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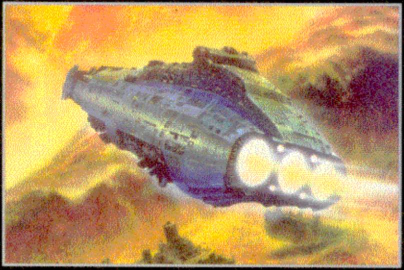

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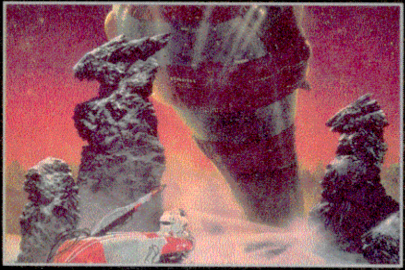

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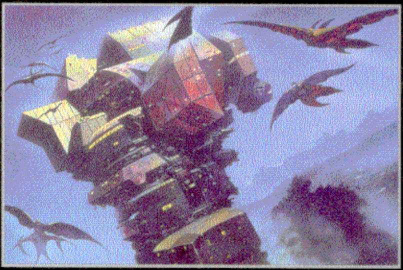

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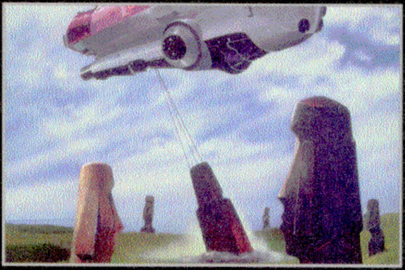

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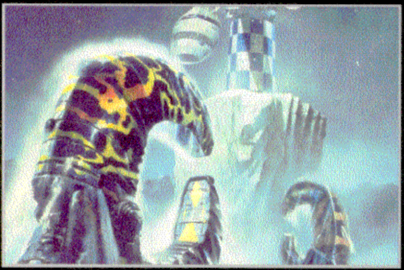

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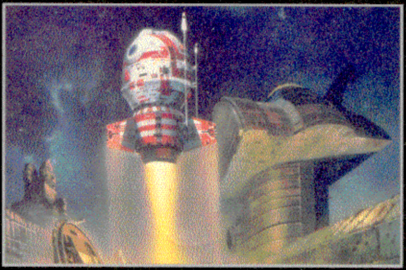

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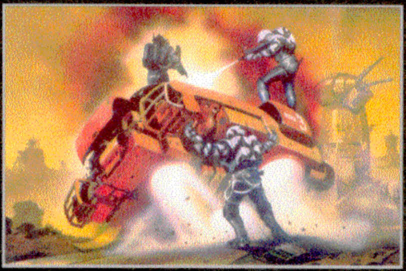

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MARC MILLER'S TRAVELLER®

FIRE, FUSION & STEEL

Science-Fiction
Adventure in the Far Future

Get started designing your own spaceship on page 9.

Create weapons for your ship or your holster, beginning on page 29.

Peruse an arsenal of weapons accessories on page 61.

Wire your ship for quick response, starting on page 69.

Customize your life support and accommodations on page 75.

Power up on page 81.

The Future is Just Around the Corner

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We would like to thank Marc Miller for this opportunity to contribute to *Traveller*.

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Playtesting and Further Advice: Andrew Akins, Per Bernhardssen, Rob Brennan, Steve Charlton, Chris Cox, Ryan Christensen, Brody Dunn, Joseph Heck, Bruce Johnson, Bertil Jonell, Bri Kaszycki, K.C. Komosky, Chuck McKnight, Frank Piotrowski, Robert Piper, Bill "Commander X" Prankard, Allan and Susan Shock, Douglas N. Sinclair, Mark Urbin, and Andrew Vallance.

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"If I have seen further, it is by standing on the shoulders of giants."
Sir Isaac Newton (1642-1747)

Traveller®,
Science-Fiction Adventure in the Far Future
by Marc Miller

Edition 4.1

1 2 3 4 5 6 7 8 9

The game and universe presented in this book envisions a referee or game master as the ultimate supervisor of game play. The publisher is prepared to answer questions about Traveller provided a stamped, self-addressed envelope accompanies the request.

Imperium Games, Inc.

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INTRODUCTION

Fire, Fusion, and Steel is the **Traveller** technical architecture manual. It contains rules and guidelines that allow players and referees to create many types of vehicles, weapons, and other equipment to meet the specific needs of their games. Science fiction as a literature is based on scientific fact and imagined extensions of scientific knowledge, and **Traveller** is a part of that literary genre. Of course, science fiction is fictitious, and **Traveller** technology departs from reality in a number of significant areas, usually as required to support the high-adventure plot line of the game. We firmly believe, as did the authors of the original edition of this book, that a grounding in hard science for much of the game's technology adds to the sense of realism and contributes to the "willing suspension of disbelief" that is so important to enjoyable roleplaying.

A secondary goal has been to provide real-world units of measure for the fictional technology of this universe, so that this edition of *Fire, Fusion, and Steel* is not tied to any specific set of game rules but is as extensible as the **Traveller** game system itself—this book allows referees to tailor the **Traveller** rules to fit a variety of possible science-fiction settings.

No single book, or even a series of volumes, could hope to circumscribe the **Traveller** universe. A science fiction game should always be open to additional technological possibilities. We hope that readers will treat this book as a signpost pointing toward what is possible and not as a limitation to their own imaginations. We feel we've covered the most important subjects relating to starships and vehicles in this volume, and we hope to present additional material in future products. That material might include nautical vessels, walker vehicles, cybernetics and robotics, and expansions or additional material (such as configurations) for use with this volume. Another option is an integrated spreadsheet to handle all the calculations for most designs.

The Design Process

The bulk of this book is devoted to design sequences, step-by-step procedures to design a particular piece of equipment. These sequences are meant to be used as a component of the overall design process, to help you arrive at a final design:

1. Define the Mission
2. Determine Limiting Factors
3. Design Subcomponents
4. Use the Design Sequence
9. Evaluate the Design
6. Tinker With the Design

Define the Mission

Equipment is not designed in a vacuum. Each vehicle, weapon, or other piece of gear has a specific purpose. This purpose determines many characteristics of the equipment. For example, a light weight handgun has very different requirements than a sniper rifle. Briefly note the mission before beginning the design, and keep it in mind throughout the rest of the design process.

Determine Limiting Factors

Depending on the design sequence, several factors are important in the design sequence. All designs depend on the technology level of the manufacturing world, so the governing TL must be determined. Additional limiting factors (such as total volume, maximum mass, or muzzle energy) depend on the design sequence to be used.

Design Subcomponents

Many of the design sequences require information from other design sequences. For example, before a tank can be designed, the main gun it is to carry must be designed, and before the gun can be fully evaluated, the ammunition it fires must be designed. Determine what subcomponents are required by your design, and design those items before proceeding.

Use the Design Sequence

Now that you have all of the information you need to complete the design sequence, proceed to the appropriate section of this book, and work through the design sequence, step by step. Many design sequences frequently refer to common components such as hulls, thruster agencies, or power plants. Instead of being repeated throughout the book, these components have been grouped at the back of the volume. You will need to refer to them during the course of your design.

Evaluate the Design

When the design is complete, evaluate it with respect to the mission. Does the equipment meet the requirements? If it does not, are the requirements unrealistic, or can the design be improved?

Tinker With the Design

Sometimes the initial design does not fully meet the requirements of the mission, or it is impractical. If there is need for improvement, return to the design sequence and alter the design slightly. Evaluate the results of the change, and repeat the process until the design meets the requirements (or is as close as it's going to get).

Technology Assumptions

Traveller has never been limited to a single "official" campaign background. Some 20 years ago, the original edition of **Traveller** closed with these words: "Virtually anything mentioned in a story or an article can be transferred to the **Traveller** environment. Orbital cities, nuclear war, alien societies, puzzles, enigmas, anything can occur, with the imagination being the only limit." These rules are intended as a framework that allows players and referees to play in a wide variety of science-fiction settings. *Fire, Fusion, and Steel* presents a set of technological assumptions for **Traveller** games, but they are not restricted to any assumptions for a particular milieu or universe.

Not all referees will wish to design their own, unique universes. Many would rather start playing in a standard campaign setting that they know will be supported by future products. For **Traveller**, this standard campaign begins with *Milieu 0* and the founding of the Third Imperium. *Fire, Fusion, and Steel* supports *Milieu 0* as well as the entire future history of the Third Imperium that will be covered in projected milieu books.

Traveller divides the technology of the future into two types: baseline technology and projected technology. Baseline technology is based on what is possible at the end of the 20th Century, and it includes all of the physical laws that are known and understood today. This includes technologies such as firearms, internal combustion engines, nuclear fission, electronic computers, and everything else that is a part of modern civilization. Projected technologies are those developments that are postulated in the **Traveller** universe but have yet to occur in reality, such as inexpensive nuclear fusion, faster-than-light travel, and contragravity. These are projected technologies because they are created by extending the scientific principles we currently understand into a fictional technology.

Organization

Fire, Fusion, and Steel is divided into two sections: design sequences and components. The first section contains design sequences for vehicles and weapons, in separate chapters. Each design sequence chapter presents, step by step, the procedure used to design a particular item, be it a spaceship, an airplane, a round of ammunition, or a weapon. In a few cases, a design sequence references another chapter, where something must be designed before you can complete the design that's in progress. The design sequence should be obvious: For example, you must design the ammunition before you can design a weapon that fires it, and you must design the weapon before you can design the vehicle that carries it.

The second section contains information on components, like power plants or life support systems, that are used by more than one design sequence. To eliminate the redundant information (and make all of these design sequences fit into one book), the components have been grouped together in the back of the book. Each chapter presents information about similar types of components: The power plants are in one chapter, life support is in another, and electronics are in yet another. Most designs require some of these components, but no design uses all of them.

Standards

Much of the information presented in this book is mathematical, so a system of standards must be established for ease of interpretation. Take a few extra minutes to fully grasp the information below; it will greatly speed your design process.

Units and Measurement

The **Traveller** game uses the metric system (also known as the "International System," and abbreviated SI) of units exclusively. To assist players who are more familiar with the Traditional System of units, approximate conversions are provided in **Table 1: Metric Units.**

Metric Prefixes

The metric system is a decimal system of measure. Each type of measurement (length, volume, mass, and so on) has a base unit of measure (meter, liter, gram). Each unit of measure also has a unique abbreviation (m, l, g). All other measurements of the same type are decimal multiples of the base unit of measure. The multiplier is indicated by a prefix on the base unit, or an abbreviated prefix on the unit abbreviation. **Table 2: Metric Prefixes** provides the abbreviations, prefixes, and multipliers for all of the metric prefixes.

Length

The primary length unit is the meter, and is abbreviated "m". One meter is 3.28 feet, or about 3 feet, three and one-third inches. Common multiples of the meter include the kilometer (km), the centimeter (cm), and the millimeter (mm). One kilometer is approximately 0.621 miles. A centimeter is approximately 0.394 inches. 25.4 millimeters is exactly one inch.

Interplanetary distances are frequently measured in astronomic units (abbreviated AU). One AU is 145,900,000 kilometers. Interstellar distances are measured in light-years (l-y) and parsecs (Pc). A light-year is the distance light travels in a year: 63,279AU or 9.46(10^{12}km. A parsec is 3.26 light-years (or 206,292AU or 3.084(10^{13}km).

Speed

Speed is measured in meters per second (m/s) and kilometers per hour (kph). One meter per second is approximately 2.2369 miles per hour, while one kilometer per hour is 0.621 miles per hour.

Acceleration

Acceleration is measured in meters per second per second (abbreviated m/s/s or m/s^2). Acceleration measures the rate at which speed changes. Acceleration is also frequently expressed in "Gs", or "gravities". A standard **Traveller** gravity is defined as 10 m/s^2. (The average surface gravity of the Earth is 9.8 m/s^2, which has been rounded up to 10 for ease of calculation.) To convert from acceleration in m/s^2 to acceleration in Gs, divide by 10. To convert from acceleration in Gs to acceleration in m/s^2, multiply by 10.

It is important to understand the difference between speed and acceleration. Speed measures how fast an object is actually moving: an automobile at 100 kilometers per hour, or a spacecraft at 100,000 kilometers per hour. Acceleration measures the rate at which the object's speed is changing: the change in speed divided by the elapsed time. If an object's speed is not changing, then acceleration must be zero. On the other hand, knowing an object's acceleration does not give you the object's current speed, unless you know the starting speed (before the acceleration started) and the amount of time the object has been accelerating.

For example, if the automobile mentioned above accelerates from a standing start (speed zero) to 100 kph in 5 seconds, we can calculate acceleration: the change in speed divided by the elapsed time is acceleration. The example sports car has changed speed by 100 kph (this is 27.8 meters per second) in 5 seconds, so acceleration is 5.6 m/s^2. (That's a little over half of a standard gravity, and a pretty good sports car—0 to 60 miles per hour in 5 seconds.)

Volume

Volume is measured in cubic meters (abbreviated m^3). One cubic meter is the volume enclosed by a cube that measures 1m on each side. For reference, a cubic meter is about 264 U.S. gallons or 35.3 cubic feet. A cubic meter of pure water masses one metric ton.

Spacecraft volume is also described in displacement tons (abbreviated dton or T_D). A displacement ton is 14 cubic meters and is the volume requiring metric ton of pure liquid hydrogen. Because jump drives require large quantities of liquid hydrogen fuel, starship volumes are traditionally described in displacement tons.

Mass

The basic unit of mass is the gram (abbreviated g). Mass is a fundamental property of matter and is independent of the local gravity (if any). One gram is one gram on any planet in the Imperium, regardless of the surface gravity, and it is still a gram (although a lot harder to measure) in a weightless environment. The gram is a very small unit of mass—about 0.03527 ounces. Kilograms (kg) and metric tons (t) are used more frequently in these design rules. A kilogram is 1,000 grams and is about 2.2 pounds in Earth gravity (9.8 m/s^2). A metric ton is 1,000 kg and is about 2,205 pounds, or 1.1 short tons.

Strictly speaking, ounces and pounds are measures of weight and not mass, and any conversion of kilograms to pounds depends on the local gravity. On Earth's Moon, which has a surface gravity of 1.7 m/s^2 (that's 0.17G), a kilogram weighs 0.374 pounds. In common usage, weight and mass are treated interchangeably. Because of the wide variety of environments encountered in **Traveller**, this book treats weight and mass separately. Mass is measured in kilograms, and weight is measured in units of force.

Force (Weight)

The metric unit of force is the Newton (abbreviated N). Mass, acceleration, and force are all related: A force is the "push" that causes a mass to accelerate. Stated mathematically, force equals mass times acceleration. The force (thrust) of a rocket engine can cause a spaceship to accelerate. Gravitation causes all objects in the gravity field to experience a force (weight) towards the center of the field. A Newton is the force required to accelerate one kilogram at 1 m/s^2 and is about 0.225 pounds. In more familiar terms, a 1kg mass in a standard gravity (10 m/s^2) has a weight of 10N, or about 2.25 pounds. Large forces are more often measured in kilonewtons (kN). One kilonewton is 1,000N, or a force of 225 pounds.

Power

The metric unit of power is the Watt (W), but kilowatts (kW) and megawatts (MW) are used more frequently. One kilowatt is 1.34 horsepower. Equipment which generates or consumes electrical power is rated in Watts.

Energy

The metric unit of energy is the Joule (abbreviated J). One Joule is one Watt per second, or about 0.24 calories, or 0.7377 foot-pounds. Kilojoules (kJ) and megajoules (MJ) are also commonly used. The energy of a handgun slug ranges from a few hundred joules to over a kilojoule, depending on the weapon.

The distinction between power and energy is sometimes hard to grasp. Power is the rate at which some work is getting done. The total amount of work that's being done can be measured by energy. As an analogy, the power is the amount of water that's coming out of a garden hose, while energy is the total amount that's in the bucket (or swimming pool) that you're filling. For example, a simple battery-powered circuit can charge a capacitor (in an electronic photoflash). The power of the circuit is a fraction of a Watt, and it takes many seconds for the circuit to fully charge the capacitor. The total charge stored in the capacitor is energy, and when released all at once can be spectacular (lighting up the room).

Money

The Imperial unit of currency is the Credit, abbreviated Cr. Thousands of credits are frequently called kilocredits (kCr), and millions of credits are megacredits (MCr).

Calculations

Tables and formulas abound in *Fire, Fusion, and Steel.* In some cases, both are provided; the designer may choose which is more appropriate. Tables are usually easier when you're calculating by hand, and formulas are easier when working with a computer spreadsheet. If you need a value that does not appear on the table, and no formula is provided, you can interpolate from the values provided.

Unless otherwise noted in the text, retain fractions for intermediate results. When rounding is required, round to the nearest whole number. (Fractions less than 0.5 are rounded down, and fractions of 0.5 or greater are rounded up.)

Tools

To make effective use of this resource, you'll need pencil, paper, and a calculator. A computer is also desirable but not required.

Pencil and Paper

No matter what your other tools, you'll find that a pencil and a pad of paper are valuable whenever doing design work, to take notes, figure out small side problems, and to work out options and rules of thumb. If you're good with math, it is possible to use many of the design sequences with nothing more than a pencil and paper (and perhaps a few tables of logarithms and roots). But we strongly recommend investing in a pocket calculator.

Pocket Calculator

Fire, Fusion, and Steel is designed with the assumption that anyone using the design rules has a pocket calculator available to help with the mathematical chores. For use with this book, a recommended calculator has square (usually labeled x^2), square root $\sqrt{x}$, and logarithm (log) keys, as well as a power function (y^x), which allows you to raise a number to any exponent. A variety of good calculators are available at about the same cost as this volume.

Many calculators do not have keys to cube a number or extract a cube root, but the power key can be used to perform this function: Raising a number to the third power is the same as cubing it, and raising a number to the one-third (0.3333) power is the same as taking the cube root. A number can also be squared or cubed by multiplying it by itself: $A \times A = A^2$ and $A \times A \times A = A^3$. Similarly, calculators that have a power key but lack a square root key can also perform square roots by raising a number to the one-half (0.5) power.

Computer

Many **Traveller** players have access to a personal computer and a spreadsheet program. Some consider this the best way to design because changes can be made, and the results can be seen immediately throughout the entire design. Most spreadsheet programs have a power function, which can be used to take square roots and cube roots using the same technique described for calculators above.

Additional design resources may be available from the Internet. Imperium Games maintains a world-wide web site at http://www.imperiumgames.com/ which will be used to distribute official errata. The Internet is also home to a number of **Traveller** enthusiasts (including the authors and playtesters) who exchange equipment designs and other information.

Accuracy

Although pocket calculators and electronic spreadsheet programs allow anyone to compute to eight-digit accuracy, *Fire, Fusion, and Steel* designers do not need to use all of these digits. Most of the tables in this book have between two and four significant digits. When calculating by hand or with a calculator, three digits is normally sufficient. When using an spreadsheet program, the computer calculates with additional precision internally, but designs only need to be recorded to three significant figures in the final results.

When working with historical equipment, a representation that's within 10% of the actual values is usually "close enough," although greater accuracy is usually possible by tinkering with the design. Another (perfectly valid) method of representing historical equipment is to gather enough information about the real thing to generate the ratings required in your **Traveller** game. For example, if you can find out the barrel length, overall length, empty and loaded masses, and muzzle energy of a real-world gun, this is enough information to produce game ratings for the weapon using the rules in this volume.

SECTION I: DESIGN SEQUENCES

1: VEHICLE DESIGN

This section of *Fire, Fusion, and Steel* details design sequences for vehicles, weapons, and defensive systems, in separate chapters. Great care has been taken to present the information in a logical, easy-to-understand order, allowing you to design as you read, but it might be helpful to read all sections pertaining to your individual design before proceeding. Sometimes, a design sequence refers another chapter, where another component must be addressed or designed before you can complete the design that's in progress.

Spacecraft

Why not begin with the interstellar chariot? **Traveller** doesn't necessarily require player characters to become space voyagers, but it's a rare group that doesn't take to the stars almost from the moment they begin a campaign. Of course, hopping aboard a Free Trader and blithely slipping into jumpspace is one thing, and building a starship from the ground (or "space station") up is another. The self-made architect/engineer of the future must proceed with deliberation and vision.

Mission and Limiting Factors

Before beginning to design a spacecraft, decide on the basic parameters for your design. Think about its mission: independent trader, luxury liner, warship, scout, private yacht, or some other kind of vessel. This drives everything else, from size on up. For comparison, a standard Free Trader, the workhorse tramp cargo vessel, is $200T_D$. Small passenger liners operating for the large merchant lines range from $400T_D$ to $2{,}500T_D$, while larger liners on important routes can get as big as hundreds of thousands of displacement tons. Private yachts are usually a few hundred displacement tons. Military vessels run the gamut, from $400T_D$ system defense boats to million-ton dreadnoughts.

In addition to volume, the other limiting factor in starship design is the tech level it will be built at. That's going to affect just about everything else, from your choice of weapons and maneuver drives to how far you can jump.

Consider if you want it to be armed, and how much. If it's going to be a battleship built around a specific weapon, you might want to go pick the weapon first. What level of armor is appropriate? Merchants try to get by with as little as possible because armor costs money and takes away from available cargo volume. On the other hand, a good rule of thumb for large military ships is that they should be armored enough to survive a shot from their own main weapon.

Also choose the acceleration you want, in Gs. Again, military vessels want as high an acceleration as they can afford while merchants want to spend as little money and space as they can on drives and fuel. But remember: You have to consider how you'll be able to take off and land. Maybe you'll install auxiliary contragravity lifters, or maybe your ship will have wings.

Is this ship going to be jump capable (a starship), or only for knocking around in a single star system? If it's jump capable, what rating do you want?

Once you've got a fair idea of the basic requirements for your design, you're ready to start. You may find halfway through your design that you can't meet every one of your requirements. (Don't even *try* building a heavily armored, 6G, J6 merchant vessel!) In that case, you're going to have to revise your requirements—which ones are vital to the ship's mission, which ones are useful additions, and which ones are simply nice to have. Start weeding them out. You may even have to back up and redo a part of your design if you've put nonessential equipment in early but can't fit in a mission-critical component later in the sequence.

Hulls

Design the hull for your spacecraft using the hull component construction rules. An additional option, only available for spacecraft, is the asteroid hull described below. In addition to the volume of the hull and the TL, there are three things you need to specify to create a hull. The first is the maximum acceleration the hull must withstand. The next is the shape of the hull. Together, the size and shape of the hull set how much of the available volume will be taken up by armor and internal structure, and how much surface area is available for mounting external features. The final characteristic is the streamlining.

Standard Hulls

Standard hulls are built in a shipyard. An internal skeleton of some kind supports an external skin, or shell. The shell serves to both keep the atmosphere in, radiation out, and act as armor against weapons. Design standard hulls using the rules in the "Hull" component chapter (page 62).

Streamlining specifies how much attention was paid to airflow over the hull, which affects the ship's performance in an atmosphere. Although many configurations and streamlining options are available, spacecraft streamlining can be grouped into three broad categories: *unstreamlined, streamlined,* and *airframe.* Note the streamlining category that matches the hull you've designed, and if skimming for fuel is allowed.

Unstreamlined

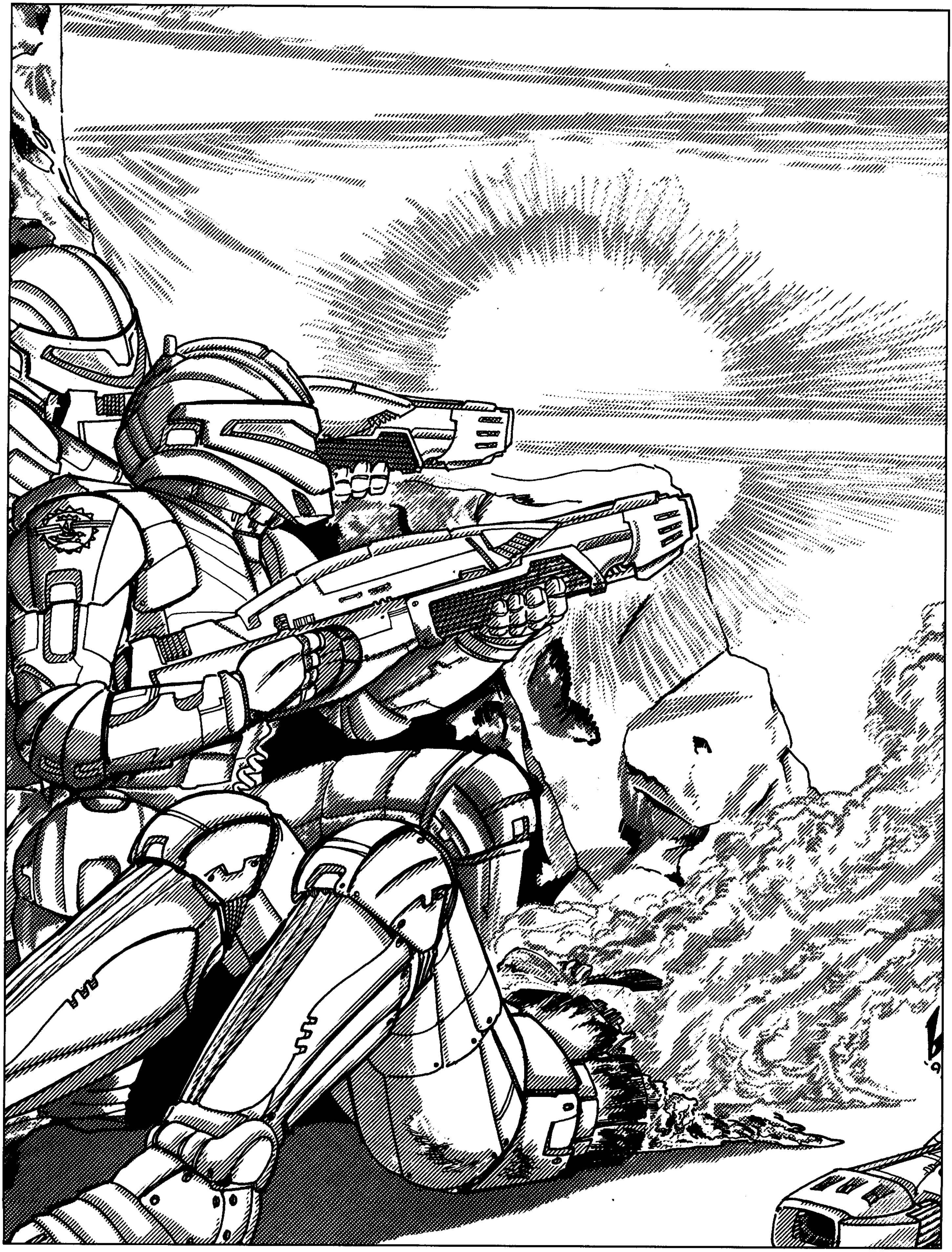
The hull was not designed to operate in an atmosphere. Sharp edges, antennas, bracing, and all kinds of other things stick out from the hull at various places. This hull is extremely vulnerable to wind turbulence and shouldn't land on any planet with greater than a trace atmosphere. If you do, you run the risk of damage or loss of control due to wind turbulence. Unstreamlined hulls are not normally designed for any type of planetary landing but can be capable of landing on airless worlds at the designer's option. Hulls intended for planetary landing are normally equipped with contragravity units. Unstreamlined hulls may not skim gas giants under any circumstances.

