere that's nearly 25% oxidizer. Ships are on the surface of water, and punching holes below the waterline will cause a ship to sink fast, a common theme in movies ranging from *Das Boot* to *Titanic*. Submarines that go too deep will pass through their crush depth and kill everyone onboard. Aircraft that have a wing sheared off suddenly have unbalanced lift and drag and rapidly tumble from the sky. Aircraft that explode in the sky explode because something ignited fuel in an environment full of oxidizer. Fire onboard a naval ship usually involves paint, lubricant, or some sort of artificial material. Structural aluminum can burn when exposed to rocket fuel.

In space, there is no ambient source of oxidizer. The vacuum of space is not about to crush your ship or pull it below the surface where the crew will drown. Aerodynamic stresses will not cause a "rapid unexpected disassembly." We expect spaceships to explode, largely because of the mental zeitgeist fostered by *Star Trek* and *Star Wars* movies, but the reality is that there's very little on a spaceship that would explode in the way depicted onscreen.

Spaceships in the real world will have a gantry-type spine, with habitat and propulsion and power generation/heat dissipation modules. They will have plumbing that shifts coolants and water about in various stages of recycling. In addition, pivoting a ship may be slower than we're conditioned to expect, just to save wear and tear on gyroscopes or propellant for pivot thrusters.

Damage to a spaceship is likely to punch a hole through a compartment, and the compartment may be pressurized. If the punctured compartment or container has a self-oxidizing propellant like hydrazine, it may cause a secondary explosion. However, single catastrophic hits that destroy a ship because they damage something explosive (like the HMS *Hood's* powder stores going up in World War I) are unlikely in the extreme.

A better way to model how spaceships take damage might be to look at a large sheet of Styrofoam™. Weapon hits striking a spaceship would be analogous to ice picks or shots with a .22 caliber rifle striking the Styrofoam. It would take a lot of hits with the bullet or ice pick to turn the sheet of Styrofoam insulation into Styrofoam dust.

From the perspective of an SF writer, this means that spaceships as a whole are fairly durable, but the location where your characters are working may be subject to immediate dangers.

Lasers in Space

No single weapon system is as beloved to Hollywood effects artists as the beam weapon scything across the screen, causing rippling, burning gashes in a ship's hull. It's dramatic! It immediately telegraphs danger! It's also, sadly, not going to happen in realistic space combat.

This isn't to say that lasers won't be used. It's just that they won't be visible to the naked eye. (A visible beam happens when the laser is moving through a medium that's partially opaque to it; vacuum is not, generally, opaque.)

Lasers will have multiple roles in future space warfare. They're arguably the best active sensor mechanism available. A LIDAR pulse can be directional, and can have its frequency tuned in ways that make radar-absorptive materials less effective.

If you increase the laser's energy, it can damage soft targets on the surface of the ship. Examples include external ordnance and surface-mounted broadcasting and receiving antennae. Lasers like this will need to linger over a small spot on the target for seconds (or longer) at a time. Easy countermeasures will be spinning the hull of the target, and putting some sort of armor over the hull. A setting where weaponizable lasers never exceed this level of energy density per pulse is quite plausible.

If you increase the energy again, it can burn through or vaporize part of the surface of the ship. If lasers like this exist, then armor on the hull of the ship is a reasonable countermeasure. This armor will almost certainly be layered carbon composites with expansion gaps between layers, and mathematical models show it to be quite effective. Carbon has a very high energy of vaporization for a given unit of mass. Lasers capable of burning through armor will have a very high intensity (energy per second). They'll also pulse rapidly to allow vaporized material to expand out of the beam path. When beam intensities are high enough to damage carbon composites, the normal rules of how photons interact with matter don't apply. The photons are literally stripping electrons off of the surface material and depositing energy, and vaporizing the material under the beam's focal point. The energy densities used can cause materials to shatter and explode. This means that mirrored surfaces don't make a good defense against the beam; the mirror has to be highly reflective at precisely the wavelengths used by the laser to work as an adequate defense. As the energy per square millimeter increases, the tighter the match between the material's reflectiveness and the beam's wavelength has to be.

Lasers are surprisingly inefficient at converting energy into coherent light. This is less of a problem in the atmosphere, since the atmosphere itself allows the weapon to dissipate heat. It becomes more of an issue in space. In theory, a laser could lock on to a target and keep a continuous pulsing beam on it, doing continuous damage. In practice, the mechanism that generates the laser and the mechanisms that focus the laser will need cooldown times between shots.

Laser ranges are limited by physics, and are one of the more common ways that quantum mechanics interacts with your everyday life. This also applies to beam weapons in space. This effect is called *diffraction*. Diffraction, very simply, is how quickly photons-as-waves spread out (and diffuse) as they travel from their point of origin, called the "aperture." Shorter wavelength light, especially relative to the size of the aperture, spreads out much more slowly. Thus, shorter wavelengths yield longer ranges for laser weapons. These increases will be linear as the wavelength decreases. A laser with a 1,200-nanometer wavelength will have half the range of a laser with a 600-nanometer wavelength. Wavelengths down to about 100 nanometers (roughly hard UV) can use optics with materials we currently understand; shorter wavelengths need exotic mirror materials. The shortest wavelength likely to be weaponizable with our current knowledge of physics and available materials for "optics" are X-rays, and they'll need grazing incidence mirrors made of lead. In general, the longer the wavelength, the more available materials you have to make the optics out of and the more resilient the system will be overall, but it'll be shorter ranged. In designing games, this allows for a wider array of laser weapons; in fiction, it may be more detail than your readers will put up with.

A secondary driver for a laser's range is the size of the optics used to focus it, or the focal array sizeAs focal array diameter increases, the laser's range increases by the square root of the increase in focal array sizes. Larger focal arrays make the laser weapon larger and a bit more vulnerable to damage. Larger focal arrays also allow you to increase the total energy throughput of the laser (which increases beam intensity) due to the increased surface area of the mirrors, which allows you to collect more light. Larger focal array sizes also mean more room for cooling systems on the back of the mirror, which can prevent the mirrors from breaking or cause optical problems. When engineered to the same tolerances, a laser with a larger focal array can handle more power going through it than a smaller one.

The maximum combat distance for a laser depends on a lot of setting and novel-specific assumptions. For example, there's nothing preventing someone from making very large laser emitters that fire into disposable mirror arrays that are tens to thousands of kilometers away. If you use an armored iris on the focal mirror, it might even survive multiple firings, though those mirrors will become high priority targets.

Likewise, if you're willing to accept multiple kilometer-long installations, the X-ray emitter described above can probably be made with a 12- to 13-kilometer-long linear accelerator, and would be able to put weapon-level energy densities onto targets up to several hundred light-seconds away. The drawback of this installation is that it requires micrometer-level precision for the entire length, and the differential heating and cooling endemic to space can throw it out of alignment, not to mention vibrations from any mechanical subsystems, or damage from enemy action.

For a more conventional SF approach, keep focal arrays to roughly the size of the Hubble Space Telescope, and keep your lasers in with wavelengths between about 800 nanometers to around 200 nanometers. This yields lasers with ranges of a few hundred to roughly a thousand kilometers.

Outside of the X-ray laser battlestation, how well you can target an enemy with a laser is a function of apparent target size versus the diffraction limit of your laser (how much the beam spreads). I, personally, have trouble believing in weaponizable lasers that, under combat conditions, maintain the adequate angular precision needed to target something more than about 4,000 to 6,000 kilometers away. I could make a theoretical case going out to roughly a tenth of a light-second (30,000 km). If those ranges seem short to you, keep in mind that your laser system has a heat rejection system and will need to circulate coolant, which will cause vibrations in the system. Anti-jitter systems are, of course, possible, but even they have limits, and they're really not designed to deal with these kinds of energy densities.

Particle Beams

A large number of SF settings use particle beams as "the other flavor of beam weapons." They're usually the "space navy carronade," a shorter-ranged, more damaging beam weapon than the "space navy cannon" represented by lasers. (Using a higher throughput, larger focal array laser with a shorter wavelength, perhaps driven by the durability of the focal array system, can get you the "space navy carronade" effect.)

There is one element of truth to that. Space-based particle beams will be shorter ranged than lasers built with a comparable engineering capability. However, the damage that a space-based particle beam does won't be something cinematic, like raking lines of hot death down the hull. It will be invisible, and it will attack the two

most vulnerable components of the ship: the crew, who will die messily from radiation exposure, and the electronics, most of which will be fried when the beam passes through them.

A neutral particle beam (charged particle beams are discussed below) does damage by smashing neutrons or helium atoms into the nuclei of the materials that make up the first layer of your ship that they encounter. This will result in secondary neutron cascades, which will turn everything in the beam path into varying levels of high-emission radioactive waste. Thermal shock effects will take place near the surface at the point where the beam intersects the ship, but nearly all of the damage will be radiological. While space is a radioactive environment in general, a neutral particle beam is generally three or more orders of magnitude more radioactive than the worst environmental effects.

Battles in which "one shot means everyone onboard the ship loses their hair, pukes up blood, and feels their teeth fall out in a matter of hours" tend to be less than thrilling to readers. Fortunately, making a particle-beam weapon isn't as easy as making a laser weapon.

The simplest kind of particle beam is an electron gun. For those who can remember back to the distant days of 2002, there's lots of photographic evidence of people sitting in front of electron guns for hours. They're the primary mechanism of CRT monitors.

Electrons are lightweight and easy to accelerate with magnetic fields. The problem with electrons in a weaponizable particle beam is that Coulomb repulsion causes the beam to spread, very quickly. Because the beam is charged, magnetic fields can redirect it.

Protons are more than 1,800 times as massive as an electron, and they take a corresponding increase in energy to accelerate to weaponizable energy levels. Their greater mass gives them longer range, as the Coulomb repulsion has to impart much more momentum per unit to spread the beam focus. They're still going to interact with the magnetic field, but the magnetic field will need to be somewhat more powerful.

Spaceships are likely to have powerful magnetic fields. A plausible way to reduce fuel for interplanetary propulsion is by using a magnetic sail, which generates thrust from the solar wind and allows a ship approaching Earth or Jupiter to decelerate against the respective magnetospheres (other planets in the Solar System have negligible magnetospheres for a magnetic sail to interact with). A magnetic sail will be a near-perfect defense against a charged particle beam and will turn electron or proton beams into a highly localized aurora borealis.

Making a neutral particle beam is a tricky challenge. Right now, we don't have a good mechanism for doing so. The easiest method is to take helium atoms, ionize them and accelerate them, then try to deionize them just as they leave the accelerator. The problem with this is that the process of deionizing them scatters the beam and slows down the helium atoms considerably. A good visualization would be to coat a screen door with food coloring and then use a garden hose from the other side; you want a stream of colored water to come out the of the screen door with minimal spraying or spreading

Assuming your setting has some sort of fine-tuned gravity control, using gravitic acceleration of neutrons generated by a neutron source could generate a neutral particle beam. At least two currently not-disproven models for quantum gravity allow for the theoretical possibility of making neutron beams.

However, in general, unless you're looking for a radiological-kill weapon for your setting, everything a particle beam can do to a ship, a laser can likely do as well or better.

Plasma Weapons

Lots of SF writers love plasma weapons, and they get portrayed as terrifying close in weapons, often used by alien swarm tactics. A plasma is a highly ionized gas, with all that entails. In space, it can be thought of as a high-volume charged particle weapon moving at non-relativistic speeds. Unfortunately, when real plasma physics is applied to them, the end result is much less dramatic. A plasma weapon is functionally an ionized hot gas sprayed into a vacuum. Both the ideal gas law *and* Coulomb repulsion are working to spread the molecules out. Plasma weapons would have ranges measured in single-digit kilometers, and they would have all the vulnerabilities to magnetic fields that proton beams would have.

The likeliest plasma "weapon" in space combat is the exhaust from a constant thrust fusion rocket or other thermodynamic rocket. Notwithstanding the Kzinti Lesson (that any interesting rocket is a weapon of mass destruction), the reality is that a plasma rocket won't be able to damage another ship outside of around two to three kilometers. Space combat, even the much shorter-ranged space combat I advocate in this article, will take place at much greater distances than this!

Nuclear Explosions

Nuclear weapons are functionally energy weapons in space combat. Most of the energy of a nuclear explosion is released as X-rays. In the Earth's atmosphere, both oxygen and nitrogen are largely opaque to X-rays, so the X-rays get absorbed by the atmosphere and reradiated as heat, through a process called *bremsstrahlung*; this causes the iconic mushroom cloud. Most of the blast damage of a nuclear weapon in atmosphere stems from the superheated atmospheric effects.

In space, the blast effects of a nuclear warhead will decrease by the inverse of the square of the distance to the point of detonation, and in a vacuum, there's no atmosphere to propagate blast effects. Consequently, nuclear warheads are orders of magnitude less dangerous in space than they are as air bursts. They'll need to get within a few kilometers (five or less) to harm the target, and their impact on the target will be through X-rays being absorbed by the surface material and shedding energy as infrared photons as they compensate for the reduced speed of light in the target's hull material.

A nuclear blast is certain to strip off the surface features on the outside of the ship; nothing with an antenna or a receiver will survive. A nuclear blast will ablate off whatever armor you're using on the surface of the ship. This ablation will propagate some blast effects to the interior of the ship, shattering bulkheads and breaking conduit runs.

A side effect of nuclear blasts in a vacuum is that they encourage smaller warheads. When used to obliterate planet-bound cities, larger warheads mean larger blast radii. When used in space, nuclear weapons are single-target weapons, and much more than one or two megatons won't make much difference. It's entirely reasonable to use much smaller weapons—in the 250 to 400 kiloton range—and still have a plausible weapon system for a space combat scene.

Enhanced radiation nuclear weapons (neutron bombs) work just fine in space; they'll have the radiological effects described under “Particle Beams.”

In terms of making nuclear blasts dramatic, from the perspective of characters in your fiction, the two factors are "How close was the nuclear blast when it went off?" and "How much radiation did we take?" One side effect of enhanced radiation weapons is that a crew that knows it's going to die from radiation exposure may decide that it'll have an honor guard of enemy ships going to Hell with it…

Bomb-Pumped X-Ray Lasers

Beloved of people who imprinted on space combat in the late 1980s, during the more aggressive stages of the Strategic Defense Initiative, bomb-pumped X-ray lasers (BPXLs) are widely misrepresented in science fiction. In SF, BPXLs convert all of the X-rays of a nuclear blast into a single beam of coherent light, and this matches many of the late 1980s popularizations of the weapon system. Lasers work by exciting the electron shells of a material (a lasant) into releasing a photon; in effect, you pump energy in to excite a lasant, and everything that comes out of the lasant is the same wavelength and frequency.

Unfortunately, getting all of the energy of a nuclear blast to go in only one direction to excite your lasant is tricky. The lasant effect favors narrow cross sections of the lasant material. A BPXL won't produce a single coherent beam that scythes across space in a Docsmithean ravening beam of destruction. Instead, it will create a lot of very small beams with narrow cross-sectional areas. Rather than being a single-target weapon, a BPXL turns a nuclear blast into a functional-in-space area effect weapon with a radius of anywhere from 60 kilometers to perhaps 200 kilometers.

That assumes that the weapon works at all. BPXLs rely on perfectly aligned, whisker-thin lasants with micrometer precision that remain perfectly aligned while attached to a nuclear explosion. It's may be impossible. Even if it is, it's certainly challenging engineering.

To get the science-fictional BPXL, you need techniques for harnessing all of the energy of a nuclear blast in one direction, feeding it into a large cross-sectional lasant, and focusing it. If you can overcome the extreme narrowness requirement of lasants as we currently know them, the individual beams will gain significantly in range. Practical limits regarding vibrations and target cross sections will limit ranges as were discussed for lasers lasers, probably peaking with a maximum range of around a tenth of a light-second.

Kinetic Impactors

Kinetic impacts are a known hazard for objects in space, though they have, to date, been rare. The United States, Russia, and China have all tested "satellite killer" weapons, bringing a capability commonly associated with science fiction into the real world. Space-based collisions happen even without hostile intent; satellites that have hydrazine tank failures spray debris in their orbits, and at orbital velocities, a one-gram paint chip has kinetic energy comparable to a round out of an AR-15.

Kinetic energy increases with the square of the impact velocity, and linearly with the mass of the projectile. This means that doubling the impact velocity quadruples the energy delivered to the target. In round numbers, an object impacting at three kilometers per second delivers kinetic energy equal to its mass converted to TNT. Increasing that impact velocity to three and a half to four km/second will cause an impactor to deliver energy

equal to more advanced explosives. Mach 1 at sea level is just over 343 meters per second; Mach 3 is 1.029 km/sec, and is a decent approximation of 1 km/second.

For a point of comparison, the round from the main gun of an M1A2 Abrams tank, fired with discarding sabots, has a muzzle velocity of just under two km/second. Most bullet rounds are considerably slower than that. A Tomahawk cruise missile pokes along at about 240 meters per second. An SM-6 antimissile/antiaircraft missile can do Mach 3.5. As this piece was written and researched, "hypervelocity kinetic kill" missiles capable of Mach 5 to Mach 6 (approaching two km/sec) are being talked about in the defense press.