Streamlined

In this case, airflow over the hull was considered by spaceship architects as an afterthought. Sharp edges were rounded off and protuberances were covered by a fairing, for example. However, the hull does not generate lift and no aerodynamic control surfaces have been provided. Streamlined hulls are normally equipped with contragravity units so that they can take-off and land on any world with ease. Streamlined hulls may skim gas giants for hydrogen fuel if they are capable of hypersonic speeds.

Airframe

Atmospheric performance and the airflow over this hull were prime considerations in the design of the hull. All protuberances were kept to a minimum, and aerodynamic lifting and control surfaces are incorporated into the hull. The space-



craft has full atmospheric maneuverability and generates lift so it can take off from worlds with a surface gravity greater than its G-rating. Airframe hulls do not require contragravity drives: Calculate the take-off and landing rolls, and minimum and maximum airspeed using the rules in the "Hull" component chapter (page 62). If they are capable of hypersonic speeds, airframe hulls may skim gas giants for hydrogen fuel and can safely reenter any atmosphere.

Displacement

Based on long-standing tradition dating back to the Ramshackle Empire, spacecraft are customarily recorded in official documents by their "displacements." This refers to how many tons of liquid hydrogen (LH_2)—the most common fuel—they would displace. One ton of liquid hydrogen has a volume of 14 m^3, which is referred to as one displacement ton, or T_D. However, this is a rather large unit, often inconvenient during design. It also has little if any relationship to day-to-day life and can be hard to visualize. Therefore, "displacement" is reserved for official documents, and designs are actually carried out using m^3. Note the remaining interior volume, in cubic meters, of your hull.

Surface Area

An important limitation in designing a ship is how much surface area is available on the hull. Sensors, weapons, heat radiators, and drives all require a place on the surface of the hull—once you run out of area, you can't add anything more. Note the available surface area of the hull.

Stealth

By carefully shaping the hull, it's possible to provide some control over how the hull reflects energy back to a sensor. Each level of stealth reduces the signature of the hull for active sensors; specific effects are explained in the "Sensor" section (page 72) and in the combat rules.

Asteroid Hulls

Asteroid hulls are constructed somewhat differently. Rather than building a frame and a skin over it, you simply tunnel out the interior of the asteroid to make room for whatever you want to put in it. The cost of the hull is based on the cost to tow the raw asteroid to the shipyard, plus the cost of tunneling out what you need. Note that asteroid hulls are only useable for spacecraft.

Asteroid hulls use a slightly modified form of the hull construction sequence. For simplicity, asteroids are assumed to be roughly spherical in shape and use the spherical configuration factors where needed.

Asteroid Size and Type

Choose what size and type asteroid you're going to use. In a campaign, this may be limited by the presence of asteroid belts in the system. The price to tow the asteroid to a shipyard in the inner system is Cr1 per cubic meter of asteroid. **Table 3: Asteroid Materials** lists the toughness of different types of asteroids, and the price to tunnel.

Tunneling

Determine how much tunneling you need to do. Since asteroids generally have imperfections throughout, they don't provide internal structure quite as well as a normal framework, and more material has to be left in place compared to normal interior structure.

Minimum Internal Structure: The minimum amount of material left after tunneling out an asteroid must be 3 x SF x Gmax/Toughness, **where Table 159: Basic Hull Size** lists structural factors for different size hulls.

Tunneling Cost: Multiply the amount of material removed by the price of tunneling in credits per cubic meter removed.

Surface Area: For simplicity, use the surface area for a spherical hull of the same size, from **Table 159: Basic Hull Size.**

Armor Material Thickness: Multiply the volume of material remaining by 1/3 to get the volume available for armor, and divide that volume by the surface area of the asteroid. That will give you the thickness, in meters, of the external layer of the asteroid.

Armor Rating: The armor rating is then 100 cm/m x Thickness x Toughness.

*Example: Let's create the hull for a 100,000*T_D *monitor—a large, nonjump warship intended to defend critical points in the system. We need a 1,400,000*m^3 *asteroid, which costs us MCr1.4 to tow into the inner system. We'll use a metallic asteroid, just like the hundreds of others in the belt, to hide from invaders. We want to be able to pull 6Gs, the structural factor is 7,360, and the toughness for metallic bodies is 1.2, so we have to leave at least 110,400*m^3*. However, we want this to be fairly well armored, so we'll leave half of the asteroid. That's 700,000*m^3 *times Cr100/*m^3*, or MCr70 for the tunneling. The surface area is 60,521*m^2*. 1/3 of the material left acts as armor, or 233,333*m^3*. Divide that by the surface area, and our average armor thickness is 3.85m. That equates to an armor factor of 858.*

Drives

Once you've created your hull, you need to make it go. There are several ways to make things go in space. At lower technology levels, some kind of reaction drive is needed. These operate on the well-known principle of equal and opposite reaction: By throwing mass out the back of the vehicle at very high speed, the vehicle experiences a force in the opposite direction. The drawback here is you have to carry the reaction mass to throw away. Beginning at TL12, the reactionless thruster plates become available. These devices operate on gravitic principles to convert power directly into thrust.

Amount of Thrust Required

To compute the amount of thrust required, you can use two methods.

Standard Method

Begin with the following equation.

Equation 1: Standard Thrust Requirements

$$\text{Thrust} = \text{Accel} (\text{Volume} (10\text{kN}$$

For ease of play, one cubic meter of spacecraft normally requires 10kN of thrust per G of acceleration desired. For simplicity, **Traveller** has always based spacecraft thrust requirements on volume rather than mass. If we assume ships average about 1 ton per cubic meter, then Newton's law tells us that the needed thrust for a given acceleration equals 10,000N (or 10kN) times the volume of the ship times the desired acceleration.

However, very dense ships (such as heavily armored military ships) would get out of hand under this rule, and very light ships (hydrogen tankers, for example) would be penalized. At the end of the design sequence, divide the total mass of the loaded ship by the volume. If the result is greater than 1.2 tons/m^3, you need to recalculate the G-rating based on the actual mass. If the result is less than 0.8 tons/m^3, you may also choose to recalculate the G-rating or go back and reduce the drive size.

Realistic Thrust

In the real world, the acceleration of any object is given by force applied, divided by mass of the object. Therefore, the needed thrust for a spacecraft should depend on the mass of the spacecraft. But that would require some iteration during the design sequence: Right now, you don't know what the final mass of the vehicle is. At the end, when you do know, you'll have to go back and change things to try to get the desired acceleration, but those changes will themselves change the mass of the vehicle, and you'll wind up going through several cycles to get where you want to be. That's the most realistic method, and with spreadsheets really it isn't that tedious. But the mass will also change during play, as you burn fuel, take on or offload cargo, and so forth. Rather than dealing with the bookkeeping involved, for simplicity's sake **Traveller** has always assumed an average mass for ships, basing acceleration on the volume instead of the actual mass.

However, if you're willing to go an extra step for realism, do the following. Calculate the loaded acceleration of the ship, strictly using Thrust/Loaded Mass. This will result in the actual acceleration in meters per second per second. Divide by 10 to find acceleration in Gs. Calculate the actual acceleration for other configurations of the spacecraft similarly: at full, half-full, and empty cargo holds, and with full, half-full and empty fuel tanks.

Fuel for primitive rockets consumes such a large fraction of the total mass of the rocket that these rules seriously underestimate the total change in velocity. After all, as the fuel burns, the vehicle accelerates more for the same amount of thrust. For primitive rockets (including rocket-powered missiles), the total change in velocity in meters per second possible is given by:

$$\Delta V = \ln(M_f / M_{tot}) \leftrightarrow \frac{3600}{FC \leftrightarrow FD}$$

M_f is the mass of the fuel, M_{tot} is the total mass of the vehicle (fuel and everything else), and FC is the listed fuel consumption, in m^3/kN/hour. For reference, a launch from the Earth's surface to low earth orbit requires slightly under 10km/sec total delta-V. More detailed treatment of primitive rockets will be handled in the future (see page 66).

Faster-Than-Light Drives

Faster-than-light (FTL) drives allow starships to move from stellar system to stellar system at speeds faster than allowed by normal physics. This usually involves some method of "stepping outside" normal space, into a place where either the speed-of-light limit doesn't apply or where equivalent locations in our space are closer together.

The standard method in **Traveller** has always been the jump drive, which pushes a ship into a tunnel through "jump space." Due to the nature of "jumpspace," the fall through the tunnel takes about the same amount of time (168 hours) regardless of distance. This is a rather unique feature of jumpspace—no matter how far a ship travels, it stays in jumpspace for about 124+(2d6x6) hours. The distance traveled is controlled by the amount of energy a jump drive can channel to create the opening. Thus, jump drives are rated by their maximum distance, measured in parsecs (1 parsec = 3.26 light years).

Jump Drive Operation

The jump drive consists of two main components: the drive, itself, and a lanthanum hull grid. The grid is applied to the exterior of the ship, and the cost of the grid (and installation) is included in the cost of the drive. Adding a hull grid to an existing hull costs Cr150 per m^3 of hull. The drive requires a percentage of the ship's volume equal to 1 plus the maximum jump number (Equation 2: Jump Drive Volume), while the grid requires a portion of the hull's total surface area (Equation 3: Jump Grid Area).

Equation 2: Jump Drive Volume

$$\mathrm{Vol}_{JD} = 0.01\mathrm{x}(1+\mathrm{Jn})\mathrm{x}\ \mathrm{Vol}_{ship}$$

Equation 3: Jump Grid Area

$$\text{Grid Area} = \text{Total Area x } 0.005 \text{ x } (2 + \text{Jn})$$

The drive is connected to the hull grid network. The jump drive requires fuel (liquid hydrogen) and energy (electricity). Practically all of the energy and fuel are consumed in creating the tunnel through jumpspace. Once the tunnel is open, the ship must enter jumpspace or risk damage, misjump, or destruction. The amount of fuel required for a successful jump is equal to 10% of the displacement of the ship per parsec of jump distance attempted. The amount of energy required to initiate a jump is equal to 64MJ per cubic meter per parsec jumped. This energy must be provided to the drive in an hour or less (meaning that a starship must have 0.018MW of power plant per cubic meter per jump number).

Once in jumpspace, the jump drive maintains a small bubble of real space around the ship, using power input to the jump drive from the power plant (0.018MW per cubic meter per jump number). The fuel remaining in the jump drive's surge tank is used to create a thin hydrogen atmosphere around the ship during jump, which helps to delay the collapse of the jump bubble. If power to the drive is interrupted, the bubble collapses, causing jump sickness, death of crew members, misjump, damage, or destruction of the ship (any or all of these, at the referee's option).

Drop Tanks

Drop tanks are possible since the fuel is entirely consumed before jumpspace entry, but drop tanks must be jettisoned promptly so the ship can enter jumpspace before the tunnel begins to collapse. The tanks must also be jettisoned so that they will be far enough away from the ship so as not to interfere with the jumpspace entry.

Gravity

Gravitational fields interfere with the alignment of the jump drive. Ships do not usually jump until they're 100 or more planetary diameters away from the nearest body. Otherwise, a misjump may occur.

Jump Fuel

Jump drives require a large quantity of fuel to stabilize the interface with jumpspace. As mentioned above, this fuel is consumed before the ship actually enters jumpspace. The fuel requirement is 10% of the ship's volume per parsec (Equation 4: Jump Fuel). Jump fuel must be pure liquid hydrogen, or a misjump may occur.

Minimum Size

The smallest hull that can safely enter jump space is 1,400 cubic meters.

Equation 4: Jump Fuel

$$\text{Jump Fuel} = 0.1 \text{x} \text{Jn} \text{x} \text{Vol}_{\text{ship}}$$

See Table 4.

Weapons Mounts

Spacecraft may choose from turrets, bays, fixed weapons mounts, and spinal mounts—each with their own particular advantages.

Turrets

Spacecraft turrets are used for weapons which are aimed by pointing the entire weapon, and they have the most flexibility in terms of arc of fire. Turrets have effectively unlimited arcs of fire—as long as the ship's hull or appendages aren't in the way, the turret can fire at any target, independent of the attitude of the ship. For most configurations, that means the arc of fire is 180° in any direction. **Table 5: Turret Sockets** lists several common turret sizes. However, the Imperial Navy, in an attempt to make battlefield swaps between partially damaged and inoperative ships easier, has standardized on 42m^3 and 84m^3 turrets. Imperial ships only mount turrets of those sizes, and most weapons manufacturers follow suit by only producing weapons to fit the standard Imperial sockets. However, custom designs are still possible. For larger or custom sizes, the mechanism volume is 0.005 x Socket Size$^{5/3}$. Mechanism mass is 1 ton per m^3, and power requirements for the mechanism are 0.01MW per m^3 of turret. Standard Imperial turrets have a constant length/diameter ratio of 7/6, but custom sockets may have different height/diameter ratios. All turrets are assumed to be cylindrical and have a specific length and diameter chosen when the socket is installed. Weapons must fit within the turret in all dimensions to be placed there.

Turret sockets cost nothing to install if installed when the hull is laid down. Ships may be built with empty sockets intended for later expansion. Such empty sockets do not consume any power, but power should be reserved for the future turret mechanism and weapon installation. Adding a turret socket to an existing hull requires volume equal to the total socket size multiplied 1.1, to account for extra reinforcement that has to be added because the hull wasn't designed with the socket in mind. Cost to retrofit a turret socket is MCr0.1 per m^3.

Bays

Bays have reduced range of tracking, as they're intended for larger weapons which are more difficult to swing around. The mechanical overhead is somewhat less than turrets, but they can only fire on targets within a 45° arc, side-to-side. **Table 6: Bays** lists some common bay sizes. Bay-mounted weapons are usually custom fitted to a ship and are not commonly interchangeable. For larger or custom sizes, the mechanism volume is 0.001 x Socket Size$^{5/3}$. Mechanism mass is 1 ton per m^3, and power requirements for the bay mechanism are 0.005MW/m^3. Bays are usually long boxes with a square cross section, and they have specific dimensions that are chosen when the bay is designed. Weapons must fit within the bay in all dimensions to be mounted there. This may result in some waste space in the bay, which can be used for installing associated workstations, sensors, and other equipment.

The weapon bore points out the small face of the bay (it's oriented along the long axis of the bay), but the bay requires surface area on the hull equal to the length x width. **Table 6: Bays** lists both the surface area required by the bay and the surface area available for a round weapon. Custom bays may have different proportions and need not even have a square cross section.

Like turret sockets, bays cost nothing to install if installed when the hull is laid down. Ships may be built with empty bays intended for later expansion. An empty bay requires no power, but power should be reserved for the future bay mechanism and weapon installation. Adding a bay to an existing hull requires space equal to the total bay size times 1.1, to account for extra reinforcement that has to be added because the hull wasn't designed with the bay in mind. Cost to retrofit a bay is MCr0.1 per m^3.

Fixed Mounts

The main difference between spinal and fixed mounts is size. Any weapon can be placed in a fixed mount. For example, fighters may have a standard "turret-sized" laser, fixed forward. Spinal mounts are large enough to require special planning; they basically become the main structural member for the ship. This then limits the maximum length to the length of the ship (+/–5%). Fixed mounts have limited arc of fire (no more than 15° side-to-side) and require the entire ship to be pointed in order to aim the weapon, but they have no overhead for pointing.

Standard

The size of the weapon is fairly small compared to the ship. The length of the weapon can be no more than 25% of the shortest dimension of the hull.

Parallel

The maximum length is 0.8 times the length of the ship (if firing fore/aft) or 0.8 times the dimension in which the mount is aimed (height, width). They're called "parallel" because they're usually used to mount several forward firing weapons in parallel.

Spinal

Maximum length is length of ship; only one spinal mount allowed. There is one exception: a so-called "Janus" mount consists of two half-length weapons installed in a single spinal tunnel, one facing fore, one facing aft.

Missile Launchers

Facilities for launching missiles from spacecraft are fairly simple. There's no need to point the missile in the desired direction before firing; just open the firing tube door and eject the missile. A missile launch facility requires a standard crew workstation (optional—if the launcher will only be remotely operated, this isn't needed), a laser or tight-beam radio communicator with the necessary range, and one or more launchers. A launch facility can be built as a fixed mount, placed in a turret socket, or installed in a bay. Standard starship missiles are 7m^3. The design of the missiles and launchers is covered in separate sections of this book.

Electronics

Spacecraft require sensors, controls, computers, and communicators. All spacecraft intended to take off or land on a planet also require flight avionics. For safety, most spacecraft carry three redundant computer systems. Select the required electronics from the "Electronics" chapter of this book (page 69), and add them to your design.

Power Systems

Spacecraft require power for numerous systems. Select power plants from the "Power Systems" component section of this book (page 81), and add them to your design.

Miscellaneous Components

This section lists some miscellaneous components, most applicable to spacecraft, which you might want to add. However, feel free to use ideas from other vehicle sections as well, if they apply.

Internal Armor

You may wish to add additional armor to vital internal components. Any time that a protected component is then hit, the damage must penetrate the additional armor before having any effect. The procedure for internal armor is similar to the hull's armor—look up the volume of the component on the hull size table and use the same configuration modifiers for armor volume as the ship itself (but don't worry about internal structure or streamlining effects).

Small Craft, Carried Vehicles, and Launch Facilities

Table 7 summarizes information on craft within craft. Explanatory notes follow.

Internal Hangar

Hangars store carried craft and vehicles completely within the hull of the parent vessel, and they provide room to perform maintenance, load and unload the vehicle, and so forth. Minimal hangars, because of their cramped space, cause all maintenance and repair tasks to be at one difficulty level higher than normal. Spacious hangars provide enough room that the tasks are normal. All hangars require launch ports, explained under "Area," below.

A spacious hangar may be used to store more than the original volume of craft or vehicles as long as the vehicles can fit through the launch port. The absolute maximum volume of craft or vehicles the hangar may store is what it could hold as a minimal hangar (0.5 times the overall hangar volume).

Docking Ring

A docking ring is simply a pocket in the mothership's hull which exactly fits the carried craft. Docking rings are designed for one specific vehicle design and may not be used for any other vehicle. Docking rings allow no maintenance or repair.

Jettison Bay

Jettison bays are intended for quick-release-type vehicles such as lifeboats. Hence, they are designed to be able to launch immediately, with no regard for returning to the ship (usually they use some kind of explosive separation/launching system). Launch times are essentially immediate—under 30 seconds—but the craft may not redock once launched, nor can another craft dock. Once used, a jettison bay can only be "reset" at a starport. A jettison bay is designed for a specific vehicle. Also, once a jettison bay has been activated, the parent ship's configuration becomes unstreamlined, regardless of what it was originally, until the port is covered.

External Grapples

A grapple allows a vehicle to be carried on the outside of the mothership's hull. Note that, for jump and acceleration purposes, the combined volume of mothership + grappled craft must be used whenever they are docked. A grapple requires surface area equal to the final length times the final width (after shape modifiers) of the carried craft. A grapple is designed for a specific size and shape vessel, and it may hold any vehicle designed with the same configuration and size. The type of grapple used also depends on the streamlining of the mothership. In order for the mothership to keep its original streamlining class (unstreamlined, streamlined, or airframe), the same class grapple must be used, and the carried craft must have at least the same level of streamlining.

Universal grapples may also be installed. These are grapples designed to hold any craft up to a certain size and shape. Choose the maximum size craft desired, and the maximum length x width desired. Design a grapple based on that, then multiply price by 1.25. This accounts for the extra flexibility and grappling points required to accommodate many different craft. The grapple can then accommodate any craft whose length, width, and volume are below the maximums.

Normally, grapples are built into the ship when designed. Adding a grapple to an existing ship increases the mass and volume by 20% to cover the extra reinforcing that has to be added, and it increases the price by 25%.

Area

All vehicle facilities require area on the surface of the mothership's hull. Hangars require surface area for at least one launch port equal to the square of the largest carried craft's basic length (from **Table 159: Basic Hull Size**, unmodified by shape). Launch tubes require area equal to twice the square of the basic length of the largest craft that will use that tube. Docking Rings and Jettison Bays require area equal to the specific carried craft's width x height.

Launch Rates

A launch port can launch one vehicle or craft every 30 minutes. A launch tube can launch one vehicle or craft every three minutes. Grapples and docking rings each require five minutes to launch. These times are for normal launches, with proper safety checks, coordination with the launch control officer, and so on, and they do not require a success roll by the pilot or launch control officer. In an emergency, the launch control officer can try to speed up launching. Doubling the rate is a Routine task for the launch control officer (not the pilot of the small craft). Each doubling of the rate after that increases the difficulty one level. A pilot may choose to leave without coordinating, which is a Routine task for the pilot. If the pilot also wants to leave quicker, increase by one difficulty level.

Research, Repair, and Medical Facilities

These features may or may not be included in your design, depending upon your mission needs. See Table 8.

Electronics Shop

An electronics shop includes workspace, tools, diagnostic equipment, and bench parts for performing electronics work. A standard electronics shop can support four electronics technicians maintaining or repairing equipment.

Game Effects: An electronics shop decreases the difficulty level of diagnosis tasks by two levels, and the difficulty of repair or construction tasks by one level. Additionally, it increases the maintenance efficiency of up to four technicians by 25%.

Machine Shop

A machine shop includes workspace, tools, measuring equipment, and raw stock for minor mechanical work. Up to four engineers or technicians may benefit from a machine shop at one time. Small parts can be made from scratch, and medium parts can be repaired or modified.

Game Effects: A machine shop decreases the difficulty of mechanical tasks by one difficulty level.

Laboratory

A laboratory provides workspace and equipment for scientific research. One laboratory can support four researchers.

Game Effects: Determined by referee, but should be similar in nature to the benefits gained by electronics shops and machine shops.

Sickbay

A normal sickbay provides workspace for medical personnel to treat wounds and illnesses on an outpatient basis. Other versions of sickbays are dedicated to performing surgery, providing intensive care, or inpatient wards.

Game Effects: A sickbay can support two medical personnel treating outpatients (decreasing the difficulty level of routine care by two levels, or of emergency care by one), or a surgery suite capable of performing two surgeries at once (decreasing the difficulty level by two), or an inpatient ward for four patients, or a critical care ward for two patients. In each case, the sickbay also includes space to store medical supplies and equipment appropriate to the purpose of the sickbay.

Other Miscellaneous Facilities

The following features are fairly specialized.

Ship's Locker

Normally, the ship's locker should be separate from the ship's cargo holds. It contains things that may be needed by the crew during flight or in an emergency but aren't used every day. The cargo holds are inconvenient to dig things out of during an emergency, and they may be entirely inaccessible, depending on the nature of the problem. The ship's locker usually contains small tools: vac suits, equipment, survival gear, hull patches, and so forth. On small ships without an armory, it may also serve as a storage for weapons, although it's not intended to be secure. (It's supposed to be easy to get into for emergencies.) The statistics listed below are for the empty locker; contents are extra.

Volume: Designer's choice; perhaps 0.5m^3 per 1,000m^3 of ship or per crew member. Mass: negligible. Area: none. Price: none.

Brig

Someplace to store unruly passengers, crew members, and other miscellaneous uses. Use normal accommodations (bunks, staterooms), but price is x1.1 to cover the additional security features. Low security would be a series of bunks—prisoners share a common cell, so there must be at least four bunks. Medium security would be a stateroom, with two prisoners to a small stateroom or four to a large. High security would be a stateroom per prisoner. If desired, an additional small stateroom may be added to act as "security office."

Armory

Troop carriers and large military vessels have dedicated facilities to store and maintain weapons, ammunition, and special equipment for use by the troops. Approximate by using 0.5m^3 per trooper.