Earth-centric orbital velocities are in the range of 7.5 to 11 km/second. Two objects impacting on directly opposite orbits sum their impact velocities. As the impact angle changes from directly opposed, the percentage of the velocity used to calculate the collision drops by the cosine of the impact angle. In case high school trigonometry was some time ago, an impactor coming in at thirty degrees off of a direct collision angle would deliver 86% of its velocity to the collision. One that's sixty degrees off delivers only 50% of its velocity; one that's ninety degrees off contributes none of its velocity. One impacting at 120 degrees off (or more) is overcoming a stern chase and subtracts 50% of the target's velocity from its own, while one coming from 150 degrees off subtracts 86% of its target's velocity, and one from 180 degrees off subtracts all of the target's velocity.

Provided your universe has narratively interesting levels of spaceship thrust (hundreds of milligees sustainable for minutes or more at a time), kinetic weapons become maneuver constraint weapons. In this context, a kinetic weapon is anything that uses impact velocity to harm the target, rather than a conventional explosive warhead. Kinetic weapons will have limited lateral thrust capabilities, to remain lined up for their intercept shot, but they won't be able to make sweeping course changes. The closest analogy is World War I vintage straight-running torpedoes, not the torpedoes from World War II and later that can turn after launch. You'll launch spreads of kinetic weapons, rather than single ones. Some will be targeted at where the ship will be if it applies maximum thrust, and some at where the ship will be if it pivots perpendicular to the line the kinetic weapons will approach on and applies maximum thrust. Some will be targeted to hit the ship if it applies no thrust at all.

The defining constraints are the shot geometry described above and the amount of thrust the target can apply perpendicularly to the kinetic weapon's approach. It helps to imagine that the target is sitting still and to add all of the target's vectors to those of the launching ship's before adding the velocity imparted by your kinetic weapon's launch mechanism. When this perspective shift is in place, the incoming projectiles will have a constant bearing and decreasing range (CBDR). Realistically, only thrust perpendicular to this bearing matters; adjust by the cosine of the angle separating your ship's thrust axis and inbound bearing. The amount of time it takes your ship to change heading (accelerate to rotate, decelerate to stop the rotation) begins to matter in this maneuver regime; it's not quite the difference between an F-4 Phantom II and a MiG-21 for maneuvering, but there are dramatically useful differentiations in fine-grained maneuver to be used. You can use this information to turn space combat into something that combines a bit of chess and air combat maneuver, happening in longer time frames. If this is the kind of space combat description you find gripping, a "Tom Clancy or Larry Bond writes hard SF," you really owe it to yourself to buy *Attack Vector: Tactical* and get it on the table.

As your reaction drives get more realistic, their maximum thrust decreases, and kinetic weapons get more effective. This also effectively increases kinetic weapon ranges, as the target requires more time to get a given

amount of delta-*v* off the axis of approach. At the very extreme end of things (thrusts in single-digit milligees), the kinetic-weapon environment resembles modern surface naval combat…once the "search for the enemy" phase has ended. (Modern surface naval combat assumes that ships cannot meaningfully maneuver in the time frames of an engagement after weapons have been launched; at best they can change their facing that takes the hit.)

Once maneuver ceases to matter, the primary defense is shooting down the inbound kinetic weapons. Shooting them down in space is more energy intensive than shooting down missiles in an atmosphere, where once you cause a missile's skin to rupture, aerodynamics takes care of the rest. In space, you might try to ignite the lateral thruster fuel on a shell; however, if it's designed properly, you'll only see the armored nose-cone of the shell, and more energy will be needed to mission-kill it. Mission kills will likely be the result of killing its sensor package when it is far enough away that you can avoid the no-longer-maneuvering shell.

The primary tool for killing missiles is probably the good old-fashioned laser. Lasers used for point defense will be optimized for high cyclical fire rates, and for the purposes of space combat, they effectively don't miss. Your defense contractors will try to make sure that the weapon delivers enough energy per pulse to reliably kill a missile matching the performance parameters your intelligence service provides. This may, or may not, work as specified in the contract. Because the amount of energy fed through the laser increases the energy delivered to the target, while also making the cooling requirements more onerous, there will be a definite trade-off.

An alternative kill mechanism is to launch a smaller missile at the inbound missile; the smaller missile is commonly referred to as a “countermissile”. This is somewhat easier in space than it is on the surface of the planet. The inbound missile doesn’t have aerodynamics assisting it in altering course, and it won’t be following an arcing trajectory without gravity.

The same kinetic energy that makes a kinetic weapon a threat to a ship makes it vulnerable to a countermissile coming in for a head-on collision. Technologically, it’s still hitting a with a bullet. Variations on this kind of countermissile include “warheads” of spin stabilized nets – think of a circular skirt on a dancer. This makes the missile’s cross-section for sweeping into an inbound shell larger without significantly increasing the mass of the countermissile. Unlike lasers, countermissiles will have a finite amount of ammunition.

Some settings may deploy mines, or pods, of countermissiles that thrust slowly in the direction of an enemy’s probable launch point, and can be remotely activated. While not quite the same as submarine countermeasures (which get an inbound torpedo to pursue a stronger sonar signal and detonate away from the ship), they’ll have similar dramatic potential.

What Happens When Kinetic Weapons Hit?

First, it's likely that kinetic weapons in space will be delivered at net closing velocities of only 2 to 10 km/second, with some of that velocity added by thrust of the launching ship, and the rest delivered by the launch mechanism itself. As we covered earlier, two km/second of closing velocity is right in the realm of how cutting-edge weapons move now. The reason for the "relatively paltry" net closing velocities is twofold. The first is that space battles will take place at or near planetary orbits, and ships moving much faster than that aren't positioned for orbital insertions. The second is that getting more velocity than that into your projectile within a combat time frame is troublesome engineering and, well, energy expensive.

Armor for kinetic weapons will come in two varieties: Whipple-shield composites (hard surface, high tensile strength mesh behind it, aerogel or other expansion space behind that, and repeat for multiple layers) or large amounts of inert and hard mass. The former is much likelier on a spaceship; the second might happen on an asteroid fortress.

At somewhere around 2 or 3 km/second, a kinetic weapon impacting an object creates a plasma sheath at the point of impact. This plasma sheath almost acts like a lubricant. As the weapon's impact velocity increases, the amount of time it spends in any compartment of the target decreases, and the amount of energy the kinetic impactor can deliver to any specific compartment is reduced. This plasma-sheath effect will allow the kinetic weapon to penetrate deeper into the hull or exit from the other side. An analogous situation happened in World War II when armor-piercing shells would fire straight through the structure of destroyers without detonating, because the destroyers didn't slow down the higher-velocity shell enough to set off the fusing on the conventional explosive warhead.

Ultra-high-velocity kinetic weapons matter most for cracking asteroid fortresses. A nickel-iron asteroid that's been partially hollowed out and is used as a battlestation. The primary defense is sheer amounts of mass, which also make it unable to maneuver. If you're having trouble visualizing an asteroid fortress, picture NORAD, buried under the bottom of Cheyenne Mountain in Colorado…only make the mountain larger, and make it out of nickel-iron rather than granite Such a fortress will be largely immune to laser weapons, and it may well be immune to particle-beam weapons. Super-high-velocity kinetic impactors, however, could penetrate to the core of the fortress and damage the installations. Larger kinetic strikes, with more mass, might be able to shatter an asteroid, but those won't be delivered by ship-mounted weapons.

Finally, expect most kinetic weapons with inherent propulsion systems (missiles, rather than coilgun/railgun shells) to have payload bays with submunitions. In light of the way that kinetic energy gets deposited into ships, you're better off having lots of medium-sized impactors rather than one large one. As the expected impact velocity increases, the projectile size will decrease. The lowest useful size for a kinetic impactor will probably never drop below 2 kilograms, to keep it large enough to get through a typical Whipple-shield style of micrometeoroid armor.

The description of a kinetic weapon impacting a ship could reasonably discuss the plasma sheathe mentioned above, the sensation of feeling the ship shudder from impact (though it will be far short of *Star Trek* style "shaky bridge") A character in the compartment that gets hit is very likely to die or be severely injured. Depending on the material used for the projectile and whether or not the compartment has oxygen in it, secondary porphyric explosions may happen. The projectile will be moving *fast* from the perspective of a human observer – it will blast through the compartment in a fraction of a second.2 km/second is only slow when crossing hundreds or thousands of kilometers.

Secondary effects of damage will depend on what subsystems of the ship got hit. That will be a discussion for a later essay.

Relativistic Impactors

Every science fiction author likes "*c*-fractional" weapons. They're like a kinetic weapon, but moving at a significant fraction of the speed of light, only Einstein (well, Lorentz, actually) makes them even kaboomier via relativity.

The first problem with relativistic impactors is getting them to that speed. In general, the only way you'll do that is to drop them from a ship already moving at relativistic speed, and have them inherit that ship's velocity. The first rule of vector movement applies when ships are moving at relativistic speeds: the greater your velocity, the more predictable your flight path will be. Ships moving at relativistic velocities will, from the frame of reference of someone in a merely solar system-scaled velocity regime, seem to be moving in a straight line with no ability to change course.