Volume: 0.5m^3 per trooper. Mass: 0.05 tons per m^3. Area: none. Power: 0.02kW per m^3. Price: MCr0.002.

Gym

A gym usually contains a wide variety of exercise machines and facilities for both strength and aerobic training. The standard gym can be used by up to four people at once. Gyms aren't necessarily a luxury—long voyages cooped up in a small starship can cause a significant loss of conditioning for both crew and passengers. Exercise is also a good way to relieve stress and avoid psychological problems between people. At the referee's option, you may reduce characters' strength and endurance by one point after two weeks without exercise, and two points after two months. Military ships usually have sufficient gym facilities to support 5% of the crew at once.

Volume: 35m^3. Mass: 0.5 tons. Area: none. Power: 1kW. Price: MCr0.002.

Yet Other Facilities

Briefing rooms, passenger lounges, restaurants, shops, wet bars, and other accommodations can be added at the designer's whim. Rather than having specific rules for each, simply choose the volume you want to allocate and the amount you wish to spend on furnishings. Area is required only if you want such things as external windows or access.

Volume: Designer's choice; mass 0.05t per m^3; area designer's choice; power 0.02kW per m^3; price MCr0.001 per m^3, plus the cost of the furnishings.

Umbilical Docking Tube

An umbilical docking tube allows ships to dock to each other, to space stations, or to planetary facilities without having to be physically nearly touching. Constructed of a flexible tube reinforced with rigid rings, the standard docking tube can be used anywhere the pressure difference between the inside and the outside is no more than one atmosphere either way. That means that if the ship's internal pressure is one atmosphere, the tube can be used in a vacuum or on a world with twice the normal atmospheric pressure.

At the far end are special fittings to allow an airtight seal to standard airlock fittings, or in an emergency, to seal to any flat, smooth metallic surface. The end also contains tiny nozzles using air to maneuver the tube end in zero-G. This is controlled from a control panel usually mounted inside the ship's airlock. Once the tube is connected, it's pressurized. Normally built in around an airlock's external hatch when the hull is built, it can be added to any airlock for 10% extra. If it has to be streamlined (to maintain the hull's streamlining), the cost is 15% extra.

A docking tube may be extended up to 50m. If the docking tube is installed with an airlock or hatch, the area required by the docking tube includes 2m^2 for the hatch.

Volume: 35m^3; mass 0.09t; area: 2.5m^2; price MCr0.025.

Cargo

There are various means to store and transport cargo.

Internal Holds: Cargo holds may be designated at no cost or mass for the empty hold itself, although they do take up volume. The cargo hold is normally included in the life support volume, to ensure consistent temperature, gravity, and air pressure. Designers may choose to leave the cargo hold out of the life support volume; in that case, it cannot be accessed in space without using vac suits, and delicate cargoes may not survive. The cargo hold is usually off limits to passengers during flight.

External Cargo Pods: External cargo pods are detachable containers which can be used to increase the cargo capacity of a ship or allow for quick loading/unloading. Cargo pods are designed as separate hulls—usually cylindrical or box—and are usually only minimally armored (at least armor 10). Cargo pods are connected to the ship using a special type of grapple, built only to hold the pod and provide power connections. These cargo grapples cost 10% of the cost of a normal grapple and only require 50% the volume and mass but require the full area. However, this connection provides no access to the cargo pod, nor does ship's life support cover the pod. Optionally, you may use a standard grapple, which allows you the flexibility of grappling a vehicle in place of the cargo pod. Remember that you have to design the cargo pod and the grapple to the same level of streamlining as the ship, or else your streamlining suffers. Cargo pods increase the ship's mass and size, requiring jump and maneuver performance as well as signatures to be recalculated.

Normally, grapples are built into the ship when designed. Adding a grapple to an existing ship increases the grapple mass and volume by 20% to cover the extra reinforcing that has to be added, and it increases the price by 25%.

Cargo Hatches: All ships with any internal cargo holds at all require at least one cargo hatch. The standard cargo hatch has an area of 20m^2 and costs MCr0.02. These cargo hatches are large enough to handle all standard cargo containers, although some types of cargoes (such as vehicles) may require even larger hatches. Ships with under 100m^3 of cargo may instead use a small hatch, with an area of 12m^2 and a cost of MCr0.012. Cargo hatches of any size can be constructed at a cost of MCr0.001 per square meter of hatch area.

The basic rate at which cargo can be loaded is determined by dividing the volume of the cargo hold (in cubic meters) by the number of cargo hatches. The optimum ratio is 350 cubic meters per hatch, although very large vessels are unable to install enough hatches achieve this ratio.

Handling Equipment: All but the most primitive starports have equipment and facilities for loading and unloading cargo, available for a price. Large ships or ships designed to call at primitive starports may include their own cargo handling equipment. At most tech levels this consists of winches and hoists, but really advanced ships may choose to include gravitic manipulators (found in the "Defense Design" section, on page 57). For low tech equipment, assume that each cubic meter of lifting equipment has a maximum load of one ton per TL, itself masses one ton, and requires 0.001MW per ton of capacity. The equipment can load or unload cargo equal to its load capacity in one hour. Alternatively, you may design the cargo hold and handling equipment for containerized cargo. The handling equipment must be capable of lifting one standard container, and the cargo hold hatch must have an area at least 10% larger than the side of the container passing through it. A dedicated container handling system can unload one container every 15 minutes.

Fuel: A ship has to be able to carry enough fuel for its power plants and its drives (if they use fuel) for at least the ship's intended endurance, plus fuel for all carried craft and vehicles, plus some extra for emergencies.

Normal Fuel Storage: Normal fuel storage requires volume equal to the fuel to be carried. No additional cost or mass for the tankage.

Collapsible Tanks: These are large, flexible bladders that can be installed in the cargo hold of the ship, to hold extra fuel. However, the fuel in the bladders can't be used directly; it has to be pumped into the ship's regular tanks for use. This time to pump a full load into the ship's regular tanks is six hours. When empty, the tanks can be collapsed to a volume of 10% of their volume when full. Cost is Cr35/m^3.

Dismountable Tanks: These are fixed, semipermanent tanks installed in the hold. Basically identical to the ship's regular tanks, fuel from them can be used directly. They take up their full space even when empty. The tanks can be constructed at any class B starport. Storage space when dismantled is 25% of their normal volume. Cost is Cr200/m^3.

Exterior Dismountable Tanks: These are fixed, semipermanent tanks mounted to the outside of the ship's hull and act as regular fuel tanks. Installing these renders the ship unstreamlined regardless of its original configuration. Furthermore, ship volume (and hence maneuver and jump drive performance) is increased by the volume of the tanks. Ship mass is increased by the mass of the tank plus the fuel. Ship's performance and sensor signature has to be recalculated. Exterior tanks are designed as separate hulls, usually using cylinder or box configuration, and should be armored to the same level as the ship itself. Cost of the mountings and fuel couplings is Cr35/m^3.

Exterior dismountable tanks may be constructed with explosive mountings and quick-release fuel couplings (doubling the cost of these items). The tank can then be detached at any time, the explosive couplings ensuring that the tank will fly clear of the ship. This allows the ship to discard the mass and volume of the tanks at any time in an emergency, regaining full performance.

Exterior Conformal Tanks: These are fixed, semipermanent tanks mounted to the outside of the ship's hull and act as regular fuel tanks. The total volume of conformal tanks may not be more than 20% of the volume of the ship. Installing these increases ship volume (and hence reduces maneuver and jump drive performance). Ship weight is increased by the weight of the tank plus the fuel. Ship's performance and sensor signature has to be recalculated. Conformal tanks are designed as separate hulls, using the same configuration, streamlining, and stealth options as the ship itself, and should be armored to the same level as the ship. Cost of the mountings and fuel couplings is Cr70/m^3.

Exterior conformal tanks may be constructed with explosive mountings and quick-release fuel couplings (doubling the cost of these items). The tank can then be detached at any time, the explosive couplings ensuring that the tank will fly clear of the ship. This allows the ship to discard the mass and volume of the tanks at any time, regaining full performance.

Drop Tanks: Drop tanks are disposable exterior tanks that can be used to provide fuel for a jump. The fuel from the drop tank is consumed in establishing the jump interface, and then the tanks are dropped away so they do not reduce the ship's jump performance. Drop tanks are designed as separate hulls, usually cylindrical, and are usually only minimally armored (at least armor 5). They are connected to the ship using a special type of grapple, built only to hold the tank and provide fuel couplings. The drop-tank grapples cost 15% of the cost of a normal grapple, and only require 50% the volume and mass, but require the full area. Optionally, you may use a standard grapple, which allows you the flexibility of grappling a vehicle in place of the drop tank. Remember that you have to design the drop tank and the grapple to the same level of streamlining as the ship or else your streamlining suffers. Drop tanks increase the ship's mass and size, requiring jump and maneuver performance as well as signatures to be recalculated while they're installed.

Normally drop tank grapples are built into the ship when designed. Adding a grapple to an existing ship increases the grapple mass and volume by 20%, to cover the extra reinforcing that has to be added, and increases the price by 25%.

Scoops: Fuel scoops allow a streamlined or airframe vessel to skim the upper atmosphere of gas giants for hydrogen fuel and compress it. They also allow vessels to scoop fuel from bodies of water on planets. Although scoops don't take any volume or mass, they do take up surface area. For each 5% of the hull surface dedicated to fuel scoops, a ship can scoop 20% of its total volume in a gas giant per hour. Scoops cost MCr0.000075/m^3 of hull. A ship must be capable of hypersonic flight to be able to scoop fuel from gas giants.

Purification: While fusion reactors and jump drives run

Rating The Design

Fill out the following worksheet.

General Data

TL:

Displacement: ####T_D / ####m^3 clean (without drop tanks, cargo pods, or carried craft); ####T_D / ####m^3 loaded (with all pods, tanks and external craft). If the ship uses drop tanks or externally carried craft, calculate its displacement with and without all drop tanks and grappled craft.

Configuration: SL Box.

Dimensions (LxWxH): ####m x ####m x ####m.

Mass (loaded/empty): #####t / #####t. Calculate two masses, loaded and empty. Loaded includes full fuel tanks, full cargo bays (assume 1 ton/m^3), and all carried craft and vehicles. Empty is without all that. If the spacecraft is designed with drop tanks or cargo pods, calculate an additional loaded mass with all pods and tanks loaded.

Shipyard:

Engineering Data

Since G rating and jump rating depend on the displacement of the ship, which can vary depending on drop tanks and externally carried craft, you have two choices: You can calculate just the rating for the fully loaded ship, and ignore the "clean" rating, or you can calculate both. Some ships aren't really intended to operate without all the attached accessories. For example, the only time a subsidized merchant is normally without her launch is when she's in orbit around a planet, landing passengers. (Exception: Ships with drop tanks calculate their G rating both with and without the drop tank, and their jump rating without the drop tank, as the tank is dropped prior to jump. If the ship is intended to make short jumps with the tanks attached, and longer ones dropping it, calculate the jump rating both ways.

Power Plant: ####MW.

Jump Performance: J# (##m^3 fuel per parsec).

Maneuver Performance: #G (##MW/G).

Fuel Tankage: ####m^3 maneuver; ####m^3 jump (###m^3/parsec without drop tanks); nx###m^3 drop tanks (###m^3 per parsec with drop tanks); ##m^3 power plant.

Fuel Purification: ####m^3 in # hours.

Maintenance Points: ###. For maintenance points, add up the total mass of the ship without any cargo or fuel, then subtract the mass of the armor and internal structure. Divide the result by the factor in **Table 11: Maintenance Point Divisors.** If the ship has at least two regular or fiber-optic computers installed (not flight computers), capable of providing online diagnostic and troubleshooting, divide that result by 4.

Electronics

Computers:

Communications:

Sensors:

ECM/ECCM:

Sensor Signatures: Passive Sig (vis/IR): –1/–0.5 (–1/–1 at 50 MW power). Active Sig: 0.

Visible signature: The ship's visible signature depends on the amount of light reflected by the hull, which in turn depends on the area of the hull. The base signature is given in **Table 12: Visible Signature.**

This is modified by the hull coverings (as determined in the "Hulls and Streamlining" chapter, on page 62):

- Bare metal/non-black: +1
- Color-changing (TL10+) or black (TL8-9): 0
- Military Black (TL11+): –0.5
- Military Ultrablack (TL13+): –1

Infrared Signature: The base IR signature is based on the ship's total power plant output. Look up the total power produced by all power plants on board **in Table 13: IR Signature.**

This is modified by the ship's radiators:

Basic Masking: –0.5

Advanced Masking: –1

Extreme Masking: –1.5

Optionally, designers may rate the emitted signature under different power plant loads (for example, under full combat power output and under minimum life-support-only).

Active Signature: The base active signature depends on the surface area available to reflect signals back to the sensor. Start with **Table 14: Active Signature.**

Subtract 0.5 from the signature for each level of stealthing.

Example: A TL12 100T_D scout ship has a spherical hull, with an area of 600 m^2 and a power plant output of 150 MW. It would have a visible signature of –1. Its effective power plant output is 150 MW, for an IR signature of 0. Its active signature is 0.

If the ship were equipped with basic thermal masking, the emitted signature would be reduced to –0.5. If the ship were then running with no weapons or sensors, with the power plant running at 50 MW, the emitted signature would be reduced still further to –1 (–0.5 + –0.5).

A designer would record this on the ship record as follows: Passive Sig (Vis./ IR.): –1/–0.5 (–1/–1 at 50 MW power).

In combat, signatures are further modified by conditions—for example, reflected signature is reduced for a ship hiding in shadow.

Controls: List type of controls, level of automation, and number and type of workstations/crewstations installed.

Armament

Offensive:

Defensive:

Fire Control:

Accommodations

Life Support:

Crew: ## (_xCommand; _xManeuver; _xElectronics; _xEngineering; _xMaintenance; _xGunnery; _xFlight; _xShip's Troops; _xStewards; _xMedical)

Crew Accommodations: _xLarge Stateroom; _xSmall Stateroom, and so on.

Troops: Note these are in addition to "Ship's Troops"—this is for troop carriers and other vessels that have troops as "passengers" not attached to the ship's crew.

Troop Accommodations:

Passengers: _xHigh; _xMedium; _xLow

Passenger Accommodations:

Carried Craft

List all carried craft.

Other

Cargo:

Shops and Labs:

Airlocks:

on hydrogen, fuel skimmed from an ocean is water, and fuel from a gas giant is contaminated with a variety of other substances. Fusion reactors tolerate this moderately well, but jump drives are a little more finicky and are more likely to misjump if using unrefined fuel. A fuel purification plant removes those impurities to produce pure liquid hydrogen. **Table 9: Fuel Purification Plants** lists the requirements to purify one cubic meter of fuel in six hours. Multiply the amount of fuel you wish to purify by the factors in the table to get the size plant you need. Note that there is a minimum plant size at each tech level; smaller plants are not possible. **Table 10: Standard Purification Plants** lists a few "standardized" sizes you can drop into your ship.

Crew and Passengers

Compute the required crew complement using the rules in the "Life Support and Accommodations" component chapter (page 75). Starships normally carry Type III life support with a duration of two weeks. Install appropriate accommodations from the same chapter.

Gravitic Vehicles

Now that you've given some thought, and possibly some design time, to the spaceship, it's time to think about a gravitic vehicle. Grav vehicles are very close to spacecraft and can usually make it to low orbit (a few hundred km) if they're sealed.

Chassis Design

Grav vehicles use the hull component design sequence but are seldom if ever built using open frame or close structure, as these may only be used in a vacuum. The most common shapes for grav vehicles are box or cylinder. There are a few additional special modifications you can make to your chassis, but for simplicity they are restricted to the most common box configuration. They really don't make sense or are too complex for any other configuration.

Additional Armor

If you choose a box configuration, you may choose to increase the armor on certain faces, over and above the base armor value. This adds mass and cost to the vehicle but increases the protection on that face. Increase the armor volume by the percentage listed in **Table 15: Facing Armor** for each cm of additional armor added to a face.

Armor Sloping

Again, with a box configuration you may also choose to slope your armor on certain faces. Sloped faces increase effective armor rating against direct-fire weapons because the weapon strikes at an angle and has to penetrate more material. However, sloping the face also takes volume away from the interior of the vehicle. **Table 16: Armor Slope Effects** lists the armor rating multiplier and the lost space per face that is sloped. This volume is deducted from the available volume of the vehicle and is not considered when adding things like life support.

Open-Topped Vehicles

If you choose, a box configuration vehicle can have an open top, meaning there's no roof and the sides are partially reduced. A glass or plastic windscreen or roof, with no armor protection, can be added. Multiply the armor material volume by 0.7. There is no protection against attacks from the top, and on a roll of 6 or less on 2d6, attacks from the sides, front, or rear go through the window or open sides instead of armor. List the front, side, and rear armor in square brackets—like this: [4]—to indicate an open-topped vehicle. Open vehicles may not be stealthed.

Propulsion

At TL9, the burgeoning science of gravitics allows vehicle designers to manipulate the local gravity fields and create a lifting force. Most of the force is directed parallel to the gravity field (straight up and down), but a fraction of the lift is available to provide thrust. If you need greater thrust, some other form of auxiliary propulsion needs to be added to the vehicle. Also note that in level flight, the lift must equal the weight, and hence the maximum thrust available equals the thrust factor multiplied by the vehicle's weight.

The acceleration of the vehicle, in m/s^2, depends on the thrust divided by the total mass, and in turn determines the atmospheric speed of the vehicle.

Power Systems

Install power systems per the "Power" chapter (page 81). You must provide at least sufficient power for the contragravity lifters, controls, and other installed electronics. Remember to also provide any power required for weapons.

Weapons

This section describes the various ways to install weapons rather than the design of weapons, themselves. (See the "Weapon Design" section, on page 29, for that information.)

Mounts

Vehicle-mounted weapons don't need carriages, tripods, or any other kind of mount from the weapon design sequence, as the vehicle provides mounting equipment. The types of mounts available are turrets, chassis mounts, pintle mounts, open mounts, or aircraft mounts. Indirect fire weapons (mortars and so forth) must be in a turret or open mount.

Turrets

You may choose to equip your grav vehicle with turrets for mounting weapons or other equipment. The volume for the turret comes out of the chassis volume. Also, a turret needs considerable space around it to be able to pivot and aim. The space for this comes out of the chassis volume as well. Rather than calculate exactly how much of the chassis needs to be "cut away" to do this, simply assume that components mounted in the turret take up much more than their actual volume. This excess volume represents the free volume around the turret and depends on the size of the turret. The volume of a component after multiplying it by the modifier is called the "effective volume."

Main Turrets

A large or main turret takes up 10% or more of the total chassis volume. A vehicle may have only one main turret, usually located on the top.

Equipment mounted in a main turret has an effective volume which varies depending on tech level. **Table 17: Main Turret Efficiency** lists the multipliers used at different tech levels.

Main turrets, because of their size, reduce the aerodynamics of the vehicle. Reduce the maximum speed by 1% for each 1% of total chassis volume dedicated to turret volume.

Main turrets have to be locked down pointing aft when the vehicle is moving at high speeds or the vehicle becomes unstable and possibly crashes. The maximum safe speed of any grav vehicle while moving its turret is 300kph.

Small Turrets

Small turrets can be mounted on any face of the vehicle, although they're usually located on top of the main turret or on the deck (top), and they take up less than 10% of the total chassis volume. Equipment mounted in small turrets has an effective volume of 10x normal volume. A manned small turret is also called a "cupola" and must allocate volume for one-half the gunner's crewstation (see below). An unmanned small turret is also called a "remote mount" and is controlled by a gunner elsewhere in the vehicle.

Intermediate Turrets

In some cases, designating a turret as "small" and using the fixed 10x multiplier for equipment might result in it being over the 10% size limit, requiring it to be a main turret. But if you use the main turret multipliers, the effective volume of the equipment is less than 10%, requiring it to be a small turret. In this case, design the turret as a main turret, using the main turret multipliers, but it must be the only turret on the vehicle. For targeting and damage purposes, treat it as a small turret.

Chassis Mounts

A chassis mount is simply a fixed mount in one of the six faces of the vehicle. Although some minor adjustments are possible, chassis mounts are aimed by pointing the whole vehicle—hence, they're usually in the front face.

Pintle Mounts

A pintle mount is simply a pivoting post or rail supporting a light weapon. Usually mounted on the top of the vehicle, a pintle mount and its associated weapon take no volume from the chassis. However, the gunner is exposed to enemy fire. If a pintle mount weapon is equipped with a gunshield, the gunner is protected. A pintle mount may not be used on a sealed vehicle without breaking the seal.

Open Mounts

An open mount is simply a weapon mounted in the chassis of an open vehicle.

Aircraft Mounts

Any of the aircraft weapon mounts may be added to grav vehicles. Wing-mounted hardpoints include the mass and cost of stub wings. Grav vehicles may only have one set of stub wings and one fuselage hardpoint.

Electronics

All grav vehicles require controls, flight avionics, and computers. Almost every world also requires grav vehicles to operate under central traffic control when in urban areas. Planetary regulations also usually require grav vehicles to have at least two redundant computer systems.

Crew and Passengers

Grav vehicles normally carry only the minimum crew necessary to operate them for their short periods. Grav vehicles that operate at high altitudes or in space require some type of life support. The type of accommodations provided should be determined by the nature and duration of the expected mission, but most grav vehicles simply provide some type of seats for passengers and workstations or crewstations for the crew.

Rating The Design

Fill out the following worksheet.

General Data

TL: ##
Size: ###m³.
Configuration: SL Box.
Dimensions (LxWxH): ####m x ####m x ####m.

Mass (loaded/empty): #####t / #####t. Calculate two masses, loaded and empty. Loaded includes full fuel tanks, full cargo (assume 1 ton/m³), and all hardpoints loaded. Also include 100kg per passenger. Empty is without all that. The total lift produced by the drive in kN must be equal to or greater than ten times the loaded mass of the vehicle.

Speeds: Max ### km/hr; Cruise ### km/hr; NOE ### km/hr. Verify that you've installed enough CG to provide lift in kN equal to the vehicle's weight. Weight is equal to the mass of the vehicle multiplied by the local gravity (in m/s^2; multiply gravity in Gs by 10 to find gravity in m/s^2). This is called the "CG Lift" and is a bare minimum, necessary to keep the grav vehicle up. Thrust equal to the CG Lift times the CG thrust efficiency is available for propulsion. Calculate the total propulsion thrust by adding the thrust produced by any auxiliary drives to this value.

Use the atmospheric performance rules, located in the "Propulsion Component" chapter (page 68), to determine the atmospheric performance of your vehicle.

Power Plant: ####MW.

Propulsion: ###kN contragravity lifters, with ###kN ____ auxiliary propulsion.

Fuel Tankage: ####m³ maneuver; ####m³ jump; ##m³ power plant; nx###m³ drop tanks.

Maintenance Points: ###. For maintenance points, divide the loaded mass by the factor in **Table 11: Maintenance Point Divisors**. If the vehicle has at least two regular or fiber-optic computers installed (not flight computers), capable of providing online diagnostic and troubleshooting , divide that result by 4.

Electronics

Computers:
Communications:
Sensors:
ECM/ECCM:
Controls:
Armament
Offensive:
Defensive:
Fire Control:

Accommodations

Life Support:
Crew: ## (Driver, 2 gunners, and so forth; cramped crewstations).
Passengers: ## (cramped seats).

Lighter-than-Air Vehicles

Lighter-than-air vehicles, also called "airships," include a range of craft from unpowered balloons to giant airships used as scheduled passenger liners or military reconnaissance and bombardment platforms. Airships are only possible in Standard and Dense atmospheres.

Weight

Weight is the limiting factor in designing airships. Weight is expressed in kilonewtons (kN). The weight of a airship is the useful lift weight (the weight of the structure that contains the gas is neglected in these rules).

Envelope

Airships use gasses that are lighter than air to produce lift. The envelope is the portion of the airship which contains the lifting gasses. Lift generated by lighter-than-air gasses and the volume of the envelope needed to hold the lifting gasses are the two constraints on the useful lift of airships. The designer selects the lift desired, and then calculates the envelope required to produce that lift with the available lifting gasses. The useful lift is the lift produced by the gas, less the weight of the envelope needed to contain the gas.

Envelope Types

There are two types of envelope available: rigid and nonrigid. A rigid envelope is constructed out of a metal framework, with a fabric or metal covering. Nonrigid envelopes are constructed of fabric without the metal frame. Rigid envelopes are preferable for large, high-speed airships.

Gas

There are three types of lifting gasses available: hydrogen, helium, and hot air. Hydrogen is the lightest element and provides the most lift per cubic meter. Hydrogen can be produced in effectively unlimited quantities from water by electrolysis. Hydrogen is also extremely flammable when mixed with air or oxygen. Helium provides less lift than hydrogen but is not flammable at all. Significant quantities of helium are present on only about 50% of the worlds in the Imperium. Hot air can also be used as a lifting gas, but it produces the least amount of lift per cubic meter. Hot air does have the advantage of being readily available, however.

In Table 19, *H* is the number of cubic meters of hydrogen required per kN of useful lift, in standard and dense atmospheres. *He* is the number of cubic meters of helium required per kN of useful lift, in standard and dense atmospheres. Hot air is the number of cubic meters of hot air required per kN of useful lift, in standard and dense atmospheres. *Speed Mult* is the speed multiplier. (Multiply the maximum speed for the envelope configuration by this factor.) Note that the speed multipliers are different for standard and dense atmospheres.

The cost of the envelope is in credits per cubic meter. Multiply the total volume of the envelope by the cost per cubic meter to determine the overall cost of the envelope.

Envelope Configuration

Once the volume of the envelope is known, choose a configuration from **Table 21: Envelope Configuration.**

Balloon

The balloon configuration is a nonrigid, spherical gas bag from which a passenger or cargo compartment is suspended. Many balloons are tethered to the ground and raised to provide an elevated observation platform. Nontethered balloons are almost always unpowered and free to drift with the wind. Propulsion is difficult due to the bulky and unstable nature of the envelope, but thrusters can move balloons at low speeds.

Cigar

Elongated envelopes, shaped like a cylinder with rounded or tapered ends, are available in both rigid and nonrigid configurations. Cigar envelopes are equipped with fins for stability and steering and are much better suited to powered flight than balloons.

Cyclo-Crane

The cyclo-crane is a complex airship in which a cigar-shaped envelope is pierced from front to back by a central shaft. Four or more pylons radiate from the central shaft and mount airfoils and engines well outside the envelope itself. These airfoils and engines can be turned to different angles to maneuver the craft, or to cause the bag to spin around its central axis, generating lift from the airfoils. The cabins and payload are suspended from cables attached to the central shaft at each end.

Magnus Sphere

The Magnus sphere configuration consists of a spherical gas bag pierced through its center from side to side by a shaft. The engines are mounted on the ends of the shaft and the cabin and payload are carried by conformal arms attached to the shaft. The engines can be rotated to provide additional lift for takeoff, but the main lift augmentation comes from powered rotation of the sphere during flight (from the "Magnus Effect," which provides lift to a spinning ball). Due to its compact nature, the Magnus sphere is safer in high winds and bad weather than other airships.

Airfoil

A rigid envelope may be constructed in the shape of an aerodynamic lifting body. The airfoil envelope has a minimum speed needed before it gains its lift modifier (just like an aircraft, which must reach its minimum speed before it can start to fly). This usually means that airfoil airships take-off and land using conventional runways.

Multiply the effective lift of the envelope by the lift multiplier. Note the required minimum speed (for airfoil envelopes) and maximum speed. Minimum and maximum speed may be modified by the envelope type and TL. Multiply the cost of the envelope by the cost multiplier.

Gondola

Airships require one or more cars (also called "gondolas") within the envelope or suspended below it. The mass of the gondola depends on the mass of the contents (and not the total useful lift of the envelope).

In Table 22, Mass is in metric tons (1,000kg) per ton of capacity. Cost is in megacredits (MCr, 1,000,000 credits) per ton of capacity.

Hot Air Burners

Airships that use hot air for lift require a burner system to keep the air heated and keep the airship aloft. The burner itself masses 50kg, and consumes 50kg of hydrocarbon fuel per hour while the airship is aloft.

Thrust

Select thrust agencies by referring to the "Thrust Agencies" section (page 65). Airships generally use propellers for thrust, but practically any thrust agency could conceivably be used. Note the total thrust available, in kilonewtons.

Vertical Thrust

Although airships primarily rely on gas for lift, they may have thrust agencies installed to provide additional vertical lift. This allows the airship to operate at weights greater than its useful lift. At TL5 and above, the additional thrust may be made vectorable, to provide lift *or* forward thrust. Helicopter rotor assemblies and power plants may be installed to provide lift and forward thrust as well.

Controls

Unpowered airships do not require controls. Powered airships require simple controls; select controls from the "Electronics" component section (page 69).

Crew and Passengers

All crew members must be at crewstations; aircraft with more than three crew members (excluding gunners) must have a flight deck, and all crew members (except gunners) must have an open crewstation (which is considered to be on the flight deck). Gunners may still have cramped crewstations.

Pilot

All airships require a pilot. The pilot acts as gunner for fixed forward-firing weapons, bombs, rockets, and missiles.

Bombardier

A bombardier or weapons officer is required if the airship is intended to launch air-to-ground attacks from above 2,000 meters of altitude.

Gunners

Turret and flexible guns require a gunner. One gunner may control any number of remote turrets but may only fire one during a combat turn. A gunner in a simple turret may only fire the guns in the turret. A gunner firing guns attached to a flexible mount may fire only those guns during a combat turn but may move to a second flexible mount to fire its guns (taking a full turn to move there).

Navigator

A navigator is required if the airship's normal mission duration is six hours or longer. Navigators are not required in airships with TL7 (or higher) navigational aids and a flight computer.

Flight Engineer

A flight engineer is required in any airship with three or more engines, or more than 25kN of propeller thrust, unless a flight computer is installed.

Copilot

A copilot is required if the aircraft's normal mission duration is four hours or longer. A copilot is required on all commercial aircraft. A copilot is required on any aircraft of more than 25 metric tons mass, unless a flight computer is installed.

Sensor Operators

A sensor operator, or second pilot who can act as sensor operator, is often included on aircraft that employ terrain-following radar, or target-acquisition and fire-control radar and high-performance operator-guided missiles. This crewperson may also operate a laser target-designation system.

Passengers

Seats or other accommodations must be installed for passengers. Most airships provide only seats for their passengers, but some designs (particularly those intended for long-duration missions) provide more spacious accommodations.

Life Support

Airships flying above 3,000 meters in a Standard atmosphere (5,000 meters in Dense) require life-support systems. These range from oxygen masks to full pressure suits, sealed cabins, and basic life support. Select life-support appropriate to the airship's mission from the "Life Support and Accommodations" component section (page 75).

Weapons Mounts

Any type of aircraft weapon mount may be installed on airships. Airships with more than one car may have multiple bomb bays and multiple stub wings with wing-mounted hardpoints. Airships may have one fuselage hardpoint per car, if a bomb bay is not installed. Rigid airships may base bomb bays, missile bays, and gun mounts on the total useful lift of the airship. Nonrigid airships must mount these items in gondolas or cars and base them on the mass capacity of the car.

Electronics

Electronic systems of any sort may be installed. Airships are assumed to have 1 square meter of "usable" surface area for electronic systems per ton of useful lift.

Cargo

Designate any amount of mass for cargo carried internally. Airships may carry cargo, up to their useful lift, in an external sling. Each metric ton of cargo carried creates 10 drag points.

Fuel

Any quantity of fuel tankage may be designated, at no additional cost or mass. An air-to-air refueling probe may be installed in any powered airship. The cost is Cr1,000, and the weight is 0.1 metric ton. Refueling pods (which can be carried as an external store, to allow an airship to act as a tanker) cost Cr5,000 and weight one ton per ton of fuel carried (500kg fuel minimum).

Design Ratings

The following values determine the specs of a lighter-than-air vehicle.

Weight

The airship's maximum useful lift was determined at the beginning of the design sequence. Be sure that the sum of the masses of all of the components, including external stores, fuel, cargo, ammunition, and ordnance in internal bays is less than this amount. All equipment must be carried in gondolas in nonrigid airships; ensure that the masses of all of the equipment fits within the mass limit of the gondolas. Rigid airships may have gun mounts, bomb bays, and missile bays in the envelope itself; all other equipment must be mounted in gondolas; ensure that sufficient capacity is provided in the design.

Find the weights in kilonewtons (kN) by multiplying the mass of all of the equipment by the acceleration due to local gravity (remember that 1G standard is an acceleration of 10 m/s^2). Ensure that the total weight of all equipment is less than or equal to the airship's total useful lift (as augmented by any thrust used for lift).

For airships that have external hardpoints, total the number of drag points for each configuration.

Thrust

Total the thrust of all of the airship's engines that are being used for forward thrust, to find the total thrust, in kilonewtons (kN). Remember that helicopter rotors provide a thrust equal to 10% of the lift.

Speed

Compute an airship's speed using the rules for atmospheric performance in the "Thrust Agencies" component chapter (page 65). All airships except airfoil ships are lift vehicles with simple airframes (and have a thrust efficiency of 1.28). Airfoil configuration airships are airfoil vehicles with fast subsonic airframes (and have a thrust efficiency of 0.90).

Terrain-Following

Airships are capable of terrain-following flight, but not NOE (Nap Of the Earth) flight.

Overpower

Airships have a low minimum speed, and it is easy to overpower an airship. This power is not wasted; airships are very susceptible to wind, and they get into trouble with high winds, particularly near to the ground. Excess thrust beyond the airship's maximum speed can be used to reduce the difficulty of such maneuvers.

Compute airship speed normally, and if the result is greater than the maximum speed allowed, take the excess speed and divide by the maximum speed, dropping fractions. The resulting number indicates the relative ease of controlling the ship in dangerous situations near the ground or in high winds. Larger numbers indicate better control.

Take-off and Landing Rolls

Airships that have a minimum speed have take-off and landing rolls.

Maneuver Points

Airships are notoriously slow and unmaneuverable. Compute maneuver points as described in the atmospheric performance rules, but subtract one from the number of maneuver points available. Maneuver points may never be less than zero, however.

Volume

An airship's volume is approximately equal to its envelope volume. Nonrigid airships which do not have helicopter rotor assemblies installed can be disassembled for transport; the volume (in cubic meters) is three times the mass of the gondolas, in metric tons. Nonrigid airships that have helicopter rotor assemblies require a volume (in cubic meters) of 20 times the mass of the gondolas, in metric tons.

Fuel Use and Endurance

Total the fuel consumption of the aircraft's engines; this is the fuel consumed, in metric tons per hour. Determine the aircraft's endurance by dividing fuel consumption by the quantity of fuel available. This is endurance in hours and assumes the aircraft is using the most efficient cruise power settings available. The aircraft's range is the distance it can travel at cruising speed during this time. Multiply the cruising speed in kilometers per hour, but the endurance in hours to determine range in kilometers.

Combat requires the aircraft to go to full military power, consuming twice the fuel as cruising. Aircraft with afterburners double fuel consumption again when the afterburners are used (four times the base cruising fuel consumption).

Price

Total the price of all of the components of the aircraft to determine total price.

Maintenance

For maintenance points, divide the loaded mass by the factor in **Table 23: Maintenance Point Divisors.** If the vehicle has at least two regular or fiber-optic computers installed (not flight computers), capable of providing online diagnostic and troubleshooting , divide that result by 4.

Aircraft

This section describes craft that are not necessarily products of the future, but there are many ways to blend today's technology with tomorrow's inventions.

Mass

Mass is the limiting factor in designing all aircraft. Mass is expressed in metric tons (1,000kg). The mass selected by the designer is the maximum mass of the aircraft and includes a full internal fuel load, the crew, passengers, cargo, weapons, ammunition, and external stores. The performance of the aircraft depends on the aircraft's weight (which varies from world to world, depending on the local gravity), the atmospheric density, and the thrust produced by the engines.

Airframe

Aircraft hulls are called "airframes" and are specifically designed for optimum flight performance. Airframes are not constructed using the general hull rules but use instead the airframe tables in this design sequence.

Basic Airframe

Once the aircraft's maximum mass is known, the airframe can be selected from **Table 24: Airframes.** Each type of airframe has its own price per ton of maximum mass, minimum and maximum flight speeds, and efficiency factor.

Mass is in metric tons (1,000kg) per metric ton of maximum aircraft mass. Cost is in megacredits (MCr, 1,000,000 credits) per metric ton of maximum aircraft mass. Min Speed, Min STOL, and Max Speed are in kilometers per hour.

The airframe table gives the characteristics of the airframe in a standard atmosphere. Aircraft are only possible in thin, standard, and dense atmospheres (including the tainted variants of each, if the taint is compatible with engine operation). Different atmospheres affect the minimum and maximum speeds of the airframes. Thin atmospheres increase the minimum and maximum speeds of all airframe types by 50%. Dense atmospheres decrease the minimum and maximum speeds of all airframe types by 50%.

Aircraft Type

Aircraft can be either fixed-wing or helicopter. Both types of aircraft use wings to generate lift. Fixed-wing aircraft have the wings fixed to the body of the aircraft and generate wing lift due to their forward motion through the air. Helicopter rotors are wings that are fixed to a central hub. Helicopters generate lift by using engine power to rotate the wings through the air. Airframes which are designated "either" may be used for helicopters or fixed-wing aircraft. Those designated "fixed" may only be used for fixed-wing craft. The maximum speed for a helicopter is 320kph (compound helicopters are an exception to this rule).

Autogyros

Autogyros have rotary wings, but unlike helicopters, they do not use engine power to rotate them. The forward motion of the autogyro causes the wings to rotate and generate lift. Although autogyros use a rotary wing, they are designed in the same way as fixed-wing aircraft. Only helicopters and ornithopters (both of which use a powered wing) are designed differently.

Ornithopter

Ornithopters use powered flapping wings and are designed as helicopters. See Table 25.

Carrier Aircraft

Carrier aircraft may have the ability to fold their wings, to allow them to be stored in a smaller volume. Add 5% to the airframe weight and cost to allow folding wings. Strengthening the airframe to allow arrested landings aboard the carrier costs a percentage of the aircraft weight equal to 8.5%, minus the aircraft's maneuver points (maximum takeoff weight configuration), with a minimum of increase of 0.5%. Corrosion resistance (to resist the effects of sea water or mildly corrosive atmospheres) may be added to any aircraft by increasing the cost of the airframe and power plant by 5%. There is no weight increase for corrosion resistance.

Helicopters

Helicopters are unique in that they rely on overhead rotors for both lift and thrust. The rotors, along with the required gearboxes, transmission assemblies, and drive shafts needed to convert engine power into lift are termed "rotor assemblies."

Choose a rotor assembly from **Table 26: Rotor Assemblies.** Install a total lift equal to, or greater than, the maximum takeoff weight of the aircraft. The helicopter's thrust is equal to the lift multiplied by 0.1. If additional thrust is desired, install additional thrust agencies from **Table 170: Aircraft Thrust Agencies** (usually turbojet or turbofan). The table below gives the characteristics of rotor assemblies, per kN of lift.

In Table 26, Mass is in kilograms (kg, not metric tons). Cost is in credits (Cr, not MCr). Power is in kilowatts (kW, not MW). MaxL is maximum lift in kilonewtons (kN).

Compound Helicopters

Conventional helicopters have a maximum speed of 320kph (due to aerodynamic limitations of the rotor design). Compound helicopters may exceed this speed by using advanced rotor designs. Compound helicopters receive no thrust from the rotor assembly. They must have some other thrust agency (typically a turbojet or turbofan) that provides enough thrust to meet the minimum speed for the airframe type selected. Compound helicopters at TL6 and TL7 must use the Main + Tail Rotor assembly. At TL8 they may use the Coaxial Rotor assembly, and at TL9+ they may use the X-Wing rotor assembly.

Thrust

Select thrust agencies from the "Thrust Agencies" section (page 65).

Controls

All aircraft require controls. (See the "Controls" component section on page 71.) Helicopters larger than 10 metric tons mass require enhanced mechanical controls; all other helicopters need only basic mechanical controls.

Crew and Passengers

All crew members must be at crewstations; aircraft with more than three crew members (excluding gunners) must have a flight deck and all crew members (except gunners) must have an open crewstation (which is considered to be on the flight deck). Gunners may still have cramped crewstations.

Pilot

All aircraft require a pilot. The pilot acts as gunner for fixed forward-firing weapons, bombs, rockets, and missiles.

Bombardier

A bombardier or weapons officer is required if the aircraft is intended to launch air-to-ground attacks from above 2,000 meters altitude.

Gunners

Turret and flexible guns require a gunner. One gunner may control any number of remote turrets but may only fire one during a combat turn. A gunner in a simple turret may only fire the guns in the turret. A gunner firing guns attached to a flexible mount may fire only those guns during a combat turn but may move to a second flexible mount to fire its guns (taking a full turn to move there).

Navigator

A navigator is required if the aircraft's normal mission duration is six hours or longer. Navigators are not required in aircraft with TL7 (or higher) navigational aids and a flight computer.

Flight Engineer

A flight engineer is required in any aircraft with three or more engines, or more than 25kN of propeller thrust, unless a flight computer is installed.

Copilot

A copilot is required if the aircraft's normal mission duration is four hours or longer. A copilot is required on all commercial aircraft. A copilot is required on any aircraft of more than 25 metric tons mass unless a flight computer is installed.

Sensor Operators

A sensor operator or second pilot who can act as sensor operator is often included on aircraft that employ terrain-following radar, or target-acquisition and fire-control radar and high-performance operator-guided missiles. This crewperson may also operate a laser target-designation system.

Passengers

Seats or other accommodations must be installed for passengers. Most aircraft provide only seats for their passengers, but some designs (particularly those intended for long-duration missions) provide more spacious accommodations.

Life Support

Aircraft flying above 3,000 meters in a Standard atmosphere (5,000 meters in Dense, 1,500 meters in Thin) require life-support systems. These range from oxygen masks to full pressure suits, sealed cabins, and basic life support.

Weapons Mounts

Install any required weapons mounts from the "Aircraft Weapons Mounts" section (page 61).

Electronics

Electronic systems of any sort may be installed. Aircraft are assumed to have one square meter of "usable" surface area for electronic systems, per ton mass of aircraft.

Cargo

Designate any amount of mass for cargo carried internally. Helicopters may carry cargo, up to their maximum takeoff mass, in an external sling if they do not have fuselage hardpoints. Each metric ton of cargo carried creates 10 drag points.

Fuel

Install any desired amount of fuel tankage. There is no additional cost or weight (beyond that for the fuel itself) for fuel tankage.

An air-to-air refueling probe may be installed in any aircraft. The cost is Cr 1,000, and the weight is 0.1 metric ton. Refueling pods (which can be carried as an external store, to allow an aircraft to act as a tanker) cost Cr 5,000 and weigh one ton per ton of fuel carried (500kg fuel minimum).

Maneuver Enhancement

Designers may allocate any percentage of an aircraft's mass to maneuver enhancement. There is no cost. The higher the percentage of mass devoted to maneuver enhancement, the more maneuver points the aircraft has.

Variable Geometry

Aircraft with 20% or more of their mass devoted to maneuver enhancement are assumed to be variable-geometry aircraft of some sort. Variable-geometry aircraft automatically count as having folding wings for purposes of storage and do not need to devote any additional weight to that feature.

Design Ratings

The following values determine the specs of aircraft.

Weight and Drag

The aircraft's maximum takeoff mass was determined at the beginning of the design sequence. Ensure that the sum of the masses of all of the components, including external stores, fuel, cargo, ammunition, and ordnance in internal bays is less than this amount. For fixed-wing aircraft with external hardpoints, no more than 25% of the aircraft's maximum takeoff mass may be carried on the external hardpoints.

Fixed-wing aircraft that carry stores on external hardpoints also have a maximum internal load (or "clean" mass). This is the mass of the aircraft without any external ordnance but with a full internal fuel load, and all ammunition and ordnance that is carried internally.

Some aircraft may have additional configurations. Calculate the mass for these configurations. (For example, a dual-role fighter may have an "air superiority" configuration with only air-to-air missiles and a maximum air-to-ground configuration with all of the hardpoints loaded with heavy bomb racks.)

Find the aircraft's weights in kilonewtons (kN) by multiplying the weight of each configuration by the acceleration due to local gravity. (Remember that 1G standard is an acceleration of 10 meters per second per second.)

For aircraft that have external hardpoints, total the number of drag points for each configuration.

Thrust

Total the thrust of all of the aircraft's engines to find the total thrust, in kilonewtons (kN). Remember that helicopter rotors provide a thrust equal to 10% of the lift.

Glide Ratio

All fixed-wing aircraft, and compound helicopters with Main + Tail Rotors or X-Wings, have a base glide ratio of 5, and add 1 for every 5% of the airframe devoted to maneuver enhancement. STOL (Short Take Off and Landing) aircraft double their glide ratio. Compound helicopters are not considered STOL for this purpose.

Subtract 1 from the glide ratio for every drag point the aircraft has (exclude drag points due to the STOL airframe option).

All ornithopters have a glide ratio of 20.

All other helicopters may autorotate to unpowered landings and do not have a meaningful glide ratio.

Thrust-to-Weight Ratio

For each configuration of the aircraft, divide the total thrust by the total weight and multiply the result by the efficiency factor of the airframe. This is the aircraft's thrust-to-weight ratio. If the aircraft includes afterburners, perform the calculation twice (with and without afterburners). If the aircraft includes AZH (Advanced Zero-speed to Hypersonic) engines, perform the calculations for each mode the engine operates in. The result is acceleration in meters per second per second.

VTOL (Vertical TakeOff and Landing) aircraft must have a thrust-to-weight ratio of at least 5 or they are treated as STOL aircraft. VTOL aircraft with a thrust-to-weight ratio of less than 5 at their maximum takeoff weight but a thrust-to-weight ratio of 5 or greater in their clean configuration are called STOVL (Short Take-Off, Vertical Landing) aircraft, as they require a short takeoff roll to become airborne but can land vertically once they expend ordinance and burn off fuel.

Speeds

Compute aircraft speeds using the atmospheric performance rules in the "Thrust Agencies" component chapter (page 65). Helicopters (except compound helicopters) cannot exceed 320kph. If the maximum speed is below the minimum speed for the airframe, the aircraft cannot fly; a redesign is called for (remove mass or add thrust).

Minimum

Note the aircraft's minimum speed from **Table 24: Airframes.** Most VTOL aircraft, and helicopters, do not have a minimum speed.

Terrain-Following

Terrain-following flight is defined as flying a fixed, and usually very small, distance above the ground and obstacles on the ground. Any aircraft may perform terrain-following flight. The maximum safe terrain-following speed is determined by the aircraft's terrain-following avionics. If none are installed, the maximum safe terrain-following speed is 80kph. Terrain-following speed may not exceed 25% of the aircraft's maximum speed.

NOE Flight

Nap-of-the-Earth (NOE) flight is defined as flying around obstacles, and not over them, and is conducted at an even lower altitude than terrain-following flight. In order to perform NOE flight, an aircraft must be capable of hovering. Only helicopters and VTOL aircraft can perform NOE flight. The maximum safe NOE speed is the maximum NOE speed allowed by the aircraft's terrain-following avionics (or 40kph, if none are installed). NOE speed may not exceed 25% of the aircraft's maximum speed.

Take-off and Landing Rolls

All aircraft (including ornithopters) except for helicopters and VTOL aircraft have take-off and landing rolls.

Maneuver Points
Maneuver points, which represent the aircraft's ability to turn, and the energy required to perform the turn, are determined by the aircraft's speed and the amount of the airframe devoted to maneuver enhancement. When dogfighting, the aircraft with more maneuver points has a maneuverability or energy advantage (or both) over the opposing pilot. Compute maneuver points using the atmospheric performance rules. Add maneuver points to aircraft based on the percentage of the airframe mass that is devoted to maneuver enhancement.

In Table 27, calculate maneuver points for the aircraft at NOE speed, maximum clean speed, and maximum loaded speed. Aircraft flying at NOE have their maneuver points doubled.

Volume

An aircraft's storage volume, in cubic meters, is equal to its mass in metric tons multiplied by 60. Folding-wing aircraft has a storage volume equal to its mass in tones multiplied by 30. Helicopters and autogyros with the rotor folded or removed for transport have a storage volume equal to their mass in tons multiplied by 20.

Fuel Use and Endurance

Total the fuel consumption of the aircraft's engines; this is the fuel consumed, in metric tons per hour. Determine the aircraft's endurance by dividing fuel consumption by the quantity of fuel available. This is endurance in hours and assumes the aircraft is using the most efficient cruise power settings available. The aircraft's range is the distance it can travel at cruising speed during this time. Multiply the cruising speed in kilometers per hour, but the endurance in hours, to determine range in kilometers.

Combat requires the aircraft to go to full military power, consuming twice the fuel as cruising. Aircraft with afterburners double fuel consumption again when the afterburners are used (four times the base cruising fuel consumption).

AZH engines consume additional (or different) fuel in different modes. This is the cruise fuel consumption for each mode; full military power consumes twice the listed amount of fuel.

Price

Total the price of all of the components of the aircraft to determine total price.

Maintenance

For maintenance points, divide the loaded mass by the factor in **Table 28: Maintenance Point Divisors.** If the vehicle has at least two regular or fiber-optic computers installed (not flight computers), capable of providing online diagnostic and troubleshooting , divide that result by 4.

Ground Vehicles

From cycles to tanks, the **Traveller** engineer pays close attention to the details—as much so for a ground vehicle as for a spaceship.

Chassis Design

A vehicle's hull is also referred to as its "chassis." Ground vehicles almost always use the "box" configuration, although disk and cylinder configurations are also permitted.

Chassis Size

Choose the desired chassis size in **Table 159: Basic Hull Size.** This table lists the diameter and surface area for a spherical chassis.

Surface Area and Dimensions

Choose the specific shape you want, and look the factors up in **Table 160: Hull Shape Modifiers.** You may also use one of the other configurations listed in the Spacecraft section (page 63).

Surface Area
Multiply the surface area for a sphere by the number listed under "Surface Modifier" (in Table 160). This is the actual surface area available on your chassis.

Dimensions
Multiplying the diameter for the sphere by the "Dimension Modifiers" gives you the actual length, width, and height of your chassis.

Airframe Modifications

Ground vehicles have no airframe modifications.

Armor

Choose the armor material desired from **Table 158: Hull Materials** or from another material table elsewhere, if the material you want isn't listed here).

Thickness
To determine how thick the hull needs to be, based on a desired armor rating, divide the armor rating by the material toughness. This gives you a hull thickness in cm. The absolute minimum armor thickness required is 0.25cm.

Volume
Divide the armor thickness in centimeters by 100 to get thickness in meters, then multiply by surface area to get the total volume taken up by the armor. Remember, this comes out of the available volume. Note that the surface area used is the total area calculated under "Surface Area" and "Dimensions," above.