Which means that if the relativistic projectile is on a course to smash into your planet, the ship that launched it is also on a course to smash into your planet…or you've seen it accelerating the object for years and have had time to send something out to investigate.

For what it's worth, a ship traveling at relativistic speeds is also moving fast enough that it's dealing with relativistic impacts from anything it plows into. Stray grains of dust carry tens of thousands of times their own mass in TNT equivalence, as does the odd hydrogen atom in the ship's way. Ships expected to travel at these velocities will be very durable, or they may not have a human crew at all.

The energy delivered by a relativistic projectile increases by the Lorentz factor, which is 1/SQRT(1–(Projectile Speed/Speed of Light)^2).

If you are going to use relativistic impactors in your fiction, here are some rough figures for you:

An object traveling at 14% of *c* will deliver about 1% more energy from relativity than its mass times its velocity squared would indicate. 14% of *c* is roughly 42,000 km/second.

An object traveling at 30% of *c* delivers about 5% more energy from relativity. 30% of *c* is 90,000 km/second.

An object traveling at 41.7% of *c* delivers about 10% more energy from relativity. 41.7% of *c* is 125,100 km/second.

An object traveling at 74.5% of *c* delivers about 50% more energy from relativity. 74.5% of *c* is 223,500 km/second.

86.6% of *c* doubles the energy of impact, 94.3% triples the energy of impact, and 96.8% quadruples it.

The Lorentz multiplier for the energy delivered is also applied to the amount of energy (and reaction mass…) needed to accelerate the object to that speed in the first place. In general, if you can get an object to *c*-fractional velocities, you have access to so much energy that mere spaceships (or, to be honest, trivialities like Jovian gas giants) won't be much of a military concern. You'll be in the realm of "Apache gunships hunting sheep" for dramatic intensity.

And, of course, if you have a ship-mounted weapon throwing a slug at a *c*-fractional muzzle velocity, you've gone well past the realms of plausible engineering and hard science as we currently understand them.

Missiles versus Beams

A kinetic or nuclear weapon needs a delivery mechanism to get it to its target. Depending on your technology assumptions, that delivery mechanism might be anything from a high-power coilgun to a chemical-fueled rocket to a fusion powered recoverable first stage deploying chemical-fueled rockets for the terminal boost phase.

Projectile propulsion mechanisms all serve the same purpose (get your payload going thataway toward the enemy), but the particulars matter. Coilguns and railguns have the advantage that their propulsion mechanism stays inside the armored hull of the ship, but they'll be problematic for launching nuclear warheads, which generally have problems with short, instantaneous accelerations at hundreds of Gs combined with inductive heating. Some coilgun and railgun models indicate that the shells will leave the barrel with temperatures in excess of 800 Kelvin.

Inherent propulsion systems, like chemical-fueled rockets and fusion torch missile busses, increase the cost per shot considerably.

The maintenance of the ammunition is a logistical concern. Maintaining a fusion torch rocket is, functionally, maintaining a fusion reactor, which we can't build yet, and involves a lot of mechanical and engineering complexity. Maintaining a chemical-fueled rocket has other logistical issues. If you've got fusion torch rockets, you've got something that may or may not be easier to maintain than a chemical fueled rocket, depending on how robust fusion drives are in your universe. You're also saying that megawatt fusion plants are cheap enough that you can make thousands of them, Navy-wide, and treat them as disposable items; this will have ripple effects on the rest of your worldbuilding.

Your chemical fuels will probably be solid, rather than liquid, just for ease of maintenance. Remember that liquid fuels pretty much require working with liquid oxygen as an oxidizer, or something even nastier (hypergolic chemicals that will spontaneously self-ignite). If you've ever been around a military motor pool, imagine those jokers handling liquid oxygen or fuming nitric acid…and you'll see why solid fuels make sense from a naval-utility perspective and handling-safety perspective.

Speed-of-light point defense weapons, like defensive lasers, make assessing the effectiveness of projectiles more complicated. A speed-of-light beam weapon is inherently very accurate. It can't be dodged by the incoming projectile, because it can damage the projectile the instant it receives the information that the projectile has been fired. Indeed, if you have very generous assumptions about the thermodynamics of power generation and laser rates of fire, it's easy to assume that lasers can stop a nearly infinite number of projectiles. Like maintenance for missile ammunition, thermodynamics provides useful limits on lasers for authors writing military SF, and it adds a bit of verisimilitude to the engineering implied by your story. In practice, the power-generation system generates waste heat, and the laser's cyclical firing rate will be heat-limited, which adds enough uncertainty to the process to make for an interesting game, and for interesting fiction. Longer-ranged lasers can fire at rockets while they're under thrust and more vulnerable to damage. There is a definite cat-and-mouse game that can be had, even in realistic "low-thrust" regimes.

Space Fighters and Their Missions

Space fighters havebeen part of space combat fiction since at least the 1940s, and have been a mainstay since the *Star Wars* and *Battlestar Galactica* franchises brought them to public prominence. Unfortunately for a lot of fiction, they don't make much sense in space combat.

An offensively tasked fighter needs to carry fuel sufficient to reach the battlespace, decelerate to the vectors used by the combatants in the battlespace to have any target discretion, have a maneuver reserve to fight within the battlespace, and then shape its vectors for a recovery by its carrier. This means that a pure space-to-space fighter generally needs four to five times as much total delta-*v* as a comparable missile. We will, for this discussion, assume that fighters are not crewed by flesh-and-blood meatsack humans, but by largely autonomous AI systems with remote telemetry and piloting capabilities.

As mentioned in other essays in this series, unlike a modern fighter and carrier combination, space fighter (generally) can't go places the carrier cannot in space. While it will probably have a higher maximum acceleration, it won't be able to go several times as fast as the carrier does due to moving through a different medium. Nor do fighters get to fly over the horizon; at best, fighters get to relay closer-in telemetry, which can be useful for positive target identification in a cluttered environment.

There are two mission taskings for which space fighters make sense. The first is as hybrid attack craft able to enter planetary atmospheres and return. Note that this probably won't allow fighters to do drone missions for ground support; a fighter able to go into atmosphere and come back is going to be a hypervelocity ramscoop design with all the aerodynamic stability of hurled golf club if it drops below Mach 7 or so. It will be the epitome of a fast-mover, doing a single pass and being over the horizon in its mission constraints. That said, it can attack things on the ground that might be pop-up targets from the perspective of a ship in orbit.

The second mission tasking is as ancillary point defense weapons, if your beam weapon technology can fit onto a fighter (or remote combat drone). If a fighter is capable of carrying weapons that can shoot down a missile, the combat posture of missile defense deploys fighters as specialized antimissile escorts; they'll build up vectors parallel to that of the ship, but spread out so that they get lateral shots on incoming kinetic weapons, so that they may have better odds of killing them by killing their maneuver thrusters.

As was covered in "Objects in Motion," getting troops down to the ground requires suppressing ground targets; fighter sweeps to clear the landing zone for shuttles full of troops is one such mission. Fighters, in this context, are the "property" of troop transports rather than the decisive arm of combat. Your landing ships will also need to secure a refueling point; they won't have the fuel to land, disgorge their troops, and take off again.

The Other Space Combat Mission

The concept of "space navies" is ingrained in science fiction's assumption set, and with that, there's a tendency to look at purely naval actions as a template. Because of orbital mechanics, it's much likelier that space combat actions will happen in planetary orbital space, after one party has decelerated and gone into an orbit insertion burn. These actions will have hours and days of matching orbits, or trying to conceal an intent to match orbits. They'll resemble the "battles in sight of the port's guns" that happened in the Age of Sail, or Coast Guard actions in the current era, especially if you're using a realistic low-thrust regime built around single-milligee thrusts and

tugs that move ships through the radiation belts. One thing that won't happen is "hiding behind a planet and springing an ambush." Ships will orbit the planet, and if they're close enough to the planet to be obscured by it, that orbit will have an orbital period ranging from 90 minutes to about 12 hours. It's possible that they won't be seen by another force in orbit because of this, but by the same token, if they're not seen, they're also several hours from the fight itself.

This is particularly handy if you want to include boarding actions. A contraband search gone wrong (or right) allows you to have zero-g firefights with small arms onboard a merchant vessel. Space piracy will still require a place to take the ill-gotten gains, as described in "The Hot Equations;" however, a robust enough Solar System–wide civilization, with lots of micropolities and asteroid city-states, could provide the markets and the deniability to make space piracy economically viable.

One benefit of the Coast Guard model, or the "Port Naval Actions" model, is that both sides have incentives to avoid overkilling the target. You don't fire a Sunburner missile at a captured civilian vessel with hostages: you use a SEAL team if you have one, the better to perform a rescue. You might use the heavy ordnance against a piratical base.