Mass
The mass of the armor is the density times the volume.

Cost
The cost of the armor is the volume times the price.

Special Features for Box Configurations

There are a few additional special modifications you can make to your chassis, but for simplicity they are restricted to the most common box configuration. They really don't make sense or are too complex for any other configuration.

Additional Armor
If you choose a box configuration, you may choose to increase the armor on certain faces over and above the base armor value. This adds mass and cost to the vehicle but increases the protection on that face. Increase the armor volume by the percentage listed in **Table 15: Facing Armor** for each cm of additional armor added to a face.

Armor Sloping
Again, with a box configuration you may also choose to slope your armor on certain faces. Sloped faces increase effective armor rating against direct-fire weapons because the weapon strikes at an angle and has to penetrate more material. However, sloping the face also takes volume away from the interior of the vehicle. **Table 16: Armor Slope Effects**, lists the armor rating multiplier and the waste space per face that is sloped.

Open-Topped Vehicles

If you choose, a box configuration vehicle can have an open top, meaning there's no roof and the sides are partially reduced. A glass or plastic windscreen or roof, with no armor protection, can be added. Multiply the armor material volume by 0.7. There is no protection against attacks from the top, and on a roll of 6 or less on 2d6, attacks from the sides, front, or rear go through the window or open sides instead of armor. List the front, side, and rear armor in square brackets—like this: [4]—to indicate an open-topped vehicle.

Internal Structure

All ground vehicles should be stressed to withstand at least gravity (1G), plus maneuvering, plus a safety margin. For most purpose, 1.5Gs is sufficient.

Volume

The volume of the internal structure depends on the volume of the hull, the maximum acceleration of the ship, and the toughness of the material used. Multiply the Structural Factor by 1.5, and then divide by the toughness. This gives you the volume of the internal structure.

Mass

The mass is simply density times volume again.

Price

The price of the internal structure is the volume times the material price. Do not multiply this by the streamlining price modifier used for armor; internal structure is independent of streamlining. See Tables 29 and 30.

Propulsion

Choose a propulsion method and decide how much power you want to dedicate to it. All propulsion systems mass 1t per m^3. Together, the power dedicated to the propulsion, the loaded mass of the vehicle, and the speed multiplier determines your top speed. See Table 31.

Power Systems

Select and install power systems required for your design from the "Power Systems" component chapter (page 81).

Weapons

You shouldn't necessarily equip your ground vehicle with weapons. Unless you operate on a planet where vehicular combat is common, it's probably more convenient (and less conspicuous) to carry a sidearm. However, if you need to mount a laser cannon on the roof of your land rover, you'd better be sure that it's mounted advantageously.

Mounts

Vehicle-mounted weapons don't need carriages, tripods, or any other kind of mount from the weapon design sequence, as the vehicle provides mounting equipment. The types of mounts available are turrets, chassis mounts, pintle mounts, or open mounts. Indirect fire weapons (mortars and so forth) must be in a turret or open mount.

Turrets

You may choose to equip your vehicle with turrets for mounting weapons or other equipment. The volume for the turret comes out of the chassis volume. Also, a turret needs considerable space around it to be able to pivot and aim. The space for this comes out of the chassis volume as well. Rather than calculate exactly how much of the chassis needs to be "cut away" to do this, simply assume that components mounted in the turret take up much more than their actual volume. This excess volume represents the free volume around the turret and depends on the size of the turret. The volume of a component after multiplying it by the modifier is called the "effective volume."

Main Turrets: A large or main turret takes up 10% or more of the total chassis volume. A vehicle may have only one main turret, usually located on the top. Equipment mounted in a main turret has an effective volume which varies depending on tech level. **Table 17: Main Turret Efficiency** lists the multipliers used at different tech levels.

Main turrets, because of their size, reduce the aerodynamics of the vehicle. Reduce the maximum speed by 1% for each 1% of total chassis volume dedicated to effective turret volume.

Main turrets have to be locked down pointing aft when the vehicle is moving at high speeds, or the vehicle becomes unstable and possibly crashes. The maximum safe speed of any grav vehicle while moving its turret is 300kph.

Small Turrets: A small turret can be mounted on any face of the vehicle, although it's usually located on top of the main turret or on the deck (top), but it takes up less than 10% of the total chassis volume. Equipment mounted in small turrets has an effective volume of 10x normal volume. A manned small turret is also called a "cupola" and must allocate volume for one-half the gunner's crewstation (see below). An unmanned small turret is also called a "remote mount" and is controlled by a gunner elsewhere in the vehicle.

Note: In some cases you can become locked in an infinite loop. Designating a turret as Small and using the fixed 10x multiplier for equipment may result in it being over the 10% size limit, which requires it to be a Main turret. But if you use the Main turret multipliers, the effective volume of the equipment is less than 10%, requiring it to be a Small turret. Loop back to beginning? Nope. Instead, treat it as a Main turret, using the Main turret multipliers, but it must be the only turret on the vehicle. For targeting and damage purposes, treat it as a Small turret. See Table 32.

Chassis Mounts

A chassis mount is simply a fixed mount in one of the six faces of the vehicle. Although some minor adjustments are possible, chassis mounts are aimed by pointing the whole vehicle—hence, they're usually in the front face.

Pintle Mounts: A pintle mount is simply a pivoting post or rail supporting a light weapon. Usually mounted on the top of the vehicle, a pintle mount and associated weapon take no volume from the chassis. However, the gunner is exposed to enemy fire. A pintle mount may not be used on a sealed vehicle without breaking the seal.

Open Mounts: An open mount is simply a weapon mounted in the chassis of an open vehicle.

Electronics

Select and install electronics systems from the "Electronics" components chapter (page 69).

Crew and Passengers

The requirements for crew and passenger vary widely, depending upon the size and type of ground vehicle. Each crew member requires a crewstation, and each passenger requires a seat. An open vehicle may use a cramped crewstation, while others must have open crewstations.

Driver

Obviously, every vehicle requires a driver.

Commander

Armored military vehicles may optionally have a commander, but it's highly recommended for combat vehicles.

Gunners

If there are weapons installed, one or more gunners and loaders may be required. The driver of a vehicle may operate weapons in forward-firing fixed mounts. All others require a gunner. A gunner may fire multiple weapons, as long as each is controlled from the same weapon station. All weapons mounted on the same face of the chassis or in the same turret may be controlled by a single station. Each small turret requires a station unless it is remotely controlled. A gunner may control any number of weapons but may only operate one weapon in a single turn.

Loaders

If weapons requiring loaders are installed, the crew must have loaders.

Accommodations

Select and install accommodations for your design from the "Life Support and Accommodations" component chapter (page 75).

Life Support

Many ground vehicles do not require lift support; if your mission includes the ability to operate in environments where life support is required, select and install life support systems from the "Life Support and Accommodations" component chapter (page 75).

Miscellaneous Components

A number of typical add-on features are listed below. You may think of and wish to add still others. Allow the guidelines below to dictate the effects on your ground vehicle.

Sunroof

You may install a sunroof on any vehicle with at least 1m^2 of unused area on the top surface. The panel has the same armor rating as the rest of the top. Cost is Cr100 x Armor Rating for a manually operated panel, and Cr200 x Armor Rating for a powered panel.

Anti-Theft System

Anti-theft systems attempt to protect your vehicle from being stolen while unattended. The actual nature of the system varies with TL and is up to the referee. The basic system monitors up to five access points (doors, trunks, and so forth) on the vehicle as well as attempts to move the vehicle. Higher TL systems become more accurate at ignoring false alarms (loud noises, wind, and other false triggers).

Attempts to bypass the system are Formidable, with the following DMs: –2 per TL higher than the thief's tools and/or skill; +1 per TL below thief's tools and/or skill; +1 for spending one minute studying system prior to attempt; +2 for spending 10 minutes studying the system; –1 for each doubling of system cost (to a maximum of –3). Cost: Basic Cr100; each additional access point Cr20, total x2 to increase difficulty by 1 DM; x4 for 2 DM; or x8 for 3 DM.

Anti-Hijack System

Depending on the local law level, you may install a system intended to foil hijackers or thieves from making off with your vehicle while you're inside (thereby neatly sidestepping any anti-theft devices). Activating the system locks all the

Rating The Design

Fill out the following worksheet.

General Data

TL: ##
Size: ###m^3
Dimensions (LxWxH): ####m x ####m x ####m
Mass (loaded/empty): #####t / #####t. Calculate two masses, loaded and empty. Loaded includes full fuel tanks, full cargo (assume 1 ton/m^3), and all weapons loaded. Also add in 100kg per passenger or crew member. Empty is without all of that.
Speeds: Max Road ### km/hr; Max Cross-country ### km/hr. The maximum road speed is 1,800 x Efficiency x Propulsion Power/Loaded Mass. Extremely heavy vehicles, which have greater momentum and lower area-to-volume ratios, increase their maximum speed by the multiplier listed in **Table 33: Speed Multipliers.** Maximum cross-country speed is 0.25 times maximum road speed.

Power Plant: ####MW
Propulsion:
Fuel:
Maintenance Points: ###. For maintenance points, divide the loaded mass by the factor in **Table 34: Maintenance Point Divisors.** If the vehicle has at least two regular or fiber-optic computers installed (not flight computers), capable of providing online diagnostic and troubleshooting , divide that result by 4.

Electronics

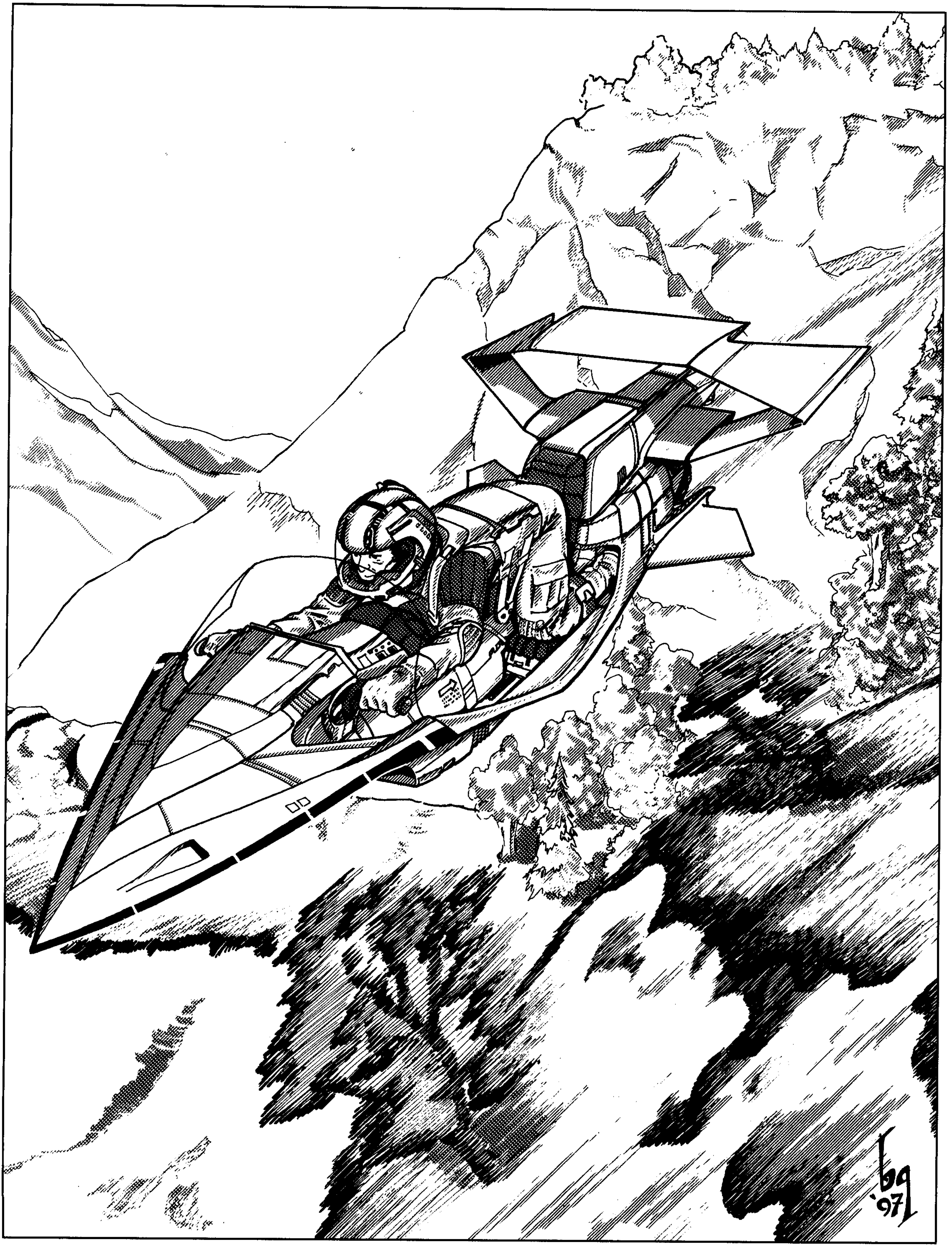
Computers:
Communications:
Sensors:
ECM/ECCM:
Controls:

Armament

Offensive:
Defensive:
Fire Control:

Accommodations

Life Support:
Crew: ## (Driver, two gunners, and so forth.; cramped crewstations).
Passengers: ## (cramped seats).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doors, delivers a nonlethal 2d6 electrical jolt to anybody who touches the vehicle, and sprays an indelible dye on anyone trying to open the doors. If the doors are opened while the system is armed, the engine automatically shuts down in 30 seconds and remains that way for 10 minutes. Installing such equipment may be prohibited or restricted by local law level or may subject the vehicle owner to extremely high liability lawsuits for "malicious injury, emotional distress, and loss of income." Volume 0.01m^3; mass 10kg; price Cr1,000.

Construction Equipment

To add specialized lifting or digging equipment, choose the size of the machinery and treat it as though it were a weapon in a turret. Lifting equipment can lift up to 1 ton per TL per cubic meter of equipment. Earthmovers can move TL x 10m^3 of normal dirt per hour per cubic meter of equipment. Digging equipment can dig to a depth of TL/2 (in meters, round down) and can remove TL x 1m^3 per hour per cubic meter of equipment. Volume is designer's choice; mass 1t/m^3; power 0.001MW per ton of capacity; price Cr5,000/m^3.

Entertainment Center

You can add an entertainment center, using the appropriate technology of your TL, for as many as to eight-to-ten passengers. Volume 0.02m^3; mass 10kg; power 0.25kW; price Cr1,000.

Fire Suppression System

Normally not used on personal vehicles, military and large commercial vehicles often mount a system capable of extinguishing fires inside the vehicle. On a 2D roll below the system's TL, the system successfully puts out a fire in one turn. Portable extinguishers roll 3D. Once the system has discharged, it has to be recharged before it can be used again. Volume 0.001m^3 per m^3 of protected volume (minimum 0.001m^3); mass 0.5t per m^3; price MCr0.05 per m^3.

2: WEAPON DESIGN

It's a rough galaxy out there! No doubt, your intentions are nothing but peaceful, yet you'd be a fool to enter that star system unarmed. The starfaring engineer doesn't simply want to point and shoot; he wants to know every part of his weapon. This part *of Fire, Fusion, and Steel* provides all the information needed to design and a variety of weapons for the **Traveller** universe.

Small Arms

In the spaceship, on the ground, and everywhere in between, it's important to have personal protection close at hand. No matter what the tech level, you'll find people *packing heat,* so you'd better be prepared!

Chemically-Propelled Slug Throwers

The origins of chemically-propelled slug throwers have been lost to the Long Night, as they date back to 14th-Century Terra, beyond the reckoning of many computer databases. Just the same, everyone knows that gunpowder has been around for hundreds of millennia, and *slug throwers* remain a fixture of small armaments across the galaxy. A slug penetrates where a meson ray is deflected, so it pays to understand this technology even if you cruise the stars with a laser pistol on your hip.

Ammunition

This design sequence handles ammunition for firearms. These weapons have the bullet, propellant, and primer contained in one unit. Black powder weapons are available at TL2, and smokeless powders are usually available by the beginning of TL4. The earliest firearms use loose powder, a supply of round bullets, and a separate ignition system. Complete cartridges containing the bullet and powder wrapped in waxed paper become available before the end of TL2. By late TL3, it is possible to manufacture small arms ammunition that contains the bullet, propellant, and a primer in a brass case. Beginning at TL8, it is possible to produce caseless ammunition—these cartridges dispense with the case and use a solid, plasticlike propellant that is strong enough to contain the bullet and primer. The ultimate development in propellants, electrothermal-chemical, is available at TL9 or above.

Ammunition Characteristics

Ammunition design typically proceeds from an intended *caliber* (diameter of the projectile) and the desired muzzle energy of the projectile (in joules). Most ammunition uses a chemical propellant (such as cordite) to propel the projectile. This is "conventional" ammunition. For conventional ammunition, the energy of the projectile is determined by the amount of propellant burned. Advanced weapons use an electrical energy source to add energy to the gasses resulting from the burning propellant. These electrothermal-chemical (ETC) rounds produce a higher energy from a given amount of propellant but cannot be caseless.

Caliber: Caliber is the diameter of the bullet in millimeters. Some references give diameter in decimal fractions of an inch (thus, "45 caliber", or ".45" indicates 0.45 inches, or 11.43mm). Any caliber between 2mm and 40mm may be selected for small arms, although calibers of less than 5mm are rarely used. Calibers of over 20mm are normally considered heavy weapons but are handled more correctly in this design sequence.

Example: We will design 11.5mm handgun ammunition.

Maximum Energy: There is a limit to the amount of energy that can be imparted to a projectile that is propelled by expanding gasses. As a rough rule of thumb, the maximum rated energy for ammunition of a given caliber is given as a function of tech level on the table below. Multiply the caliber of the round, in millimeters, by the limit (in kilojoules per millimeter) from **Table 35**: **Energy Limits** to find the maximum possible energy. Most weapons will handle considerably less energy than this, due to considerations such as weapon weight, recoil, and ammunition size and weight.

Example: Our 11.5mm ammunition has a rated energy of 500 joules and will be designed at TL5, placing it well under the energy limit.

Base Area: Calculate the base area of the bullet using **Equation 5: Bullet Base Area**.

Equation 5: Bullet Base Area

$$Area_{base} = \frac{\pi}{4} \leftarrow Caliber^2$$

Where Area$_{base}$ is the area of the base of the bullet (in square millimeters), (is the constant 3.141 and Caliber is the caliber of the bullet in millimeters.

Example: Our ammunition has a base area of 103.8 square millimeters.

Rated Muzzle Energy: Select a desired muzzle energy, E$_{rated}$ in joules with **Equation 6: Conventional Propellant Volume**. Divide the energy desired by the propellant energy density, ED$_{propel}$ from **Table 36: Propellant Energy Density,** to find the volume of propellant required.

Equation 6: Conventional Propellant Volume

$$Vol_{propel} = \frac{E_{rated}}{ED_{propel}}$$

Where Vol$_{propel}$ is the propellant volume in cubic millimeters, E$_{rated}$ is the desired rated muzzle energy in joules, and ED$_{propel}$ is the energy density of the propellant in joules per cubic millimeter.

The density given is the energy density (ED$_{propel}$, above) for powder produced at that TL, in joules per cubic millimeter. Electrothermal-chemical (ETC) is only available at TL9 and above.

Example: To achieve 500 joules energy, the round requires 625 cubic millimeters of powder.

Bullets: There is a great deal of difference between slugs of various tech levels.

Early Bullets: At TL2 and early TL3, only spherical "ball" bullets are available. Ordinarily, the ball fits rather loosely into the barrel, and these loose balls are fired from smoothbore weapons. Loose-ball ammunition can also be used in rifles but perform as if the weapon was smoothbore. A leather patch can be used when ball ammunition is fired from a rifle. Patched balls fit more tightly into the bore of the weapon to engage the rifling and improve the efficiency of the weapon.

Conical Bullets: By late TL3, conical rifle bullets are available, eliminating the need for patched-ball ammunition.

Pistol Bullets: At TL4 and beyond, pistols and submachine guns typically fire heavier, lower-velocity rounds than rifles and machine guns. The shape of these bullets reflects this difference: Rifle bullets are longer compared to their caliber. Pistol bullets are typically short and stubby.

Flechettes: At TL5 or above, smoothbore weapons can fire flechettes. Flechettes are small finned darts, machined to precise tolerances, with superior ballistics and armor penetration. Although similar in concept to discarding sabot projectiles, small-arms flechettes have different characteristics.

Shot: Shotguns fire round "pellets" or a single large slug. If the ammunition is for a shotgun, determine the number of pellets. (The greater the number of pellets, the smaller each is.) Shotgun ammunition is available at TL2 and above.

Compute the length of the bullet, Len$_{bullet}$, using **Table 37: Bullet Length.** Note that Len$_{bullet}$ is not the actual bullet length but rather is the length of the part of the bullet that protrudes from the cartridge case. Shotgun pellets or slugs are entirely enclosed in the cartridge case.

Example: The pistol round will have a bullet length of 11.5mm.

Cartridge Case: Once the powder volume and bullet design are known, a cartridge case can be designed to contain the components of the ammunition. Most weapons at TL4 and above use a metallic cartridge case constructed of brass or steel.

Loose Powder: TL2 and TL3 weapons may use loose powder and bullets (in this instance, the term "cartridge case" is a misnomer) or paper cartridges. Loose shot may consist of an ordinary spherical ball, a patched spherical ball, or a conical rifle bullet.

Shotgun Cartridges: In addition, shotgun ammunition is available at all technology levels. Shotgun cartridges must be used for multiple-pellet ammunition. Above TL3, shotgun cartridges are made of metal, or metal and paper, with plastic and metal cartridge cases manufactured as soon as suitable plastics are available, usually at TL5.

Case Style: There are two types of metallic cartridge cases: straight and necked. Straight and shotgun cartridges have a cartridge case approximately the same diameter as the bullet for the entire length of the case. Necked cartridges have a case that is larger in diameter than the bullet, and then "neck down" at the end to fit the bullet. Necked cartridges can hold considerably more propellant for a given cartridge length and are typically used for high-powered rifle ammunition. Necked cartridges are usually at least 35mm long, although shorter necked cartridges can be designed. ETC cartridges use conventional cases, straight or necked.

Caseless Cartridges: Caseless cartridges are available at TL8. (Since these cartridges have no case, the term "cartridge case" does not truly apply.) However, the propellant block is larger in diameter than the projectile, and caseless cartridges can be treated the same as necked cartridges in the design sequence.

Compute the minimum cartridge case length with **Equation 7: Minimum Cartridge Case Length**. The actual cartridge case length may be any value between twice the caliber (rounds shorter than this tend to be hard to feed and extract) and twelve times the caliber (rounds longer than this tend to bend or break and jam in the weapon). Most ammunition is designed so that the cartridge case is less than twice the minimum length. The length of the cartridge case is Len$_{ccase}$ and is expressed in millimeters.

Equation 7: Minimum Cartridge Case Length

$$Len_{cc\min} = \frac{Vol_{propel}}{Mod_{ctype} \leftarrow Area_{base}}$$

Len$_{ccmin}$ is the minimum cartridge length in millimeters, Vol$_{propel}$ is the propellant volume in cubic millimeters from **Equation 6: Conventional Propellant Volume,** above, Mod$_{ctype}$ is the cartridge type modifier from **Table 38: Cartridge Type Modifier** that indicates the relative quantity of powder that can be contained in each type of cartridge, and Area$_{base}$ is the bullet base area in square millimeters **from Equation 5: Bullet Base Area,** above.

Example: The pistol will use a straight cartridge case and therefore has a minimum length of 15mm. To avoid reliability problems with the short ammunition, we'll make the cartridge case 23mm long.

Ammunition Evaluation

Determine the technical specs of ammunition using the information provided below.

Length: Compute the overall length of the ammunition by adding Len_{case} (the length of the case) and Len_{bullet} (the length of the bullet that projects from the case). These lengths should be expressed in millimeters.

Example: The overall length of the ammunition is 34.5mm.

Weight: Compute the mass of the ammunition, in grams, using **Equation 8: Ammunition Mass.** Mod_{atype} is determined from the ammunition type, using **Table 39: Ammunition Type Modifier.**

Equation 8: Ammunition Mass

$$Mass_{ammo} = Mod_{atype} \leftrightarrow Len_{ccase} \leftrightarrow A_{base}$$

Example: The cartridge masses 19.1 grams.

Rated Muzzle Energy: Note the rated energy of the ammunition. This is the energy the round will have when fired from the ideal barrel. Compute the ideal barrel length for the ammunition **using Equation 9: Ideal Barrel Length.** The ideal barrel is a barrel long enough for the propellant contained in the cartridge to finish burning completely. Black powder (TL2) burns relatively slowly, requiring a long barrel. Conventional smokeless powders (TL4) are the most commonly used. ETC propellant technology (TL9) makes reduced barrel lengths possible. Barrels shorter than the ideal length waste propellant energy and will have a lower actual energy than the ammunition's rated energy. Barrels longer than the ideal length allow the propellant gasses to work on the bullet longer, resulting in higher energies at the cost of greater weight and lower efficiency.

Equation 9: Ideal Barrel Length

$$Len_{ideal} = \frac{E_{rated}}{Caliber^2} \leftrightarrow Mod_{rifling}$$

Where Len_{ideal} is the length of the ideal barrel in centimeters, E_{rated} is the rated energy of the ammunition in joules, Caliber is the caliber of the ammunition in millimeters, and $Mod_{rifling}$ is the rifling modifier from **Table 40: Rifling Modifiers.** Regardless of the results of the calculations, the ideal barrel length is never less than 10cm.