Putting It All Together

What would fiction using these assumptions read like? Here's the opening fiction from *Attack Vector: Tactical.* As a work of fiction, it goes into far too much technical detail for a casual reader; as an introduction to a space combat wargame, it carries a lot of freight for "showing the work" underlying the physics assumptions in the game.

Right of Passage

Originally published in *Attack Vector: Tactical*

COURT OF INQUIRY, WITRAND STATION, OLYMPIA

02/02/2268 (Gregorian)—01/27/226 (Olympian Planetary)

Karin sat outside the briefing room, waiting. The waiting is what does it to you. The Court of Inquiry had reviewed the logs and automatic recorders aboard *Warspite*, and the events of three Gregorian months earlier. She'd been waiting for this since reaching port a week ago, in and amongst the chaos of bringing a badly wounded ship home with a dead CO and news of a war that nobody wanted.

She had her notes in a folder, was dressed in her formals. Her dress cap was sitting in her lap, and she'd been pressing it and smoothing it with her fingers for what felt like forever. Butterflies were performing air combat maneuvers in her gut. Her mouth was dry. The old-style, dual-faced clock was tick-tick-ticking, showing the station time on the old Earth clock and local planetary time on the other.

The court guard, in Ground Arm dress greens, cleared his throat. "Commander Hostlicht, they're ready to see you now." He was polite enough to offer her a hand to rise, which she declined, blotting the sweat on her palms with her handkerchief.

Admiral Heinzer sat at the center of the table, large boned and florid. There was a light-haired senior lieutenant at the recorder, Captain Preuss looking blandly disapproving, and another officer she didn't recognize, built short with an artistically broken nose and beard-shadow on his cheeks.

Heinzer looked up at her, stared overtly for a moment, then cleared his throat while shuffling papers. A tiny part of her was darkly amused at his disconcertion. The rest of her wondered if he'd just judged her based on how well she filled out a set of formals. The butterflies started pulling more Gs.

The unknown man with captain's braid on his shoulder boards glanced at her, then spoke. "Commander Hostlicht, I'm Captain Manderly. Admiral Heinzer I'm sure you're aware of. Have you met Captain Preuss before?" He didn't pause to acknowledge her affirmative. "Before we discuss the events in BD+36°2219, I need to ask you some questions for the record."

"Yes, sir."

"Please state your name, rank, and duty station aboard *Warspite*."

"Karin Louise Hostlicht. Lieutenant Commander, Olympian Defense Forces Space Arm. I was prime lieutenant of the *Warspite* on 12 October 2267 Gregorian."

"Thank you, Commander. Please describe the events leading up to the incident."

"On the date in question, *Warspite* was escorting a convoy of seven merchantmen en route to Damso through BD+36°2219, under the command of Commander Karl Sieberts. We had been delayed by an extended engine retuning aboard one of the merchantmen, when we detected a drive flare vectoring in on an intercept course. Evasion would've taken us out of the bounds for a transit to Damso system. Correlation between drive spectrum and perceived vector change told us it was five ktons, and the drive was too hot to be just a small freighter.

"At approximately sixty hours to interception, Captain Sieberts broke off from the convoy to get some fighting room...."

# # #

The waiting is what does it to you.

From her station in *Warspite's* Auxiliary Control, Karin Hostlicht watched the closing vectors creep across her display. Hard to believe that closing at two-and-a-half kips would be creeping, but there it was. The lines across the gravity well of the little ember of a star had been creeping toward convergence for the better part of three days. It wouldn't be long now—under a day—and it still seemed like forever.

Admiral Riley wrote in his memoirs that combat in space was making a mad bargain with the Devil to remain ignorant of the exact hour of your death…

She'd trained for this. For the better part of her professional career, she'd trained for it. Captain Sieberts had plunked her down here in Aux Con to be a glorified passenger. Seven months she'd been on this ship as his prime lieutenant, trying to execute her duties as "right hand of God," and he'd moved her to Aux Con from CIC.

The man was a Prussian prick, through and through. No doubting that. But even relegated to the sideline, she'd be damned before giving him cause to complain. She and the ratings had been cycling through preparedness drills for the last two days, including sitting through one watch in three in protective gear, to get used to how it hindered mobility. This was, thankfully, one of the "off" shifts, and CIC was wearing theirs now, while she wore her informal blues. Which laundry had managed to shrink within a week of her arrival, another petty grievance she laid without remorse at Sieberts's feet.

She reacted to reports coming in from her crew in Aux, and had to ask two of the reports to repeat; she was having difficulty focusing. Even with nothing to do, they needed to focus, too, and she needed to radiate that air of professional competence to keep everyone else on task.

On the plot, the two ships were outside the thrust envelopes of even the longest-range missiles, and the only real option for either ship was jockeying for position and initial vectors. The chatter on the commo circuits came steadily as she flicked her way through menus on the screen in front of her.

"—their transponder's off; no ID that way, sir."

"Anyone tried to hail them with the comm laser?"

"We've got a profile on their heat signature—checking the database now."

"Carry on, Intel." That was the lord high and mighty Captain Sieberts himself. She was certain she heard disdain at him having to speak English for her benefit. Lieutenant Commander Prietzkert, the man she'd replaced at Pacifica, had been a fellow traveling *Deutschspracher*. Not that she couldn't speak it herself, but Captain Sieberts had made it a point to cut her every possible bit of slack. In the most condescending manner possible.

"Looks to be an *al-Rafik* class. We'd call it a frigate, masses what we do, sir. Commo is getting nothing—nope, there it is. In Arabic. We're still waiting on the computer translation, *Herr Kapitan*."

Karin thought something less polite in German. Intel had a habit of flattering Sieberts, or at least his language prejudices.

The captain's voice came over the net .

"Prime, punch up what data we've got on the *al-Rafik* and put it on the main board."

"Aye, aye, sir."

As Karin complied, the Intel officer came back on the line. "*Herr Kapitan*, their challenge says this system is under blockade, and they're the *Saladin*. All our traffic is subject to boarding and confiscation. I think the balloon went up."

"Speculation on which balloon?"

"We've outrun most of the news since leaving AD Leonis. Given where we are, it's got to be meddling on Damso." Lieutenant Sondergren sounded more hesitant than his words.

Karin nodded to herself. The assessment fit. Her parents were still appalled by the thought of a corporation running a planet, but she privately admitted that it was the least bad of several alternatives. News out of Medina was always hard to read, but there were parties claiming that it was a jihad requirement to assist their fellow Muslims on Damso's northern hemisphere. A jihad against whom, exactly, was hard to pin down, given that it took several weeks to months for news to propagate from foreign-language sources. Unfortunately, Damso Corporation's electronics manufacturing met every definition of "critical need." Most of *Warspite's* computer hardware came from components made there.

"And Medina is involved for what reason, Mr. Sondergren?"

"Damned if I know. Best guess, they got involved in the fight between New Bharath and New Pakistan. Or New Bangladesh and New Pakistan. To be honest, though, there isn't enough data to tell—the Muhsin government won on a slim margin, and our political reports say they're internally focused. This goes beyond the data we've got. Could be nearly anything."

The captain's muttered "*Scheisse!*" didn't quite get cut off.

Then, in English with more dignity, "That gives us the starting point for replying. Request a visual of their CIC and go on from there according to Etiquette. We may still be doing a mutual inspection, but it is not the way to bet. Commander Hostlicht, Lieutenant Chung, observe, *bitte*."

Like captains in the Age of Sail, Sieberts had no small amount of diplomatic authority. Typically, two ships would match vectors, then conduct "mutual inspections" that boiled down to inviting junior officers to one another's wardrooms for a dinner party and politesse. Intended to verify compliance with assorted treaties, the practice relied far too much on mutual honesty to work as an inspection regime. As an avenue for diplomacy, it built contacts between potentially opposing services and offered an avenue for circumventing misunderstandings. It boiled down at times to "Make sure that they know that we know what they know…" and similar headaches that made her glad she wasn't in Intel. Regardless, *Saladin's* opening challenge probably rendered it moot.

She went back to reviewing what data they had, while Sieberts recited the relevant sections of the international accords into the recorder to be sent out by comm laser. The responses that came back would need to be translated, if any replies were made at all.

Saladin's main hull was roughly spheroid, thirty-three meters in diameter, with a50-meter mast holding the main torch a safe distance away from the hull. She looked like a spiked mace sticking out of a basketball. *Warspite's* cylindrical main hull was nearly three times as long and less than half the diameter, with a longer mast and larger thrust bell. Moment of inertia gave *Saladin* a pivoting edge.

Saladin's offensive weapons inventory centered on a sextet of Bayar-3 1,200 nm lasers, while a split mount on each flank held a four-barrel coilgun and a secondary laser. The self-thrusting munitions mix was of some concern; the al-Rafik could carry missiles, and how they were configured was a true wild card. She made a note on her report, then looked back at the commo traffic from *Saladin*.

The Medinan Group Captain was talking with slow deliberation. She was surprised at how pale he was; she had been expecting something out of a holodrama. He seemed to be wearing the Medinan equivalent of non-formals;

collared uniform shirt, oak leaves on the collar in black, name stripe in Arabic, and a discrete set of ribbons opposite it. His body language had him leaning away from the camera; the machine translation from Arabic may have missed some nuances, but whatever subtleties were in use were getting pile-driver like gentility. She was surprised at Sieberts' ongoing tact. While his body language was no more conciliatory than his counterpart's, his word choices were still diplomatic, and the microphone wasn't picking up the sounds of his teeth grinding…It was clear, to her at least, that conflict wouldn't be avoided. She went back to checking the data they'd gathered and cross referencing it to what they'd known before.

The *Al-Rafik* class came in two models, Mark 1 and Mark 2, and both carried the same armament. Mark 2s mounted a less-capable but easier-to-maintain engine as a cost-cutting measure. According to *Gallo's Fighting Warships*, the *Saladin* was a Mark 1, so no luck there.

The docking clamps worried her. Both models were capable of hauling fuel pods, cargo pods, or *Musharrif*-class gunboats, and while Medinan doctrine usually kept the *Musharrifs* tethered to heavier units, this wasn't a standard situation. Intelligence analysis was often a euphemism for planning for the worst, and the gunboats would complicate things. While *Saladin* engaged *Warspite*, the gunboats would be free to harass the convoy. They were no match for a warship, but the convoy was another matter. They could also provide supplemental firepower and seeker launches from different vectors while the bigger ships danced…

Karin appended the data on the *Musharrifs* to the report, and went back to her research. "TACO, give me the range envelopes for *Saladin's* lasers."

On the display, the cutaway of the enemy ship shrank to the size of a postage stamp. Colored conic sections leaped out from it, showing the traverse of arc: bright colors up close, shading down to translucency as the range increased. Figures and calculations sprang up alongside.

Inverse square laws eventually overcame short wavelengths and multimeter focusing arrays. The threat envelope from *Saladin's* main battery started at 360 klicks, picked up considerably at 260 km, and picked up again at 200. It remained constant from there. Shot for shot, *Warspite's* main battery did much greater damage—at closer ranges.

The colored sections said that *Saladin* had a longer range; the numbers said its main battery recycled faster than *Warspite's*.

We'll have to weather a lot of fire to get that closer range.

A voice and an image on her display interrupted Karin's mental calculations.

"Prime, this is the captain. Mr. Chung says you've examined threat envelopes on *Saladin*?" He sounded fatigued, tired. Quite frankly, he sounded furious, but she squelched that thought, fast.

"Aye, sir."

"Analysis?"

"Probably the same as Chung's, sir. We need to close the range, staying clear of the laser's convergence zone. If we can avoid taking their whole forward battery in a single shot, our forward plate should be able to handle it at anything past 300 klicks. We need to be inside 140 klicks before we have a decisive edge in short-range beam work, though with the closing velocity we'd need to beat their cycle time; we could be in trouble from kinetics. We don't have the zone defense to deal well with missiles, and the *Rafik* runs a smaller missile bus than we do, with three in the tube to our one."

A stress headache was crawling behind her eyes. She willed it down, and sipped some water. "Intel doesn't know for sure, but it looks like they've got about 50% more power plant than we do; it'd make sense with their armament. It might be easiest to think of them as a less advanced version of a *Kennet* class in general capabilities. They can certainly out-turn us; just about anything our size can. But unless our intel is badly out of date, we can push higher Gs in combat, even over a Mark 1."

A pause, then the captain harrumphed. "I concur with your assessment." He sounded like he was chewing a persimilemon straight up. "Helm, how much longer before we have to button up?" Karin didn't hear the reply, from out of the microphone's range.

Diplomacy had failed. She felt her guts knot up a bit.

"Prime, we're going to pull fins at 10,000 klicks unless *Saladin* goes to its combat drive before that. We estimate engagement in three hours, tops. You have oversight of the zone defense batteries in Auxiliary Control. In the meantime, let ratings hit the head while they've got the chance. You and the other watch-standers who came on at four bells go get fed and, if you can, some rest. For the ratings who came on later, cook's mates will be around with sandwiches and coffee. Everyone into their suits in two hours; we should be buttoned up inside of three."

"Aye, sir."

Captain Sieberts's micromanagement, telling her how to manage her ratings and her kidneys, told her something important.

He's nervous, too.

Her plans for rest kept getting postponed. First, it was scheduling the ratings' downtime, then making sure they got fed. Then two other interruptions came in that were easier to handle herself than to delegate. Then it was an interruption about the preflight checks on the missiles in the tubes. They'd been loaded at Pacifica, seven Gregorian months ago, and she had a sinking suspicion that the missile maintenance teams had gold-bricked. Nobody liked suiting up when they didn't have to…and it meant that she had to badger Lieutenant Weuve on the preflights.

She found herself gulping coffee that she didn't even taste. She hadn't even noticed that the third bottle was stone cold until she'd finished it…which meant it was past time to get some rest. The clock said she had almost an hour and a half. Enough time to go to her quarters, catch a nap, and be back on station in time for buttoning up.

The fatigue of six hours of sleep in the last forty hammered her out flat.

Henry was in her dreams. Dear, sweet, beautiful, balding Henry. His last video had caught up with her at AD Leonis, and the dear, oh-so-cherished boring trivia of his emails. She ran her fingers through his hair, kissed his bald spot. Played with those long-fingered artist's hands of his. Pretended to look shocked when he wolf-whistled at her. Smirked at where his eyes fell when she came out of the shower. Felt his warm weight curled up around her, like a scratchy security blanket. Talked to him over coffee, ran around with the dogs at her parents' farm, saw them sniff at and bark over the giant snails. Damned dogs were always barking at…

It was her console, going off. Every cell in her body was telling her to turn it off and go back to sleep. Instead, she broke open the wrapping on the "For Emergency Use Only" tablets, swallowed them, and marked the time down on her wrist computer. By the time she'd changed underwear, they'd put everything into that Vibrantly Sharp Resolution that only amphetamines bring, and she was able to strap herself into the sadist's corset that the Space Arm called a positive pressure regulatory garment. It pinched around the ribs and waist, the catheter was as unpleasant as always, the pads in the armpits and under her breasts chafed, and the entire rig smelled like several days of old sweat. She remembered to scratch between her shoulders before zipping the chest seal up.

The drugs had tricked her. She had time to grab a stanchion and float and…

She shook her head. Enough woolgathering. She looked around at her spare collection of effects, her small 2 meter by 3 meter cell. It wasn't home, really, but it was all she had for now.

Damned drugs were making her eyes water. That was it.

She grabbed her helmet, dogged the hatch, and floated with (she hoped) an air of resolution back to Aux Con.

Her photonics tech, Lead Spacer Masso, was stretched out in his chair. He was already suited up and had a sign taped to his chest telling any bystanders to wake him. Though his eyes were closed, she doubted he was asleep.

# # #

The long horizon of space and the unavoidable math of Newtonian mechanics removed uncertainties. Hostlicht knew that if she wished, she could read the vector plot and know within a minute when the engagement would begin. The engagement clock's message was "Lots of time for brooding." Every second dragged. She rocked Masso's shoulder.

The drone of the air plant blurred into the reports from the techs, and time passed in lurches and dollops as micronaps mingled with acknowledging reports that she didn't consciously recall having received, punctuated with occasional bursts of drug-induced hyperclarity. It was fatigue hitting again. Her thoughts turned back to Henry.

He wanted her to switch to planet-side duty on her next assignment, command track or not. She didn't blame him. She missed him, too. And she'd grown to hate the look on his face whenever she had to leave.

I might not see him again.

That thought snapped her abruptly awake. She didn't quite bite her lip. She had accepted that she might die, she'd thought. She'd hoped. This was the first time it had dawned on her that her death would hurt people she cared about, and that…that was even worse than the fear.

She wanted that dream back. Wanted it back so much she could taste it. She wanted to be back home. If she could touch him right now, she'd even forgive him for running replica automobile parts through the dishwasher.

The console in front of her blurred. She forced a feeble excuse for a sneeze, to give herself an excuse to wipe her eyes. The ratings and the JOOD didn't even look up. She settled back, trying to rub her spine against the acceleration gel where the middle of her back itched. She focused hard on readiness reports, while the numbers alternated between blurry and sharply focused, dancing to the tempo of that returning headache. On some level, they seemed horribly abstract and unimportant. She blinked, and reread the readiness reports again and…

The klaxon signal made her jump. She rubbed her eyes and acknowledged "Ready!" from reflexes drilled deeper than sleep could take her.