In table 40, shotguns use smoothbore barrels; most other weapons rifle the barrel for accuracy.

Example: The ideal barrel length for this ammunition is 10cm.

Price: Multiply the mass of the ammunition by the price per gram from **Table 41: Ammunition Price Modifier.**

Classifications: Ordinary ammunition is any conventional, caseless, or ETC ammunition that has a rated energy of 10,000 Joules or less. Other types of ammunition have different costs.

Loose Powder: Early weapons that fire loose powder and bullets have a considerably lower cost per round. Any weapon that does not use a metallic case, regardless of the type of bullet (loose ball, patched ball, or conical bullet), uses the loose powder price.

Paper Cartridge: Paper cartridges speed and simplify the reloading process, but paper is relatively expensive at early technology levels, resulting in a considerably higher cost for the ammunition.

Shotgun: Any shotgun shells, regardless of the number of projectiles, uses the shotgun price.

Mass-Produced: Any ordinary ammunition produced on a widescale basis, by more than one manufacturer, qualifies for the mass-production price. Any round of 10,000 Joules or less, including caseless and ETC ammunition, which is a military standard-issue qualifies. Other ordinary ammunition may qualify at the referee's discretion.

High-Powered: Any ammunition with a rated energy of more than 10,000 Joules must use the high-powered ammunition price.

Example: The ammunition will be for a new military service pistol, so it will be mass produced. The cost of the ammunition will be 0.38 credits per round.

Ammunition Options: The normal small arms projectile is a solid bullet, termed "ball" by the military. Several types of projectile are available, at the costs indicated on **Table 42: Ammunition Options.**

Hollow-Point: Hollow-point ammunition expands or fragments on impact, causing increased wounding, at the expense of armor penetration. Militaries do not use it, but it is available on the civilian market, and it is widely used by police forces. The poor penetration decreases the chance of hitting a bystander that is located behind the target or unseen behind light cover.

Explosive: High-explosive rounds are hollow and contain an explosive filler that detonates on impact. High-explosive armor-piercing rounds are similar but contain a shaped charge that detonates on impact to penetrate armor. HEAP ammunition over 20mm caliber are available at TL6; ammunition smaller than 20mm is not available until TL9.

Discarding Sabot: Discarding sabot (also called "SLAP," for Saboted, Light Armor-Piercing) ammunition contains a high-velocity bullet that is smaller than the caliber of the weapon, inside a full-diameter sabot (carrier) made of lightweight material. Once clear of the barrel, the sabot falls away, leaving the bullet with the bulk of the energy. The bullet is typically designed for excellent penetration of hard armors.

Tranq: Tranquilizer rounds are a nonlethal means of subduing adversaries.

Flechettes: Flechettes are small-finned darts, machined to precise tolerances, with superior ballistics. They are designed to have enhanced penetration of cloth armor and efficiently produce wounds.

Example: Hollow-point rounds in this caliber will be produced for the civilian market, but military weapons will use ordinary "ball" ammunition.

Designation: Ammunition is frequently referred to by the caliber and the cartridge case length. Thus, a 7.65 caliber pistol cartridge that has a 25mm case would be designated 7.62x25mm. Some ammunition has a common name derived from the manufacturer or weapon it is used in. 7.62x25mm ammunition is also known as "7.62 Tokarev" because it is usually fired from the Tokarev pistol.

As a general rule, weapons can only fire the specific ammunition that they are designed for. If the designators differ, the ammunition is not interchangeable. For example, a weapon designed for 7.62x51mmR (.30-30) cartridges cannot fire 7.62x51mm (7.62 NATO) ammunition. Compatible ammunition can be produced if the designer specifically notes the compatibility and restrictions. For example, revolvers designed for 9x33mmR (.357 Magnum) ammunition can also fire 9x29mmR (.38 Special), but weapons designed for 9x29mmR cannot fire the more powerful 9x33mmR.

Special Features: Special features of the cartridge design are designated by a letter following the dimensions. Rimmed, semi-rimmed, and belted features can be added to a design at no cost. Caseless ammunition can be designed at TL8 or higher, and ETC capability is available at TL9 and above. Both of these capabilities must be designed into the cartridge from the beginning of the sequence.

Rimmed: Rimmed cartridges have a rim at the base which assists in extracting the spent cartridge case from the receiver of the weapon. Revolvers almost always use rimmed ammunition for ease of extraction from the cylinder. (Double the time required to reload a revolver that doesn't use rimmed ammunition.) Most ammunition designed before TL5 is rimmed. The cartridge case rims jam easily when fed into automatic weapons, so most modern cartridge designs are rimless.

Semi-Rimmed: Semi-rimmed cartridges have a recessed rim at the base, in an attempt to combine the ease of extracting rimmed cartridges and the ease of feeding rimless cartridges. Semi-rimmed cartridges are typically designed at TL5 for early automatic weapons.

Belted: Belted cartridge cases are reinforced with belts of thicker metal to prevent the cartridge from becoming deformed by the high pressures encountered at energies of about 10,000 joules. Most high-energy cartridges are belted.

ETC: Electrothermal-chemical (ETC) cartridges can only be fired from weapons intended for ETC ammunition.

Caseless: Caseless cartridges have no cartridge case. Instead, they use one of several methods of dispensing with the case. They may use a special case material that is entirely consumed when the propellant burns, or a plastic binder that is mixed with the propellant and holds the bullet and primer in one solid block, or they may use a propellant that is mechanically strong enough to hold the bullet and primer and be fed into the receiver of the weapon. See Table 43.

Historic Equivalents: For convenience, a number of historic equivalents are listed in **Table 44: Historic Equivalents.**

The .44-40, .45 Colt, and .50-140 Sharps cartridges are late TL3 metallic cartridges that use black powder propellant. The .30-30 is a good example of early TL4 designs with the new smokeless propellant.

Example: The example ammunition will be designated 11.5x23mm (not-so-coincidentally extremely similar to the familiar .45 Colt ammunition).

Firearms

Even in the far future, one of the most effective ways to damage many targets, including living organisms, is to hit it with a large dose of kinetic energy from a small, fast-moving projectile. Conventional firearms use gasses from burning propellants to rapidly accelerate a projectile (frequently made of lead or some other commonly available dense material) to high speeds.

Preliminary Considerations

You should decide on the ammunition your weapon fires. This determines the caliber, and it constrains the design in several other ways. If no existing ammunition is suitable, you can design new ammunition for it. You will need all of the information from the "Ammunition Evaluation" section, above, to design a weapon that fires that ammunition. The technology level of the weapon may be the same TL as the ammunition, or any higher TL.

Example: A handgun will be designed at TL5 to fire the 11.5x23mm ammunition designed earlier.

Barrel: Barrels can be rifled or smoothbore. Rifled barrels have spiral grooves that spin the bullet for greater ballistic accuracy. Rifled barrels are available beginning at TL3. Ordinary (nonpatched) spherical bullets cannot engage the rifling and are usually fired from smoothbore barrels. All shotguns have smoothbore barrels as well.

Length: Select an actual length for the barrel of your weapon. The length of the barrel may be any length from 20% to 250% of the length of the ideal barrel. This is Len_{barrel}. Compute Mod_{blen}, the barrel-length modifier.

Equation 10: Barrel-Length Modifier

$$Mod_{blen} = \frac{Len_{barrel}}{Len_{ideal}} - 1$$

Mod_{blen} is the barrel-length modifier (a dimensionless number). Len_{barrel} is the actual length of the barrel in centimeters, Len_{ideal} is the length of the ideal barrel for the ammunition, in centimeters.

Example: The pistol will have a 10cm barrel. The barrel length modifier is 0.

Mass: Two types of barrels are possible: heavy and light. Heavy barrels are required for most black-powder weapons, machine guns, and other weapons intended for high sustained rates of fire, or which have a muzzle energy greater than 5,000 joules. Heavy barrels are recommended (but not required) for weapons that mount a bipod. Smoothbore barrels (including black-powder shotguns) are usually light.

In Table 45, Mass is in kilograms per centimeter of barrel. Multiply the actual barrel length by the mass per centimeter to find the total barrel length.

Example: The barrel for the example handgun will mass 0.2kg.

Price: Multiply the price per kilogram by the barrel mass in kilograms to find the cost of the barrel in credits. See Table 46.

Example: The barrel will cost 40 credits.

Muzzle Energy: Compute actual muzzle energy, E_{muzzle}, in joules.

Equation 11: Actual Muzzle Energy

$$E_{muzzle} = E_{rated} \times (1 + \frac{Mod_{blen}}{2})$$

Example: The actual muzzle energy will be the same as the rated muzzle energy (500J) because the actual barrel is the same length as the ideal barrel.

Options:

Advanced Materials: Most weapons, even at higher technology levels, are constructed of similar materials. The advanced materials available at high technology levels can reduce the weight of the weapon barrel without compromising the strength of the weapon. Multiply the weight and price of the barrel by the appropriate modifier from **Table 47: Advanced Barrel Materials.**

Nonmetallic Weapons: At TL6 and above, it is possible to construct a weapon out of entirely nonmetallic components. Multiply the final price of all components (including ammunition, sights, magazines, and so forth) by 3. Barrels and receivers that are constructed from advanced materials are already of nonmetallic construction.

Sound Suppression: Sound suppressers effectively muffle the sound of the weapon firing while leaving the speed (and therefore the energy) of the bullet effectively unmodified. Low-energy cartridges (equivalent to a 15mm nonETC cartridge) are subsonic and effectively silent if fired from a suppressed weapon. Cartridges with higher energies than these fire supersonic bullets, and the "crack" of the bullet (a miniature sonic boom) is clearly audible to the targets.

Silencers reduce the muzzle velocity of the bullet to subsonic speeds in addition to muffling the sound of the cartridge firing. The actual muzzle energy of a silenced weapon should be reduced to the value that would result from firing a 15mm, nonETC cartridge of the same caliber.

Firefights conducted with suppressed weapons are not heard beyond 500 meters in open countryside or 100 meters in urban areas. Truly silenced weapons (suppressed weapons firing subsonic bullets or silenced weapons) are not heard beyond 25 meters in the open or 5 meters in urban areas.

A *flash suppresser* reduces or eliminates muzzle flash. All firearms have a muzzle flash at night. Weapons with an actual muzzle energy of 1,000J or more have a visible daytime flash when firing from cover or darkened areas. All weapons with a muzzle energy of 1,000J or more and a barrel that is shorter than 80% of the ideal barrel length for the ammunition used has a bright muzzle flash that's visible under all conditions. A standard flash suppresser reduces the muzzle flash by one category; a long flash suppresser reduces it by two categories.

In Table 48, length is in centimeters per kJ (1,000 joules) of actual muzzle energy. Mass is in kilograms per kJ of actual muzzle energy. Cost is in credits per kJ of actual muzzle energy.

Muzzle Brakes and Recoil Compensators: Recoil is the reaction force felt by the firer of a slug-throwing weapon. Because of the design of the grips and stocks, the muzzle of the weapon tends to rise, making subsequent shots less accurate. The problem is particularly noticeable during rapid or sustained firing. Muzzle brakes divert gasses from the propellant towards the rear of the weapon, to counteract the force of the recoil, and work directly against the recoil force. Recoil compensators divert gasses upward, counteracting the tendency of the muzzle to rise and making the weapon more controllable during sustained fire.

Muzzle brakes can be combined with flash suppressers. Add the cost of the two items; use the length of the longer device and the mass of the heavier of the two.

In Table 49, Mod_{recoil} is the recoil modifier number (used during the weapon evaluation). Length is the length of the brake in centimeters. Mass is the mass in kilograms. Price is price in credits.

Lock or Receiver: Weapons that fire metallic cartridges have a receiver that accepts the cartridge and holds it in place for firing. Early weapons have a lock mechanism that fires the powder charge.

Locks: Select a lock from the table. All locks have no length (unlike receivers, they do not add to the overall length of the weapon), and a fixed weight, price, and reload time. Because of the broad nature of **Traveller** technology levels, several locks are listed at each TL. The locks are listed in the order that they are generally developed, so that referees can determine which types are available on a given world.

In Table 50, Mass is in kilograms. Price is in credits. Reload time is in seconds. In addition, add five seconds to the reload time if the weapon fires loose powder and bullets. Add an additional five seconds if the weapon fires patched ball bullets.

Receivers—Type and ROF:

Single-Shot: Single-shot actions require the user to reload the weapon after every shot and can take many forms. All of these actions fire one round per pull of the trigger.

Revolvers: Revolvers contain several rounds of ammunition—each round in its own firing chamber—in a cylinder. After a shot is fired, the cylinder is rotated to bring a new firing chamber into line with the barrel. Revolvers can be single-acting or double-acting. Single-acting revolvers must be manually cocked (rotating the cylinder and cocking the hammer) after each shot. Double-acting revolvers rotate the cylinder and cock themselves during the trigger pull. Both types of revolver fire one shot per pull of the trigger.

Repeaters: Repeating actions (lever, bolt, and pump) fire one shot per pull of the trigger and require some type of manual operation to ready the weapon for the next shot.

Self-Loading: Self-loading actions automatically perform all of the actions required to ready the weapon for another shot. (For this reason, they are also known as "automatics.") The operation of the action can be powered by the recoil energy, by propellant gasses, or by outside electrical or mechanical energy (an electric motor, or in some early designs, a hand crank).

Semi-Automatic: Semi-automatic actions fire one shot per pull of the trigger and ready themselves for the next shot automatically. The trigger must be released fully before the next shot can be fired.

Fully Automatic: Full automatic actions continue to fire at their maximum rate of fire for as long as the trigger is held back. Most fully automatics also have a selector switch that allows the weapon to fire in semi-automatic mode and, in some weapons, allows one of several different rate of fire options to be selected. The rates of fire, in rounds per minute, is selected by the designer. Most weapons larger than 10mm caliber fire 500 rounds per minute or less. Weapons smaller than 10mm typically fire at higher rates, up to 1,000 rounds per minute. Caseless ammunition can be fired even more rapidly, at up to several thousand rounds per minute. The highest rate of fire that can be sustained for long periods of time is 500 rounds per minute (primarily due to heating).

Burst Control: Automatic burst actions were developed to address the extreme ammunition consumption common to fully-automatic weapons. These types of actions fire a fixed number of rounds each time the trigger is pulled. The designer specifies the number of rounds fired per burst. Most burst-mode weapons fire between three and five rounds per pull of the trigger. Some automatic burst weapons have a selector that switches between semi-automatic mode, burst mode, and fully-automatic mode.

Select an action from the table, and note the type of receiver required. Weapons with actions that require heavy receivers, machine guns, and other weapons that operate primarily (or exclusively) on the full-automatic setting must have a heavy receiver. All belt-fed and cassette-fed weapons must have a heavy receiver. Weapons that only operate in semi-automatic fire, or which are selective fire, may use light receivers (but are not required to do so).

In Table 51, Type is the type of receiver that is used with this type of action. All actions may use a heavy receiver; only those noted can use a light receiver. The mass of light receivers can always be increased (to improve recoil characteristics or to increase the number of chambers in the cylinder in the case of revolvers).

Example: The example handgun will have a TL5 semi-automatic receiver. This will be a light receiver, since a heavy receiver isn't needed.

Receivers—Length: Calculate the minimum length of the receiver in cm. The minimum length is the overall length of the ammunition the receiver will fire, or the length computed (whichever is larger). Weapons that will use a box magazine must have receivers that are 150mm (15cm) longer than the length of the ammunition.

Equation 12: Minimum Receiver Length

$$Len_{mrec} = Mod_{rtech} \leftrightarrow \sqrt{E_{rated}}$$

Example: The receiver must be at least 12.3cm long, but because this weapon will use a box magazine in the pistol grip, the receiver will be 18.45cm long.

Receivers—Mass: Compute the minimum mass for a light receiver using the following formulas.

Low Power: Low-power receivers are those that fire ammunition with a rated energy of 1,000 joules or less.

Equation 13: Low-Power Receiver Mass

$$Mass_{mlrec} = \frac{E_{rated}}{800}$$

Example: The minimum mass for the receiver (at minimum length) is 0.625kg.

Standard Power: Standard receivers are those that fire ammunition with a rated energy greater than 1,000 joules.

Equation 14: Standard Receiver Mass

$$Mass_{mlrec} = 1.25 + \frac{(E_{rated} - 1000)}{1000}$$

Heavy Power: The minimum mass for a heavy receiver is twice the mass of a light receiver computed above.

Adding Mass: Receivers can be constructed at greater masses than the minimum. The mass of a light receiver can be increased (without increasing the length of the receiver) until it has the same mass as a heavy receiver. A heavy receiver can only be made more massive by lengthening the receiver.

Adding Length: Any receiver can be lengthened, increasing the mass of the receiver. Select any length greater than the minimum. Multiply the mass of the receiver by the proportional increase in the length. (If you increase the length by 10%, increase the mass and cost by 10%.)

Example: Our receiver was lengthened from the minimum. The increase in length was 50% (exactly), increasing the mass of the receiver by 50% to 0.938kg.

Receivers—Price: Multiply the mass of the receiver by the price per kilogram. See Table 53.

In Table 53, the automatic price applies to any automatic action (semi-automatic, full automatic, or automatic burst) that has only one rate of fire option (a weapon that fires only at semi-automatic, or only at full automatic, or only an automatic burst). Selective fire prices apply to any automatic action that has two fire options. Multiselective fire action prices apply to any automatic action that has three or more fire options.

Example: The pistol has only one rate of automatic fire (semi-automatic), so the receiver costs 187.6 credits.

Receivers—Options:

Shotguns: Multiply the mass and price of shotgun receivers by 0.6.

Advanced Materials: Most weapons, even at higher technology levels, are constructed of similar materials. The advanced materials available at high technology levels can be reduce the weight of the weapon receiver without compromising the strength of the weapon. Multiply the weight and price of the receiver by the appropriate modifier from **Table 54: Advanced Receiver Materials.**

ETC: Halve the mass and price of ETC receivers, and add an ETC firing assembly to the weapon. The ETC firing assembly masses 0.3kg, costs 200 credits, and adds no length to the weapon. If using advanced materials, adjust the mass and price of the receiver for the advanced materials before applying the ETC modifiers.

Doubles: Any weapon using a single-shot (individually loading) action may have more than one barrel. Each barrel must have its own receiver, but only one stock or grip is needed. The barrels need not be identical in caliber, but must be the same length.

Multiple-Barrel Weapons: The maximum rate of fire that can be sustained over a long period is 500 rounds per minute. However, it is possible to design weapons that can deliver a higher overall rate of fire by using a multiple barrel rotary gun. These weapons may have as many barrels as desired, but all barrels must be identical.

Rotary guns must have a heavy receiver, and the mass of the receiver is increased by 10% for every barrel. (For example, a three-barrel gun has a receiver 30% more massive than a normal heavy receiver at that caliber and energy.)

Compute the maximum rate of fire:

Equation 15: Multiple-Barrel Rate of Fire

$$ROF_{\max} = 500 \leftrightarrow (Num_{barrels} - 1)$$

ROF_{max} is the maximum rate of fire, in rounds per minute. $Num_{barrels}$ is the number of barrels.

Stocks and Sights: Most small arms require some type of stock. Weapons that are mounted in vehicles and fired remotely do not require stocks. Select a stock from the "Weapon Accessories" component chapter (page 61). Basic "iron" sights are assumed to be included with every firearm; if other types of sights are desired, select them from the "Weapon Accessories" chapter.

Example: The weapon will be equipped with TL5 hollow pistol grips.

Options: Some small arms have bipod or tripod mounts available.

Bipod: Bipod mounts are may be custom designed for the weapon. Bipods mass 10% of the weapon's empty mass but at least 0.5kg. Bipods cost 50 credits, plus 10 credits per kilogram of bipod mass. Weapons must be at least 35cm in overall length to mount a bipod.

Tripod: Tripods may be any mass, but the tripod mass (in kilograms) must be at least equal to the highest recoil number for all of the weapon's fire modes (calculated below). Tripods cost 100 credits, plus 10 credits per kilogram of tripod mass.

Bayonet: A bayonet lug has negligible cost, mass, and length but must be specified as part of the design process. Only weapons with a bulk of 4 or more may profitably use a bayonet lug. TL2 weapons suffer a penalty when using a bayonet, due to their bulky and heavy stocks.

Grenade Adapter: A grenade adapter allows the firing of rifle grenades and adds 5cm to the length of the weapon, at a cost of 50 credits.

Feed System:

Type: Several types of feed systems are available, from none at all to high-capacity ammunition cassettes. The type of feed system should be matched to the type of action the weapon is equipped with, and the weapon's mission.

Single-Shot: Single-shot weapons have no magazine. Individual cartridges (or loose powder and bullets) are loaded directly into the weapon. There is no weight or cost for this feed system beyond that of the individual rounds carried by the weapon operator.

Revolver: A cylinder is the magazine of a revolver, but it's mass is included in the mass of the receiver (so there is no additional weight or cost for this feed system beyond that of the individual rounds). Calculate the capacity of the cylinder in rounds.

Equation 16: Revolver Cylinder Capacity

$$Cap_{cylinder} = \frac{19}{\sqrt{Cal}}$$

$Cap_{cylinder}$ is the capacity of the cylinder in rounds. Cal is the weapon's caliber in millimeters.

Belt: Belts are linked rounds fed directly into the receiver. Only heavy self-loading (automatic) receivers may be belt fed. Belts may be made with any practical capacity, although 100 rounds is common. The mass and cost of the links or webbing is negligible, so there is no weight or cost for this feed system beyond that of the individual rounds.

Cassette: A cassette is a prepackaged container of ammunition attached to an endless link feed system which moves the ammunition into the weapon. Only heavy self-loading (automatic) receivers may be cassette fed. Cassette feed systems are available at TL7 and above.

A cassette feed system masses 2 kilograms (plus the mass of the ammunition contained in the cassette), and the cost of the empty cassette is equal to 500 times the cost of a single round of ammunition. Due to the overhead of the power and feed systems, cassettes typically hold 1,000 or more rounds.

Box: A weapon may only have a box magazine if it the receiver is 150mm longer than the length of the ammunition. The magazine may have any number of rounds desired by the designer. Mechanical considerations limit most successful designs to 200 rounds for ammunition massing less 15 grams or less per round, or 100 rounds for more massive ammunition.

Compute the magazine mass (in grams). Divide by 1,000 to find the mass in kilograms.

Equation 17: Magazine Mass

$$Mass_{mag} = \frac{Mass_{ammo} \times (N_{rounds} + 4)}{3}$$

$Mass_{mag}$ is the mass of the empty magazine (in grams). $Mass_{ammo}$ is ammunition mass in grams. N_{rounds} is the number of rounds in the magazine.

Box magazines cost 10 credits per kilogram of empty mass.

Grip Magazine: A grip magazine is a box magazine inserted into the weapon through a hollow pistol grip. Grip magazines may not contain necked cartridges. If the magazine is to fit entirely within the grip, there is a limit to the number and length of the rounds it can contain.

Divide the capacity factor from the table by the caliber of the round to determine the maximum number of rounds that can be stored in a grip magazine.

In Table 55, max length is the maximum length of the ammunition that can be stored in a grip magazine at that TL.

Example: The pistol will use a box magazine (located in the pistol grip) that holds seven rounds. The mass of the (empty) box magazine will be 0.07kg (70 grams) and the cost will be 0.7 credits. Our box magazine contains seven rounds that are shorter than 40mm, so we may use it as a grip magazine.

Clip-Fed Magazine: Some weapons have permanently attached internal box magazines. These magazines are reloaded using a metal clip holding a number of rounds. The clip is discarded after reloading or, in some weapons, it is retained internally and automatically ejected when the last round is fired. The clip itself has negligible mass and cost; the internal magazine is designed like any other box magazine. The clip can hold as many rounds as desired by the designer, up to a practical limit of 10.

Tubular Magazine: A tubular magazine is a hollow, spring-loaded tube into which the individual rounds are loaded. Tubular magazines are long and must be mounted parallel to the barrel (over, under, or to the side of it) or in the stock. The maximum length of a tubular magazine is the length of the barrel, or if mounted in the stocks, the length of the stock.

Use **Equation 17: Magazine Mass** to compute the mass of a tubular magazine in kilograms.

ETC Feed Systems: ETC weapons may only be fed by box magazine, belt, or cassette systems. In all cases, a power source is included with the feed device. Belts for ETC systems are packaged in ammunition boxes, which also contain the power pack. The table below lists the cost and mass of the power source per round (in addition to the basic feed device) at each tech level. The cost is 5 credits per round.

When computing the capacity of grip magazines for ETC weapons, using Table 56, the power source occupies the space of approximately one round, reducing the maximum capacity of grip magazines by one. Power packs for ETC weapons are reusable and rechargeable.

Weapon Evaluation:

Length: Total the lengths of all of the components of the weapon. This is the overall length of the weapon. Divide the weapon length in centimeters by 15 (dropping fractions) to determine the bulk of the weapon.

Example: The length of the weapon is 28.45cm; bulk is 1.

Mass: Total the masses of all of the components of the weapon. This is the total unloaded mass of the weapon. The loaded mass is equal to the unloaded mass, plus the mass of the ammunition carried in the weapon's feed device. Some weapons have several feed device options, and have correspondingly different loaded masses.

Example: The mass of the weapon is 1.238kg empty (without magazine or ammunition) and 1.442kg loaded.

Price: Total the prices of all of the components of the weapon.

Example: The price of the weapon is 253.1 credits, including one empty magazine.

Range: Compute the basic range (using iron sights) of all weapons. Weapons that have optional sights (such as advanced sights or optic sights) should have their ranges calculated with this configuration as well. In no case can any range (regardless of sights or mounts) exceed 300 meters.

Equation 18: Basic Range

$$R_{basic} = (1 + (Mod_{blen} \times Mod_{bscale})) \times Mod_{config} \times \sqrt{E_{muzzle}}$$

R_{basic} is the basic range in meters. Mod_{blen} is the barrel length modifier. Mod_{bscale} is 0.75 if Mod_{blen} is positive, and 1.2 if Mod_{blen} is negative. Mod_{config} is selected from the table below. If more than one configuration modifier applies, multiply them together to find the final configuration modifier. See Table 57.

Example: The weapon has a basic range of 8.9 meters.

Optic Sights: Optic sights multiply the basic range of the weapon as indicated on **Table 154: Optic Sights**. Optic sights may not be used with advanced sights.

Advanced Sights: Advanced sights add to the basic range of the weapon as indicated on **Table 156: Advanced Sights**. Advanced sights may not be used with optic sights.

Mounts: Bipod, tripod, and vehicle mounts extend the range of a weapon. Multiply the range of the weapon by 1.3 when it is fired from a bipod. Double the range of a weapon that is fired from a tripod or a vehicle mount.

Ammunition: When firing some types of ammunition, range may be affected by the type of ammunition. Multiply the final range of the weapon (including any sights or mounts) by the factor listed on **Table 58: Ammunition Range Modifiers** for the type of ammunition.

The range for Tranq rounds cannot be greater than 30 meters or less than 4 meters.

Range Bands: Convert the range (or ranges, in the case of a weapon that has several optional configurations) into range bands using **Table 59: *Traveller* Range Bands.**

Example: A basic range of 8.9 meters indicates a **Traveller** *range band of Very Short.*

Damage:

Ordinary: Weapons with a muzzle energy less than 30,000 joules use **Equation 19: Traveller Damage.**

Equation 19: Traveller Damage

$$D = \frac{\sqrt{E_{eff}}}{10.5}$$

Example: The pistol has a damage of 2.

High-Power: Weapons with a muzzle energy of 30,000 joules or greater use the KEAP penetration table. Convert weapon energy to megajoules (divide by 1,000,000) and use the formula and table below. The computed value is the penetration value at medium range. To determine the penetration value at short range, increase the penetration by 15 or 10% (whichever is less). At long range reduce the penetration value by 15 or 15% (whichever is less), and at extreme range subtract 45, or 45% (whichever is less).

Equation 20: KEAP Penetration Value

$$PV = PV_{base} + Mod_{pv} \times (E_{muzzle} - E_{base})$$

See Table 60.

HE and HEAP: For HE and HEAP rounds, effective energy is the sum of muzzle energy and explosive energy. Determine the effective energy using **Equation 21: HE and HEAP Effective Energy.**

Equation 21: HE and HEAP Effective Energy

$$E_{eff} = E_{muzzle} + (\frac{Cal}{2} + TL - 7)^3$$

HE: The explosive damage of HE rounds applies only to unarmored, or "soft," targets. Compute the damage value against these targets based on the effective energy. When used against armored targets, HE rounds are much less effective. Compute the penetration value of HE rounds using only the muzzle energy of the projectile.

HEAP: The explosive damage of HEAP rounds applies only to armored, or "hard," targets. Compute the penetration value against these targets based on the effective energy. When used against unarmored targets, HEAP rounds are much less effective. Compute the damage value of HEAP rounds using only the muzzle energy of the projectile.

Shotguns: Weapons that fire multiple-projectile ammunition—usually shotguns but possibly also flechette-firing weapons and rifles that fire duplex bullets—divide the muzzle energy by the number of projectiles before computing damage. The damage calculation is then performed, resulting in the damage per projectile. Within the weapon's short range, it is assumed that 75% of the projectiles will hit a human-sized target. Damage can be determined by multiplying the number of projectiles that do hit by the damage per projectile. If the target is armored, armor reduces the damage of each projectile, before they are multiplied.

Recoil: Compute the single-shot recoil number. Higher numbers indicate higher recoil felt by the firer and make sustained, accurate fire more difficult.

Equation 22: Single-Shot Recoil

$$Mod_{rss} = \frac{-0.15 \times \sqrt{E_{muzzle}}}{Mass_{loaded}} + Mod_{energy}) \times Mod_{recoil}$$

Mod_{rss} is the single-shot recoil number. E_{muzzle} is the weapon's muzzle energy in joules. $Mass_{loaded}$ is the loaded mass of the weapon in kilograms. (For belt or cassette fed weapons, use the empty mass $Mass_{empty}$ instead.) Mod_{energy} is the recoil energy modifier from **Table 61: Recoil Energy Modifier.** Mod_{recoil} is the recoil modifier for the weapon's stocks and recoil compensation devices from **Table 49: Muzzle Brakes and Recoil Compensators**. Shock absorbing stocks also serve to reduce recoil and have a Mod_{recoil} as indicated on **Table 153: Shock Absorbers.** Finally, the type of the action may serve to reduce the recoil. Modifier values for actions are listed **on Table 62: Recoil-Compensating Actions.** If more than one Mod_{recoil} applies (a weapon that has a muzzle brake, shock absorber, and a recoil-compensating action), multiply the modifiers together to find the correct combined value.

Example: The weapon has a recoil number of 0.698, which rounds up to 1.

If the weapon can fire more than one round per pull of the trigger, compute the burst recoil number. For weapons that fire in full-automatic mode, compute the value for a 10-shot burst (or the total amount of ammunition carried in the weapon's magazine, whichever is smaller). N_{burst} is the number of rounds fired in the burst.

Equation 23: Burst Recoil

$$Mod_{rburst} = Mod_{rss} \times \frac{N_{burst}}{2}$$

Volume: Weapon volume (for installation in a vehicle) is 1 liter per kilogram of weapon mass (one cubic meter per metric ton).

Gauss Weapons

Conventional firearms accelerate projectiles using the force of expanding gasses from a controlled explosion. These weapons are inherently limited by the rate at which the gasses can expand. Chemically-propelled rounds have an upper limit on muzzle velocity of about 2,000 meters per second.

Electromagnetic weapons have no such limitation. These weapons use electrical energy to power a magnetic accelerator that propels projectiles down the barrel of the gun. For these weapons, the absolute maximum muzzle velocity in an atmosphere is about 6,000 meters per second. At velocities significantly above this, the projectile burns up due to atmospheric friction.

Electromagnetic small arms are called gauss guns and are traditionally less than 20mm in caliber, but this design sequence handles weapons up to 40mm because very-rapid-fire (VRF) weapons up to this caliber are better handled by the small arms design sequence. Larger-bore electromagnetic weapons are known as "mass drivers."

Gauss weapons become possible at TL10 and can be constructed in the same configurations as other small arms: pistols, rifles, carbines, and automatic weapons. Gauss weapons consist of four major components: a barrel which contains the electromagnetic accelerator, a power source, an accumulator that stores energy for each shot, and a stock or mount.

Caliber

Select a caliber for the weapon, between 2mm and 40mm.

Length

Length in millimeters equals caliber multiplied by 5.

Mass

$$Mass_{ammo} = \frac{\pi \times Cal^2}{50}$$

$Mass_{ammo}$ is in grams.

Price

Multiply mass by the price per gram from the table below. A round that is mass-produced by more than one supplier qualifies for the mass-production cost. Any round that is selected as standard-issue for a military service is mass-produced, as is any other round the referee designates. All other ammunition uses the ordinary cost. See Table 63.

Options

Gauss ammunition must be at least 5mm in caliber to support HE, HEAP, or Tranq options. See Table 64.

Barrel

Barrels are rated for muzzle velocity, length, mass, price, muzzle energy, input energy, and stealth.

Muzzle Velocity

Determine TL and select a muzzle velocity. Characteristics of the weapon, including maximum muzzle velocity in meters per second, barrel length modifier, and efficiency at each TL are listed in **Table 65: Gauss Weapon Characteristics.**

Length

The length of the barrel is computed from the desired muzzle velocity, and the barrel length modifier at the constructing TL, using **Equation 24: Barrel Length.**

Equation 24: Barrel Length

$$Len_{barrel} = \frac{Vel_{muzzle}}{100 \leftrightarrow Mod_{blen}}$$

Len_{barrel} is in centimeters. Vel_{muzzle} is muzzle velocity in meters per second.

Mass

Barrels mass 0.03 kg per centimeter.

Price

Barrels cost 600 credits per kilogram.

Muzzle Energy

Equation 25: Muzzle Energy

$$E_{muzzle} = \frac{Mass_{ammo}}{2000} \leftrightarrow Vel_{muzzle}^{2}$$

E_{muzzle} is muzzle energy in joules. $Mass_{ammo}$ is ammunition mass in grams. Vel_{muzzle} is muzzle velocity in meters per second.

Input Energy

Multiply the muzzle energy by the efficiency number. This is the required input energy for a single shot, in Joules.

Stealth

Gauss weapons have no muzzle blast and are therefore automatically silenced. Gauss weapons with a muzzle velocity of 330 meters per second or less are subsonic and therefore inherently suppressed. Gauss weapons never have a muzzle flash under any circumstances.

Receiver

Receivers are rated for type and rate of fire, mass, length, and stocks and sights.

Type and Rate of Fire

All gauss receivers are self-loading: either semiautomatic, fully automatic, or automatic burst. Gauss weapon rates of fire can be very high—up to several-thousand rounds per minute. Weapons with a rate of fire in excess of 1,000 rounds per minute are classed as VRF (very-rapid fire) gauss weapons.

Mass

Divide the input energy by the receiver mass factor, based on the TL of the weapon, to find receiver mass in kg. See Table 66.

Cost: Receivers cost 100 credits per kilogram. If options are installed, modify the price as indicated.

Options: See Table 67.

Length

The minimum length of the receiver is the length of the ammunition or the length calculated from the mass of the receiver, whichever is longer.

Equation 26: Receiver Length

$$Len_{rec} = \sqrt{1000 \leftrightarrow Mass_{rec}}$$

Len_{rec} is the receiver length in centimeters. $Mass_{rec}$ is the mass of the receiver in kilograms.

Stocks and Sights

Most small arms require some type of stock. Weapons that are mounted in vehicles and fired remotely do not require stocks. Select a stock from the "Weapon Accessories" component chapter (page 61). Basic "iron" sights are assumed to be included with every firearm; if other types of sights are desired, select them from the "Weapon Accessories" chapter.

Options: Some small arms have bipod or tripod mounts available.

Bipod: Bipod mounts may be custom designed for the weapon. Bipods mass 10% of the weapon's empty mass but at least 0.5kg. Bipods cost 50 credits, plus 10 credits per kilogram of bipod mass. Weapons must be at least 35cm in overall length to mount a bipod.

Tripod: Tripods may be any mass, but the tripod mass (in kilograms) must be at least equal to the highest recoil number for all of the weapon's fire modes (calculated below). Tripods cost 100 credits, plus 10 credits per kilogram of tripod mass.

Bayonet: A bayonet lug has negligible cost, mass, and length but must be specified as part of the design process. Only weapons with a bulk of 4 or more may profitably use a bayonet lug. TL2 weapons suffer a penalty when using a bayonet due to their bulky and heavy stocks.

Grenade Adapter: Gauss weapons cannot launch ordinary rifle grenades, so a grenade adapter cannot be fitted. Launchers for self-propelled grenades can be added to the design, however.

Feed System

Gauss weapon magazines are more complex because they must hold a power source as well as the ammunition. The designer must select a number of rounds for the feed system to contain, and design the power source for the gauss weapon.

Power Source

Gauss weapons can draw power from either batteries or external sources.

Battery: Most gauss small arms are powered by batteries built into the feed device. Battery mass is measured in kilograms. Note that these equations are a simplified version of the battery mass design sequence presented in the "Power Systems" components chapter (page 81), and they approximate a battery with a one-second discharge time. If the designer desires, special-purpose batteries can be designed to power gauss weapons.

Example: A gauss hunting rifle is intended to fire single shots at a relatively low rate of fire (six rounds per minute). The magazine holds 12 rounds of ammunition; the weapon's battery is designed to hold enough energy to fire 12 shots and has a discharge time of two minutes. See Table 68.

Equation 27: Battery Mass

$$Mass_{battery} = \frac{N_{rounds} \leftrightarrow E_{input}}{Mod_{btech}}$$

External: The input power (in Watts) can be found by multiplying the input energy per shot (in joules) by the rate of fire (in rounds per minute) and dividing by 60.

Equation 28: Gauss Gun Input Power

$$Power = \frac{E_{input} \leftrightarrow ROF}{60}$$

Magazine Type

Gauss weapons use cassettes, box magazines, and grip magazines.

Cassette: A cassette feed system masses 2 kilograms, plus the mass of the battery contained in the cassette (if the weapon is battery-powered). Cassettes cost 10 credits per kilogram of empty mass. (Include the mass of the battery in the empty mass, but don't include the mass of the ammunition.) Remember to include the mass of the ammunition in the mass of a loaded cassette. Due to the overhead of the power and feed systems, cassettes typically hold 1,000 or more rounds.

Box Magazine: A weapon may only have a box magazine if it the receiver is 150mm longer than the length of the ammunition. The magazine may have any number of rounds desired by the designer. Mechanical considerations limit most successful designs to less than 200 rounds for ammunition that masses 15 grams or less per round, or 100 rounds for more massive ammunition.

Compute the magazine mass (in kilograms).

Equation 29: Magazine Mass

$$Mass_{mag} = \frac{Mass_{ammo} \leftrightarrow (N_{rounds} + 4)}{3} + Mass_{battery}$$

$Mass_{mag}$ is the mass of the empty magazine (in kilograms). $Mass_{ammo}$ is ammunition mass in grams. N_{rounds} is the number of rounds in the magazine.

Box magazines cost 10 credits per kilogram. (Empty mass includes the mass of the battery but not of the ammunition.)

Grip Magazine: A grip magazine is a box magazine inserted into the weapon through a hollow pistol grip. If the magazine is to fit entirely within the grip, there is a limit to the number and length of the rounds it can contain. The maximum length for the ammunition is 60mm. Divide the 140 by the caliber of the round to determine the maximum number of rounds that can be stored in a grip magazine.

Weapon Evaluation

Gauss weapons are rated for length, mass, price, range, recoil, and volume.

Length

Total the lengths of all of the components of the weapon. This is the overall length of the weapon. Divide the weapon length in centimeters by 15 (dropping fractions) to determine the bulk of the weapon.

Mass

Total the masses of all of the components of the weapon. This is the total unloaded mass of the weapon. The loaded mass is equal to the unloaded mass plus the mass of the ammunition carried in the weapon's feed device. Some weapons have several feed device options and have correspondingly different loaded masses.

Price

Total the prices of all of the components of the weapon.

Range

Compute the basic range (using iron sights) of all weapons. Weapons that have optional sights (such as advanced sights or optic sights) should have their ranges calculated with this configuration as well. In no case can any range (regardless of sights or mounts) exceed 300 meters.

Equation 30: Gauss Gun Basic Range

$$R_{basic} = 1.2 \leftrightarrow Mod_{config} \leftrightarrow \sqrt{E_{muzzle}}$$

R_{basic} is the basic range in meters. Mod_{config} is selected from the table below. If more than one configuration modifier applies, multiply them together to find the final configuration modifier. See Table 69.

Optic Sights: Optic sights multiply the basic range of the weapon as indicated on **Table 154: Optic Sights**. Optic sights may not be used with advanced sights.

Advanced Sights: Advanced sights add to the basic range of the weapon as indicated on **Table 156: Advanced Sights**. Advanced sights may not be used with optic sights.

Mounts: Bipod, tripod, and vehicle mounts extend the range of a weapon. Multiply the range of the weapon by 1.3 when it is fired from a bipod. Double the range of a weapon that is fired from a tripod or a vehicle mount.

Ammunition: When firing some types of ammunition, range may be affected by the type of ammunition. Multiply the final range of the weapon (including any sights or mounts) by the factor listed on **Table 70: Ammunition Range Modifiers** for the type of ammunition. The range for Tranq rounds cannot be greater than 30 meters or less than 4 meters.

Range Bands: Convert the range (or ranges, in the case of a weapon that has several optional configurations) into range bands using Table 71.

Ordinary Damage: Weapons with a muzzle energy less than 30,000 joules use **Equation 31: Traveller Damage.**

Equation 31: Traveller Damage

$$D = \frac{\sqrt{E_{eff}}}{10.5}$$

High-Power Damage: Weapons with a muzzle energy of 30,000 joules or greater use the KEAP penetration table. Convert weapon energy to megajoules (divide by 1,000,000) and use the formula and table below. The computed value is the penetration value at medium range. To determine the penetration value at short range, increase the penetration by 15 or 10% (whichever is less). At long range reduce the penetration value by 15 or 15% (whichever is less), and at extreme range subtract 45 or 45% (whichever is less). See Table 72.

Equation 32: KEAP Penetration Value

$$PV = PV_{base} + Mod_{pv} \leftrightarrow (E_{muzzle} - E_{base})$$

HE and HEAP Damage: For HE and HEAP rounds, effective energy is the sum of muzzle energy and explosive energy. Determine the effective energy **using Equation 21: HE and HEAP Effective Energy**.

Equation 33: HE and HEAP Effective Energy

$$E_{eff} = E_{muzzle} + (\frac{Cal}{2} + TL - 7)^3$$

HE: The explosive damage of HE rounds applies only to unarmored, or "soft," targets. Compute the damage value against these targets based on the effective energy. When used against armored targets, HE rounds are much less effective. Compute the penetration value of HE rounds using only the muzzle energy of the projectile.

HEAP: The explosive damage of HEAP rounds applies only to armored, or "hard," targets. Compute the penetration value against these targets based on the effective energy. When used against unarmored, targets, HEAP rounds are much less effective. Compute the damage value of HEAP rounds using only the muzzle energy of the projectile.

Recoil

Compute the single-shot recoil number. Higher numbers indicate higher recoil felt by the firer and make sustained, accurate fire more difficult.

Equation 34: Single-Shot Recoil

$$Mod_{rss} = \frac{-0.15 \leftrightarrow \sqrt{E_{muzzle}}}{Mass_{loaded}} + Mod_{energy} \begin{matrix}\surd \\ \hookleftarrow\end{matrix} \leftrightarrow \frac{Mod_{recoil}}{2}$$

Mod_{rss} is the single-shot recoil number. E_{muzzle} is the weapon's muzzle energy in joules. $Mass_{loaded}$ is the loaded mass of the weapon in kilograms. (For belt or cassette fed weapons, use the empty mass $Mass_{empty}$ instead.) Mod_{energy} is the recoil energy modifier from **Table 73: Recoil Energy Modifier**. Mod_{recoil} is the recoil modifier for the weapon's stocks and recoil compensation devices **from Table 49: Muzzle Brakes and Recoil Compensators**. Shock absorbing stocks also serve to reduce recoil and have a Mod_{recoil} as indicated on **Table 153: Shock Absorbers**. Finally, the type of the action may serve to reduce the recoil. Modifier values for actions are listed **on Table 62: Recoil-Compensating Actions**. If more than one Mod_{recoil} applies (a weapon that has a muzzle brake, shock absorber, and a recoil-compensating action), multiply the modifiers together to find the correct combined value.

In Table 73, if the weapon can fire more than one round per pull of the trigger, compute the burst recoil number. For weapons that fire in full-automatic mode, compute the value for a 10-shot burst (or the total amount of ammunition carried in the weapon's magazine, whichever is smaller). N_{burst} is the number of rounds fired in the burst.

Equation 35: Burst Recoil

$$Mod_{rburst} = Mod_{rss} \leftrightarrow \frac{N_{burst}}{2}$$

Volume

Weapon volume (for installation in a vehicle) is 1 liter per kilogram of weapon mass (1 cubic meter per metric ton).

Heavy Weapons

This section describes warheads, chemically propelled slug-throwers, mass drivers, high-energy weapons, and battlefield missiles.

Warheads

Heavy weapons, which include both large-caliber direct fire weapons and indirect fire (artillery) weapons, can fire a wide variety of warheads. Each type of warhead is intended for a specific purpose, and many heavy weapons are equipped with a supply of various types of ammunition. Mass drivers fire an unadorned warhead directly while chemically-propelled round (CPR) artillery require a propellant charge that is fired to propel the warhead from the barrel of the gun.

The warhead design sequence can also be used to design warheads for other types of munitions, including aircraft bombs, battlefield missiles, grenades, and unguided rockets. The major types of warheads are summarized below.

Standard Warheads

Design warheads for use with CPR guns, rockets, grenades, mass drivers, aerial bombs, and so on. The design sequence proceeds from the warhead diameter, TL and type. See Table 74.

Damage and Penetration: Unlike small arms, warheads have two ratings: damage value and penetration value. Damage value indicates how much damage is inflicted upon "soft" targets within the round's burst radius. In other words, if a character is standing nearby when a shell explodes (and "nearby" is defined by the shell's burst radius), he suffers damage according to the shell's damage rating.

Penetration value indicates how much armor the round can penetrate (and still damage the vehicle or anything else that might be behind the armor). Penetration values are listed in terms of **Traveller** armor ratings; a round with a penetration of 9 could penetrate (for example) a tracked AFV with an armor rating of 9 and still retain enough energy to damage equipment or people inside. Divide by 1.43 to determine penetration in terms of centimeters of steel.

Explosive

Explosive warheads consist of a hollow projectile that is filled with explosives. Explosive warheads include high explosive (HE), high explosive armor piercing (HEAP), and self-forging penetrator (SeFoP). Explosive warheads may be any size, 2cm or greater.

HE: High-Explosive warheads, also known as "high-explosive dual-purpose" (HEDP), is perhaps the most common type of warhead in use. The warhead is filled with an explosive bursting charge, and the casing is frequently scored or segmented so that it separates into many small, lethal fragments (called shrapnel). HE warheads may be equipped with fuses set to explode on impact, at a given altitude or proximity (for use against aircraft), or after a certain time delay.

HEAP: Although high-velocity solid penetrators are effective at penetrating armor, they rely almost exclusively on the muzzle energy of the gun to pierce armor. This requires a massive gun system, which is not very suitable for an infantryman to carry. One solution is to produce a shaped explosive charge that relies on the energy generated by the explosive to penetrate armor.

A HEAP round has a hollow cavity, recessed into the front of the explosive and lined with metal. When the explosive detonates, the shape of the charge tends to focus the molten metal from the liner into a high-speed jet that penetrates the armor.

SeFoP: A self-forging penetrator (SeFoP) round is similar to a HEAP round in that the warhead gains its penetrating energy from the force of an explosion. The penetrator is much more massive than that created by a shaped charge explosion, and the charge fires when it is farther away from the target. The stream of molten metal becomes dart-shaped and hardens due to atmospheric resistance as it travels toward the target.

Damage: Compute the explosive damage value of the warhead using **Equation 36: Explosive Damage Value.** Modifiers for the warhead TL are found on **Table 75: TL Damage Modifier** while modifiers for the type of warhead are located on **Table 76: Explosive Warhead Type.**

Equation 36: Explosive Damage Value

$$D = \frac{Cal^2 \leftrightarrow Mod_{ammotl}}{Mod_{whtype}}$$

Burst Radius: See Tables 77 and 78.

Equation 37: Explosive Warhead Burst Radius

$$Rad_{bprim} = \frac{Mod_{mtype} \leftrightarrow \sqrt{D}}{Mod_{brwhtype}}$$

Penetration: Multiply the bore size (in centimeters) by the penetration modifier listed below. Note that HE rounds have a constant modifier (regardless of TL) while HEAP and SeFoP rounds have a modifier dependent on TL. See Table 79.

KEAP

The earliest CPR artillery was used in siege work to batter down the enemy's walls, and so penetration of armor has been an issue in gun design since the very beginning. In general, a solid projectile penetrates armor by means of the kinetic energy provided by the gun. The greater the muzzle energy, the greater the penetration, all other things being equal. KEAP warheads may be any size, 2cm or greater.

All other things are seldom equal, however. There are limits to the penetration ability of solid shot, centering around the ability of the shot to withstand the impact with the armor. Beyond a certain velocity, solid shot will simply shatter against armor plate. Various design innovations (such as hard steel armor-piercing caps) appear at higher TLs, improving the shot's ability to penetrate armor.

The next step forward is to concentrate the muzzle energy of the round over a smaller surface area. This is accomplished by embedding a small penetrator within a larger, lightweight outer shell. The lower mass of the projectile results in a higher velocity, so these rounds are usually called high-velocity armor piercing (HVAP). HVAP ammunition is relatively hard to manufacture since the penetrator has to be a particularly resistant material. HVAP also suffers from a shorter range since the full-caliber round has a high drag relative to its mass.

Ultimately, it is possible to discard the lightweight outer shell (now called a "sabot"), leaving the much smaller penetrator which doesn't suffer from the range limitation. The disadvantage to discarding sabot rounds is that they are harder to stabilize, but once fin-stabilized penetrators become available at TL7, the discarding sabot round becomes the penetrator of choice. Additional developments increase the muzzle velocity of the penetrator by firing it from a smoothbore barrel and increasing the mass of the penetrator by constructing it from increasingly dense materials.

Damage: Multiply the caliber of the round (in centimeters) by 2.2 to determine the damage value. Use this value only if the round strikes a "soft" target such as unarmored personnel.