"All hands, prepare to button up. Damage control teams, report for muster at your stations. This is not a drill!"

She hooked her suit's line to central life support. Then she pulled the self-contained life support pack out from under her couch and hooked it to the console, ready to be grabbed and hooked to the coverall in the regulation twenty-one seconds.

Around her, the team was doing the same, while reports poured through her headphones and the compartment's speakers.

"Seal all pressure tight doors. Condition Zulu is in effect. Repeat: Condition Zulu."

The last telltale flashed on her board. She took a last breath of ship air, sealed her helmet, and said to her microphone, "Auxiliary Control, secure." The other reports came through her helmet as other stations reported in.

"Engineering reports sodium flow to radiators has been cut out. Radiators retracting."

"WEPO reports mounts Abel One and Two, Baker One and Two have green boards."

"Coilgun mounts, green boards all."

"Aux Con reports multiplex fire online. All point defense arrays green boards."

"Starboard missile bay shows green boards. Port bay shows amber. Preheat problem. We've got a team troubleshooting now."

"CHENG reports sodium drawn down. Dumping to heat sinks now."

"All spaces report secure. Radiators inside the hull and armor plates locked in place. We are now buttoned up."

"Beginning initial burn. Prepare for combat thrust in three, two, one—mark!"

Sixty-odd meters below Karin's ass, deuterium met tritium and fused, heating byproducts to nearly incalculable temperatures, jacketing the remaining plasma with carbon dioxide, and spitting out a cascade of X-rays and neutrons. A giant sat on her chest. He squeezed out all her thoughts of Henry and all her breath. Also, all hint of a headache.

The waiting was over.

# # #

At the tactical level, *Warspite* should have the choice of closing vectors, due to her higher thrust. *Saladin's* armament favored a medium-range, sustained engagement. That meant keeping her maneuver options as open as possible, which in turn meant that she'd angled across *Warspite's* vector, trying to reduce the rate of closure. So far, it was all right out of the book.

The ships' vector plots crossed at 220 kilometers, with a relative rate of closure of 150-odd meters per second: the almost-leisurely pace of a jetliner. Karin's readouts told her that *Saladin* had pulled in radiators about 800 kilometers closer than *Warspite* had. Both ships were on a clock dictated by thermodynamics. In theory, *Saladin* had bought a couple of extra minutes of buttoned-up time before the radiators needed redeployment. It was unlikely to matter to *Warspite* unless the battle went severely against her.

Nobody ever said the Medinans were stupid.

As if to prove that, *Saladin* rotated away on thrusters and engaged her own combat drive, running 90 degrees to *Warspite's* nose. *Saladin* couldn't match *Warspite's* thrust, but she could run across the vector, forcing Seiberts to decide to either charge down her throat or accept a slow spiral in. Even as Karin thought that, the order came down to turn-and-burn, into *Saladin's* path.

Seconds ticked by as the closing vector crept upward, along with the tension.

"Contacts!" the comm chattered. "Captain, two missiles inbound from *Saladin*, burning at 8 G's straight into our vector!"

Karin swore, and her fingers flew across her board. Captain Seiberts's voice was clipped, harsh. "Prime?"

"Working, sir. If they burn through to just outside our firing range, the crossing vector is going to be high—call it six, six and a quarter kips. I can't give a coverage rating until we see what they drop, but anything that gets through at that rate will punch a hell of a hole in the front plate."

Seiberts snapped "Worst case."

"Worst case is a dozen 50-kilo impactors on target, ZD coverage 90%. Odds are we'll see two come through the zone."

Karin could hear Seiberts's teeth grinding. "Weapons, give me a firing solution against *Saladin's* vector. Helm, hold on a one-eighty for my mark."

Karin let out a whuff of breath she hadn't realized she'd been holding. He was taking it on the flare. Anything those missiles dropped would have to have to crawl up three kilometers of plasma. She left the ZD solutions running in case something changed, and turned her attention to the portside missile tube, which was still not green. As she tuned in the channel, she could hear two people swearing in three languages: English, German, and Engineer.

Sieberts's voice again, on the command channel. "Launch kinetics from the coilgun mounts."

She flexed her hands over the haptics of her keyboard as an almost subliminal shimmy went through the compartment. Electromagnetic tubes accelerated four 100-kilo projectiles into space; Karin's display showed their green arrow points lining up on their trajectories. Seiberts had fired into the space *Saladin* would shortly occupy if her captain didn't cut thrust. Not as harsh a message as the missiles were, but nothing that could be ignored.

"Launch coilguns. Helm, mark." Another four blips homed in toward *Saladin*, and she responded by cutting her nose "down," even as *Warspite* started pivoting in response.

The missiles flared and went silent, their fuel spent, and then Karin's heart spasmed as they expelled a field of radar balloons drifting in toward *Warspite* instead of the expected guided shells.

Nukes.

"Prime!"

"Yessir! Thirty-eight radar contacts, two 1.5-megaton warheads worst case. We'll only have 30% coverage in the zone; that's 50/50 odds on each target."

This time Karin didn't imagine it: Seiberts swore. "*Scheisse!* Helm—"

"No good, sir, we're committed. If we abort the pivot now, those are coming in on the aft starboard quarter."

A half-second pause. "Continue. Prime, get me my portside missile!" Seiberts was angry, and Karin didn't blame him. Nukes had been the subject of the Ban of Pacifica. They were what the mutual inspection regimes and swapping of side parties were meant to discourage. *Warspite* didn't even have them in stores.

Warspite slewed around and pointed her engine at the incoming threat. As they drifted into the jet of superheated plasma, thirty-six radar balloons flared and vanished. One of the nukes disintegrated from the heat before the neutron flux of the ship's drive turned its plutonium core into tacky metallic jam. The other one didn't.

A klaxon blared, and telltales registered a temperature spike in the thrust bell before the overrides cut in. The giant on Karin's chest eased off as the acceleration dropped sharply, then steadied at 1 G.

"Engineering, status!"

"We've lost some radiators off the bell, and primary choke sensors are gone; backups coming online now. We've still got full combat thrust, but it's fragile." *Push it, and we're dead in the water*, Karin silently translated.

Warspite's turn-and-burn, as well as *Saladin's* own work to dodge the coilguns, dropped the crossing vector substantially, and left them in the slow inward spiral that they'd tried to avoid. Not even five minutes had passed.

The comm crackled: Seiberts's voice again, but calm and measured now. "Helm, keep our nose plate pointed at *Saladin*. Cut back to one-half G and hold it steady. Engineering, cut the reactors." He paused. "Now we wait." Karin eyed the engagement clock as it ticked to a halt and hoped the gamble would pay off. Killing the reactors meant that until they came back online —which was a two-minute startup from when the order went down— they only had the power in the capacitors to fire with. Sieberts's plan was to look more hurt from that blast than they actually were, and hope that the nuclear flash had made hash of whatever scopes the *Saladin* had on the *Warspite.* It also meant that they had stopped building heat and could stay buttoned up that much longer. Longer than *Saladin*? Maybe. Like Seiberts said, it was a waiting game.

# # #

Minutes passed while the two ships jockeyed closer. *Saladin*, either believing *Warspite* as damaged as she pretended, or simply in no hurry, was content to let the gentle spiral continue. Karin didn't blame them; if nothing changed, *Saladin's* main batteries would cycle four times before *Warspite* reached its own ideal range.

A telltale flashed on her board; it took her half a second to process it, then "Portside tube has cycled green, Captain. Fire Control reports full readiness."

As though that was the cue he'd been waiting for, "Helm, cut thrust, then prep for full burn. Fire Control, launch missiles with a thirty-two-second sustained burn, then deploy at the edge of *Saladin's* threat envelope. Engineering, reactors on."

Saladin looked to have been ready to move too. As soon as the missiles left the tube, she slewed her nose around to aim straight at *Warspite* and started ramping up her thrust, trying to get her primary lasers into threat range on the missiles before they could deploy.

"Helm, engage thrust."

The giant sat on Karin again as *Warspite* accelerated at 1.5 Gs, chasing down the missiles. Seiberts intended to force *Saladin* to choose between shooting down the missiles or *Warspite,* with no time to cycle between the two.

Saladin had other plans.

Warspite's missiles deployed, each *Hydra*-class missile bus dropping thirty-six 50-kilo impactors. Seventy-two projectiles arrowed in on the *Saladin's* position at a shade under 4 kips. Karin did not envy her counterpart; her smile was cold.

Saladin snapped its nose around, faster than Karin expected she could, and burned hard at ninety degrees to the approaching cloud. Karin's smile faded as over twenty of the blips went dark; *Saladin* had exceeded the submunitions thrust envelope, and those projectiles could not catch her. Secondary batteries and zone defense thinned the remainder, and only four shells remained to punch into *Saladin's* forward armor. Not enough.

Seconds later, *Warspite* drifted into *Saladin's* laser envelope.

Lasers are invisible, unless they're plowing through a medium that disperses them. The twentieth-century image of visible beams slashing through the void was as laughable as fighters making swooshing turns in vacuum. The first indication that *Warspite* had been shot was the damage alert.

Four lasers focused on an eight-centimeter spot high on the forward armor plate and turned it into a scything jet of plasma, shock waves from the transformation making diamond-fiber lattice crumple and shatter. The armor dissipated some of the energy, but not all.

The audio circuit sang a tale of woe.

"Damage control reports burn-through on deck thirteen, starboard side! Dam Con team four moving in."

First section's berths. Nobody in them.

"Reporting concussion effects in Delta mount. Coilgun one is nominal, but restricted duty cycle."

"Sodium leak on deck twelve! Purging!"

One of her engineering profs had a taste for archaic space literature, and had drilled into everyone's head that the energies in space combat were quite calculable–just very large. *Warspite* had a respectable forward armor belt, but even the heaviest armor had limited effect against energy densities that high.

Karin noted the four impacts from the missiles plowing into *Saladin's* dorsal surface as the ship rolled. There weren't any obvious signs of damage at this distance. Since she could see *Warspite's* damage control reports, it was easy to assume *Saladin* was giving better than she was taking, but the range was dropping fast, toward *Warspite's* optimum combat envelope.

The closing vector pattern showed *Warspite* making an eighty-kilometer pass at closest approach without further course corrections.

She's got nothing left, and now it's our turn.

Karin hadn't finished the thought when *Saladin* launched her last three missiles.

In space combat, according to doctrine, missiles had three uses:

The opening salvo of a long-range engagement.

The finishing stroke against a mortally wounded opponent.

The last resort of the desperate.

Saladin's missiles burned hard for sixteen seconds. *Warspite* drifted right into their path, heading for her 80 kilometer interception. Doing anything about the missiles now meant giving up their shot, and the reactors weren't online yet..

Hostlicht had been too busy watching the missile tracks to study the master tactical data feed. Now she saw that they'd reached their optimum crossing point with *Saladin.*

The red emergency lights in Auxiliary Control dimmed and flickered with the power draw of the main batteries. Karin held her breath, waiting for them to come back on at full strength.

Saladin's armor blunted the laser blast from *Warspite's* main battery without turning it. Spectrographs showed her streaming atmosphere. Secondary explosions reduced her only bearing coilgun mount to twisted ruins. A plume of white-hot sodium vapor told a story of death in the bowels of the ship. On the IR, a thermal flash told of Saladin's secondary laser firing on them. The klaxons had become so omnipresent that she had to scan her boards again. Bright red showed on the compartments of deck twelve, port side.

The two ships drifted apart, while on Karin's board a proximity alert still screamed about the incoming missiles.

Red snowflakes appeared on the display as the submunitions deployed. Same pattern as before: thirty-eight blips, only two of them real. Fortunately, they were drifting slow enough that the zone defense would kill them, even with only starboard mounts bearing. Her fingers gave the order while she focused on the display.

Thirty-eight blips floated closer.

"Foxtrot mount not responding! —" Karin's stomach twisted. *Foxtrot Fire Control is on deck twelve. That last shot. Or the sodium leak…*

"Helm, hard over roll! *Führen Sie, Dammit Durch!*" Seiberts's voice, desperate.

Too late, too late, too late.

# # #

Both nukes detonated on *Warspite's* port side, just forward of amidships, sleeting a cascade of X-rays that *brehmed* down into IR and worse when they hit the skin of the ship. The titanium layer vanished, its energy of decomposition transmitted to the underlying sheets of diamond laminate. The thermal capacity of carbon, while high, is less than infinite, and the sheets vaporized, driving a wall of plasma and concussion effects that peeled *Warspite* like a sandblaster hitting a sausage.

Cocooned in the bowels of Auxiliary Control, Karin heard the spine of the ship groan from lateral stress. Her boards flared red: Reactor One showed no status, and Two was at risk of catastrophe. She had no reliable telltales on the stored power systems, and no telltales at all on the heat-sink array.

She looked at the engagement clock. It said ten minutes before waste heat fried them all, and that input went into the blur of data washing over her as she typed like mad, mouthing prayers.

Ohdeargod ohdeargod ohdear…

From his station, Masso called, "Negligible rems down here, ma'am." He stared at his radiation meter like a winning lottery ticket. Karin didn't have the guts to look at hers. "Masso, what comms have we got?"

"Nothing to CIC. Air blowers are shoving cable for Dam Con teams to plug in. Teams 2 and 3 aren't replying."

Karin's own boards indicated the after third of the portside sensor array had evaporated with the armor.

No hookup to CIC. It was up to her now. Her mouth tasted like the inside of a car battery, and the wakeup pills weren't playing nicely with the adrenaline. She wanted to puke.

No time to lose.

"Ellis, get pivot thrusters control to my board, here." *Calm. Must radiate calm. Cannot sound shrill…panic is NOT an option.*

Ellis nodded, still dazed and confused. But she did it; Karin saw the repeater board switch over to maneuver control. She thanked God and anyone else listening that the thrusters still worked. The nose of the ship swung toward *Saladin*, to put the forward armor in the way of any last incoming fire and to use the undamaged sensors in the bow to cobble together a picture of the tactical situation.

Saladin was drifting past on her prior vector; she wasn't doing any kind of controlled pivot. Karin drew her maneuver on the bubble, to keep the nose pointed at their foe…and saw the still glowing exit wound of their strike. She hadn't pivoted to bring weapons to bear. *Saladin's* radiators were still in.

"Masso, any contact with Abel and Baker mounts?"

"Yes'm. Just came online. Baker mount is hit bad; Abel's online. Let me know when you need Fire Con routed. Abel's team says they'll be cool enough to fire again 'bout ninety seconds from now."

Through her helmet, she heard someone pounding in code on the bulkhead door. She waved a hand to Masso to float over and open the hatch. A Damage Control rating with a cutting torch peered in, blinking at the battered and smoke-filled Auxiliary Control compartment, while holding to the hatchway rim with a free hand. Aux Con had a slight overpressure…smoke was drifting out the lock. Ellis's left arm was held at a weird angle, and two high-power cables were coiled over her chest and lap; the smoke was coming from the plastic of her suit burning. *Holy mother of...how did I miss that earlier...*

"Ah, ma'am—we're sealed off above deck seven…." Karin checked her boards. No comm channels open with CIC yet. She swiveled her couch to face the rating.

"Then you're going to have to strap on your gear and run a commo cable for me. I can't fight this ship if I can't control her. If you see a medic team, send someone by to pick up Ellis." She could see white all the way around Ellis's eyes, and Ellis hadn't given a single verbal acknowledgment.

"Ah—I've four people here, but two of 'em need tank charges—"

"Take them from our reserve life-support lockers. Just get me that cable run, and fast!"

The rating let himself float gently backward out of Auxiliary Control. Karin heard him calling his mates while she watched the display tank—*Saladin* drifted, slowly opening the distance.

"Aux to Engineering, Aux to Engineering. Report." Engineering was below deck ten. With luck, she would have undamaged circuits to—

The connection came through an alternate analog line and sounded like a dozen eggs frying at once. Karin winced.

"This is Preston in Engineering. We can't raise CIC."

"I know, Preston. Do you have any status on our heat sinks?"

"Negative, ma'am."

"Not the answer I need. I want status on the heat sinks now, and see if we can extend the radiators on the dorsal line. We need to bleed off some of this heat—my board shows that Reactor One is intermittent, but that's the only information I have." She paused and looked at *Saladin's* vectors, which hadn't changed.

"I think *Saladin's* hurt worse than we are. They had the perfect opportunity to blow us into scrap, but didn't fire, and they haven't extended their radiators. Please advise on capabilities. Have any Dam Con parties made it to CIC yet?"

She had not wanted to say "Please." She'd wanted to scream. She refrained from making a bad situation worse. She stifled a sigh of relief when the frying eggs faded slightly and Preston came back on.

"Boards say we've still got the dorsal radiators. Extending radiators now, ma'am." A pause. "No reports on CIC yet, ma'am."

"Thank you, Mr. Preston. When you can, detail some spacers to assist the Dam Con parties. I don't know how badly we're hurt. See if there's anything you can rig to let us reach *Saladin*. We've got power, so we might as well accept their surrender if there's anyone left on their ship to surrender her."

"Aye, ma'am!"

Karin opened the all-ship communications channels. "Commander Hostlicht in Auxiliary Control to all stations. Report status and casualties. All medically trained personnel, link up in the largest pressure-capable compartment for triage. Repeat. Commander Hostlicht in Auxiliary Control to all stations…"