Burst Radius: KEAP rounds don't explode, so they don't have a burst radius.

Penetration: Determine the penetration value of a TL4 KEAP round using **Equation 38: KEAP Penetration Value** and **Table 80: KEAP Penetration Modifiers.** If the round is constructed at a higher TL, modify the penetration value by the KEAP technology modifier found on **Table 81: KEAP Penetration TL Modifier.**

Equation 38: KEAP Penetration Value

$$PV = PV_{base} + Mod_{pv} \leftrightarrow \left(E_{muzzle} - E_{base}\right)$$

In Table 80, the computed value is the penetration at medium range. At short range, increase the penetration by 15 or 10% (whichever is less). At long range, reduce the penetration by 15 or 15% (whichever is less). At extreme range, subtract 45 or 45% (whichever is less). See Table 81.

Chemical

Chemical (Chem) warheads are hollow and filled with a chemical agent. This agent may be toxic (poison gas or biological warfare agents) or a smoke-generating compound. In both cases the design of the warhead is identical, although the effects of the agent are very different. Most chemical rounds are base-ejection rounds. This means that the agent is released through the base of the round, either after it hits or while it is in flight. Chemical warheads must be at least 4cm in diameter.

Damage: Chemical warheads less than 10cm in caliber have a damage value of 2. Those 10cm or greater have a damage value of 3.

Burst Radius:

Equation 39: Chemical Warhead Burst Radius

$$Rad_{bprim} = \frac{Cal^2}{8}$$

Penetration: Chemical warheads have no penetration.

White Phosphorus

Also known as "Incendiary Smoke" (WP/IS), the filler of this round burns at very high temperatures and produces large quantities of dense white smoke. The round is excellent for building a quick smoke screen, and the heat of the round makes it difficult for thermal or infrared vision devices to see past the impact point of the shell. Finally, white phosphorus has considerable antipersonnel capabilities. WP/IS rounds are difficult for many vehicles to use because the ammunition must be stored vertically to prevent the filler from settling and disrupting the ballistics of the round. (Most vehicles store ammunition horizontally.) WP/IS warheads must be at least 4cm in diameter.

Damage: WP/IS warheads less than 10cm in caliber have a damage value of 2. Those 10cm or greater have a damage value of 3.

Burst Radius: The burst radius of WP/IS rounds less than 10cm in caliber is equal to the caliber multiplied by 2 meters. The burst radius for warheads 10cm in caliber and larger is equal to the caliber multiplied by 3 meters.

Penetration: WP/IS warheads have no penetration.

Illumination

Illumination (Illum) rounds contain a bright flare, usually made with magnesium powder, that is suspended from a parachute, balloon, or other lift agent. The round burns brightly after it bursts over the target, providing bright daylight illumination of the battlefield. Illumination warheads must be at least 4cm in diameter.

Damage: Illumination rounds have no damage value.

Burst Radius: See Table 82.

Equation 40: Illumination Round Burst Radius

$$Rad_{bprim} = \left(Mod_{illumtl} \leftarrow\!\!\times Cal\right)^2$$

See Table 82.

Penetration: Illumination warheads have no penetration.

Submunition

Submuntion (SM) warheads are hollow shells containing a number of smaller warheads. These smaller warheads are usually the size of hand grenades (or slightly larger). The warhead bursts over the target, scattering the submunitions over the target area. Submunition warheads are particularly effective against soft targets and personnel in the open, although warheads with HEAP submunitions can damage some armored vehicles. Submuntion warheads launched from artillery are typically called Improved Conventional Munitions (ICM) while submunition bombs delivered by aircraft are called Cluster Bombs. Submunition warheads must be at least 10cm in diameter. Warheads less than 15cm in diameter are referred to as "light submunition" warheads. Medium submunition warheads are at least 15cm in diameter but less than 20cm. Heavy submunition warheads are at least 20cm in diameter.

Damage: Submunition rounds have no damage value themselves; the damage done depends on the type of submunitions dispersed.

Burst Radius:

Equation 41: Submunition Burst Radius

$$Rad_{bprim} = \frac{Cal^2}{4}$$

At TL9 or above, it is possible to add individual homing systems to the submunitions, reducing the number of munitions carried by the warhead but increasing the chance of a hitting a target. Halve the burst radius of these rounds.

Penetration: Submunition rounds have no penetration value themselves; the penetration depends on the type of submunitions dispersed.

Remotely Delivered Mine: Remotely delivered mine (RDM) ammunition is a variant of submunition ammunition. Instead of impact warheads, the round contains mines. The mines become active on striking the ground, and create a surface minefield. Although not camouflaged, the mines can be hard to detect from a vehicle. RDM warheads must be at least 10cm in diameter.

Damage: RDM rounds have no damage value themselves; the damage done depends on the type of mine dispensed.

Burst Radius:

Equation 42: RDM Burst Radius

$$Rad_{bprim} = \frac{Cal^2}{2}$$

Penetration: RDM rounds have no penetration value themselves; the penetration depends on the type of mine dispensed.

Flechette

Also called "antipersonnel" (Apers), this warhead is filled with thousands of small darts (flechettes). The round also has a time fuse and a bursting charge. When fired at the enemy, the round bursts part of the way to the target, releasing the flechettes. The round is murderous against unprotected or lightly protected personnel but has little ability to penetrate armor. Flechette warheads must be at least 4cm in diameter.

Damage: Each flechette has a damage value of 2 within the weapon's primary burst radius and 1 within the weapon's secondary burst radius. Targets may be hit by multiple flechettes (rather like a giant shotgun).

Burst Radius: Flechette rounds have an elongated burst area since the flechettes keep moving along their flight path after the round explodes. This danger space is one-fourth as wide as it is long. The secondary danger space is the same size as the primary danger space and begins immediately after it.

The danger space of flechette rounds fired from guns is equal to the short range of the gun divided by 5. The danger space of flechette warheads for rockets and missiles equal to the velocity (in kilometers per hour) divided by 20.

Penetration: Flechette penetration is the same as damage value; flechettes are not intended for use against armored targets.

Chaff

A chaff warhead is filled with lightweight strips of radar-reflective material. When fired, this material tends to reduce the effectiveness of enemy radar. Chaff warheads must be at least 4cm in diameter.

Damage: Chaff warheads inflict no damage.

Burst Radius: See Table 83.

Equation 43: Chaff Burst Radius

$$Rad_{bprim} = \left(Mod_{illumtl} \leftarrow\!\!\times Cal\right)^2$$

Penetration: Chaff warheads have no penetration.

Mass

The mass of a warhead is determined by the caliber. See Table 84.

KEAP Rounds: Some types of KEAP rounds have higher masses than other warheads. See Table 85.

Special Ammunition: The type of the ammunition also modifies the mass of the round. See Table 86.

Volume

Divide the caliber of the warhead (in centimeters) by 125,000 to find the volume of the warhead in cubic meters.

Price

Multiply the mass of the warhead by the price per kilogram from the table below to determine the final price of the warhead. See Table 87.

Options: RAM grenades cost 10 times the normal warhead price. Recoilless rifle ammunition costs 1.5 times the normal warhead price.

Special Warheads

This section covers hand grenades, rifle grenades, mines, and napalm.

Hand Grenades

Hand grenades can use HE, HEAP, chemical, WP/IS, or illumination warheads. Hand grenades consist of only a warhead and a detonator. (The mass and cost of the detonator are assumed to be included in the warhead.)

Concussion Grenades: Multiply the normal HE grenade damage by 1.6; this is nonlethal damage.

Thermite Grenades: Thermite grenades are designed as WP/IS grenades but have half the cost and one-third the burst radius.

Rifle Grenades

See Table 88.

Equation 44: Rifle Grenade Range

$$R_{rg} = \sqrt{\frac{D}{Mass_{grenade}}} \leftrightarrow Mod_{wtech}$$

RAM Grenades: RAM (Rocket-Assisted Multipurpose) grenades are available at TL8 and above as rifle grenades. See Table 89.

Mines

A mine consists of a warhead and a fuse. Design the warhead normally and halve the mass. See Table 90.

Nonmetallic mines are available: double the cost of the warhead and multiply the cost of the fuse by 10.

Napalm

Napalm is available at TL5 and is normally delivered by aircraft as air-to-ground ordnance. The canisters mass 350kg each. They inflict no explosive damage (damage done by napalm is due to the incendiary effect) and have a burst area 20 meters wide and 100 meters long.

Nuclear Weapons

There are three types of nuclear warheads: standard, collapsing, and nuclear-pumped X-ray lasers.

Standard Nuclear Warheads

See Table 91.

Collapsing Nuclear Warheads

See Table 92.

Nuclear-Pumped X-Ray Lasers

These lasers have a maximum range of 15,000km. See Tables 93 and 94 for short- and long-range detonation lasers.

TL16 or less lasers have a range of 30,000km; TL17 or above have a range of 60,000km.

Guidance Systems

The following information allows the designer to choose various methods of delivering a warhead to its intended target.

Command

Warheads intended for use in controlled and semi-independent spacecraft missiles must have TL7 or higher command guidance systems installed. See Tables 95 and 96.

Target-Designated

See Table 97.

Homing

See Table 98.

Smart Guidance

Warheads intended for use in fully-independent spacecraft missiles must have smart guidance seeker systems. See Table 99.

Top Attack

Top attack can be added to any HEAP or SEFOP warhead by doubling the cost of the warhead.

Propellant

Most warheads (with the notable exception of mines) require some type of propulsion in order to reach their targets.

CPR Guns

Warheads fired from CPR guns are propelled by the explosion of a propellant charge in the gun tube. This propellant charge is purchased separately from the warhead, but the mass and cost are added to that of the warhead (and guidance system, if any) to determine the total mass and cost of a round of ammunition.

Mass:

Equation 45: CPR Gun Propellant Mass

$$Mass_{propel} = \frac{Mass_{warhead} \leftrightarrow Len_{barrek}}{145}$$

RAP Projectiles: Rocket-assisted projectiles (RAP) are available from TL5. They require additional propellant, equal to the mass of the warhead (regardless of barrel length). This is in addition to the propellant mass calculated above.

Price: Propellant costs 5 credits per kilogram.

RAP and Base Bleed: Base Bleed propellant is available for all CPR guns beginning at TL7. Base bleed charges do not add to the mass of the propellant but do cost more. Double the propellant cost for base bleed and rocket-assisted projectiles.

Other Purposes

Warheads used for other purposes, such as mass drivers, aerial bombs, grenades, or other purposes, do not require separate propellant calculations. Propellant is either not needed for these weapons (such as mass drivers, mines, and aerial bombs) or is included in the mass of the warhead (for mortars, propelled grenades, and recoilless rifles).

Chemically-Propelled Slug-Throwers

Select the TL for the gun.

Bore Size

Select a bore size (caliber) in centimeters. The CPR Artillery table gives the characteristics of guns of various calibers. Sizes that are not listed on the table can be interpolated. Rapid-fire multibarrel guns under 4cm are better treated by the small arms design sequence.

In Table 100, Caliber is caliber in centimeters. Mass is basic mass in metric tons (1,000kg). E_{rated} is rated muzzle energy in megajoules (MJ).

Barrel

Barrel Length is expressed in calibers. Barrels must be 100 calibers long or less.

Gun Type

High velocity guns are used for direct or indirect fire and typically have barrels that are 60-70 calibers long. Howitzers are typically used for indirect fire and have barrels that are approximately 30 calibers long. Mortars are simple, lightweight weapons intended for high-angle indirect fire only. Mortar barrels are less than 20 calibers long.

Mass

The CPR gun table gives the mass of guns with barrels 60 calibers long. Each caliber of additional length increases the gun's mass by 1%. (Thus, a 70-caliber long gun would mass 110% of the value listed.) Each caliber of reduced length reduces the weapon mass by 1%. (Thus, a howitzer with a barrel 30 calibers long would mass 70% of the amount shown on the table.)

The mass of mortar barrels is calculated differently.

Equation 46: Mortar Barrel Mass

$$Mass_{barrel} = \frac{Cal^2 \leftrightarrow Len_{barrel}}{50}$$

$Mass_{barrel}$ is the barrel mass in kilograms. Cal is the caliber in centimeters. Len_{barrel} is the barrel length in calibers.

Price

Barrels cost 20 kCr per metric ton.

Muzzle Energy

The CPR Gun table lists the muzzle energy in megajoules for weapons with barrels 60 calibers long. For each caliber of additional length, increase the gun's muzzle energy by 1%. (Thus, a gun with a 70 caliber barrel would have 110% of the energy listed.) For each caliber less than 60, reduce the muzzle energy by 2% until the weapon reaches 20 calibers in length. (Therefore, a howitzer with a barrel 30 calibers long would have 40% of the muzzle energy listed.) For each caliber in length less than 20, reduce muzzle energy by 1%. (A mortar with a barrel 10 calibers long would have a muzzle energy of 10% of the value listed on the table.)

Finally, multiply the energy by the $Mod_{cprtech}$ factor from **Table 101: CPR Gun Technology.**

Electrothermal-Chemical

ETC artillery is available at TL9. Multiply the muzzle energy by 2.5, regardless of the TL.

Fire Control

Select fire control equipment from the "Weapon Accessories" component chapter (page 61). Mortars may not have direct fire control systems.

Rate of Fire

Most weapons require several seconds to reload between shots. Weapons with loaders have a higher rate of fire than those that are manually loaded.

Equation 47: CPR Gun Rate of Fire

$$ROF = \frac{60}{E_{muzzle} \leftrightarrow Mod_{reload}}$$

Loader: An ordinary mechanical loader masses 10% of the mass of the gun itself. Multiply the muzzle energy (in MJ) by the factor to determine the reload time in seconds. Weapons without mechanical loading assistance are treated as TL4 weapons (5 seconds per MJ). See Table 102.

Autoloaders mass 30 times the mass of a single round of ammunition and are typically used in vehicles (to eliminate the requirement for a loader). Autoloaders do not increase the rate of fire.

Mechanical loaders of either type cost 10 kCr per metric ton.

Rapid-Fire: Rapid-fire CPR guns fire considerably more frequently than ordinary guns (and perform rather like oversized machine guns). The largest rapid-fire gun at TL4 is 2cm. The maximum size increases by 2cm per TL above TL4.

Rapid-fire guns require an action. Mechanical actions are available at TL4 or above. The mass of a mechanical action is the same as the mass of the gun, and mechanical actions cost 3 kCr per ton. Electric actions are available beginning at TL7. They mass 30% of the mass of the gun, and cost 10 kCr per ton.

The rate of fire of a rapid-fire gun is 500 rounds per minute, divided by the caliber of the weapon in centimeters.

Multibarreled and very-rapid fire guns that are 4cm or less in caliber are better handled by the small arms design sequence.

Carriage and Shield

Carriage: If the gun is not vehicle mounted, it requires a carriage. Divide muzzle energy (in MJ) by 2 to find the mass of the carriage for a conventional gun in metric tons. Divide the muzzle energy in MJ by 3 to determine the mass of the carriage for ETC guns. Except for mortars, the carriage mass may not be less than the mass of the gun itself.

Rapid-fire guns with rates of fire above 24 rounds per minute require more massive carriages; multiply the muzzle energy (in MJ) by the rate of fire (in rounds per minute) and divide by 48 to find the minimum carriage mass for a conventional gun. Divide by 72 to find the mass of a carriage for an ETC gun. The carriage mass may not be less than the mass of the gun itself.

Mortar carriages can be man-portable or towed. A man-portable carriage masses 1.6 times the mass of the gun tube; a towed carriage masses twice the mass of the gun tube.

Carriages cost kCr 2 per metric ton.

Gun Shield: Multiply the caliber of the weapon by 0.07 to find the mass of the gun shield, in tons.

Mortars may not have gun shields.

Gun shields cost 1 kCr per metric ton.

ETC Power Source

ETC weapons require a power source. The amount of electrical energy (in MJ) required per shot is equal to the weapon's muzzle energy divided by 16. Energy storage must be provided for this amount of energy. The input power (in MW) can be found by multiplying the electrical energy per shot by the rate of fire (in rounds per minute) and dividing by 60.

Gun Crew

Indirect Fire: Carriage-mounted indirect fire weapons require a number of crew equal to the bore size in centimeters. Mortars require a number of crew equal to the bore size in centimeters divided by 3. Vehicle-mounted indirect fire weapons require half this number (round fractions up) but never less than two unless an autoloader is installed (in which case the minimum crew is one).

Direct Fire: A towed direct-fire weapon requires a crew equal to the bore size divided by 3. Vehicle-mounted indirect fire weapons require half this number (round fractions up) but never less than two unless an autoloader is installed (in which case the minimum crew is one).

Range

Indirect Fire:

Equation 48: Indirect Fire Range

$$R_{indirect} = \frac{Len_{barrel} \leftrightarrow \sqrt{(Cal + TL - 4)}}{7.7}$$

$R_{indirect}$ is indirect fire range in kilometers. Len_{barrel} is the length of the barrel in calibers. Cal is the caliber of the weapon in centimeters. TL is the technology level of the weapon. See Table 103.

Direct Fire:

Equation 49: CPR Direct Fire Range

$$R_{dshort} = 5 \leftrightarrow (Len_{barrel} + Cal + 20)$$

R_{dshort} is the short range in meters. Len_{barrel} is the length of the barrel in calibers. Cal is the caliber of the weapon in centimeters. R_{dshort} applies to kinetic rounds only. The short range for all other types of ammunition is 75% of this value. Note that the type of sights installed on the weapon imposes a limit on the direct-fire range.

Hypervelocity Smoothbore Guns: Hypervelocity smoothbore guns are available beginning at TL7. These are direct-fire-only weapons and have a higher muzzle velocity for a given barrel length than other types of weapons. Multiply the direct-fire range by the hypervelocity modifier corresponding to the TL of the gun.

In Table 104, there is no additional cost or mass for a hypervelocity smoothbore gun.

Price
Total the prices of all of the weapon components.

Set-Up Time

Indirect Fire: Towed guns require 40 seconds per centimeter of caliber to set up for indirect fire. Mortars require 20 seconds per centimeter of caliber to set up for indirect fire. Vehicle-mounted weapons require half this time to set up. If the vehicle is equipped with a TL8 (or better) land navigation system, the setup time is halved again.

Direct Fire: Towed guns require 20 seconds per centimeter of caliber to set up for direct fire. Vehicle-mounted direct-fire weapons do not need to be set up and can fire whenever the vehicle is motionless. The ability of the vehicle to fire while moving is determined by the gun's stabilization system.

Volume
The volume of the gun, for purposes of transportation or mounting it in a vehicle, is equal to its mass in tons.

Mass Drivers

Mass drivers are available at TL 8 and above. Select a TL.

Bore Size

Select a bore size (caliber) in centimeters. This determines the caliber of the ammunition (warhead) fired by the gun. The bore size also determines the mass of the gun.

Equation 50: Mass Driver Mass

$$Mass_{gun} = \frac{Cal^2}{50}$$

$Mass_{gun}$ is the mass of the gun tube in metric tons. Cal is the weapon caliber in centimeters.

Mass driver gun tubes cost 50 kCr per metric ton.

Muzzle Velocity

Select a muzzle velocity for the gun, in meters per second. See Table 105.

Muzzle Energy

Select the most massive round the mass driver will fire (this is usually a KEAP round). The mass of this warhead is used to determine the muzzle energy of the weapon. Some types of ammunition will be fired with less energy, but no projectile will receive more muzzle energy.

Equation 51: MD Muzzle Energy

$$E_{muzzle} = \frac{Mass_{warhead} \leftrightarrow V_{muzzle}}{2,000,000}$$

E_{muzzle} is the muzzle energy in MJ. $Mass_{warhead}$ is the mass of the warhead in kilograms. V_{muzzle} is the specified muzzle velocity of the weapon, in meters per second.

Fire Control

Select one or more fire-control systems.

Rate of Fire

Most weapons require several seconds to reload between shots. Weapons with loaders have a higher rate of fire than those that are manually loaded. The rate of fire depends on the mass of the heaviest warhead the mass driver is intended to fire (this is usually a KEAP round).

Equation 52: Mass Driver Rate of Fire

$$ROF = \frac{60}{Mass_{warhead} \leftarrow 2.5}$$

ROF is the rate of fire in rounds per minute. $Mass_{warhead}$ is the mass of the heaviest warhead fired, in kilograms.

Mass drivers may have mechanical loaders (which both replace the loader crew member and increase the rate of fire). Mass drivers with mechanical loaders multiply the warhead mass by 0.75 to determine reload time in seconds.

The mass of an autoloader is equal to 30 times the mass of a single round.

Mechanical loaders cost 10 Cr per kilogram.

Rapid-Fire
Rapid-fire mass drivers fire considerably more frequently than ordinary weapons (and perform rather like oversized machine guns). The largest rapid-fire gun at TL8 is 10cm. The maximum size increases by 2cm per TL above TL8.

Rapid-fire guns require an action. The action masses 50 times the mass of an individual round and costs 10 kCr per ton.

The rate of fire of a rapid-fire mass-driver is 600 rounds per minute, divided by the caliber of the weapon in centimeters.

Multibarreled and very-rapid fire guns that are 4cm or less in caliber are better handled by the small arms gauss gun design sequence.

Carriage and Shield

Carriage
If the gun is not vehicle mounted, it requires a carriage. Divide muzzle energy (in MJ) by 4 to find the mass of the carriage for a mass driver in metric tons. The carriage mass may not be less than the mass of the gun itself. Rapid-fire guns with a rate of fire above 24 rounds per minute require heavier carriages. Multiply the muzzle energy (in MJ) by the rate of fire (in rounds per minute) and divide by 96 to find the minimum carriage mass for these weapons. The carriage mass may not be less than the mass of the gun itself.

Carriages cost kCr 2 per metric ton.

Gun Shield
Multiply the caliber of the weapon by 0.07 to find the mass of the gun shield, in tons.

Gun shields cost 1 kCr per metric ton.

Power Source

Mass drivers require a power source. The amount of electrical input energy (in MJ) required per shot is equal to the weapon's muzzle energy multiplied by the weapon efficiency at the gun's TL. Energy storage must be provided for this amount of energy. See Table 106.

The power (in MW) can be found by multiplying the electrical energy per shot by the rate of fire (in rounds per minute) and dividing by 60.

Equation 53: Mass Driver Input Power

$$Power = \frac{E_{input} \leftrightarrow ROF}{60}$$

Gun Crew

Indirect Fire
Carriage-mounted indirect fire weapons require a number of crew equal to the bore size in centimeters divided by 2. Vehicle-

mounted indirect fire weapons require half this number (round fractions up) but never less than two unless an autoloader is installed (in which case the minimum crew is one).

Direct Fire

A towed direct-fire weapon requires a crew equal to the bore size divided by 5. Vehicle-mounted indirect fire weapons require half this number (round fractions up) but never less than two unless an autoloader is installed (in which case the minimum crew is one).

Range

Indirect Fire

Equation 54: Indirect Fire Range

$$R_{indirect} = \frac{V_{muzzle} \leftrightarrow \sqrt{(Cal + TL - 4)}}{154}$$

$R_{indirect}$ is indirect fire range in kilometers. Vel_{muzzle} is the muzzle velocity in meters per second. Cal is the caliber of the weapon in centimeters. TL is the technology level of the weapon. See Table 107.

Equation 55: MD Direct Fire Range

$$R_{dshort} = 5 \leftrightarrow \frac{V_{muzzle}}{20} + Cal + 20\surd\lrcorner$$

R_{dshort} is the short range in meters. V_{muzzle} is the muzzle velocity in meters per second. Cal is the caliber of the weapon in centimeters. R_{dshort} applies to kinetic rounds only. The short range for all other types of ammunition is 75% of this value. Note that the type of sights installed on the weapon will impose a limit on the direct-fire range.

Price

Total the prices of all of the weapon components.

Set-Up Time

Indirect Fire

Towed guns require 40 seconds per centimeter of caliber to set up for indirect fire. Mortars require 20 seconds per centimeter of caliber to set up for indirect fire. Vehicle-mounted weapons require half this time to set up. If the vehicle is equipped with a TL8 (or better) land navigation system, the setup time is halved again.

Direct Fire

Towed guns require 20 seconds per centimeter of caliber to set up for direct fire. Vehicle-mounted direct-fire weapons do not need to be set up and can fire whenever the vehicle is motionless. The ability of the vehicle to fire while moving is determined by the gun's stabilization system.

Volume

The volume of the gun, for purposes of transportation or mounting it in a vehicle, is equal to its mass in tons.

High-Energy Weapons

Plasma guns are available at TL10 or higher. Fusion guns are available beginning with TL13. Man-portable and rapid-pulse weapons may be designed beginning one TL after the introduction of the weapon.

Pulse Energy

Select a pulse energy in megajoules (MJ). This determines most of the characteristics of the weapon.

Firing Unit

The firing unit actually creates and launches the plasma bolt. Multiply the muzzle energy by the mass per megajoule to find the mass of the firing system. See Table 108.

The price per kg of the firing unit depends on the type of recoil system and the type of the weapon. See Table 109.

Support Systems

Multiply the pulse energy in megajoules by the mass of the support system in kilograms per megajoule. For man-portable weapons, the support systems (and power supply) may be carried as a backpack.

In Table 110, the price per kg of the firing unit depends on the type of recoil system and the type of the weapon. See Table 111.

Recoil System

Man-Portable

Multiply the pulse energy in MJ by the mass of the recoil system in kg per MJ.

In Table 112, gyroscopic recoil compensators cost 600 credits per kilogram. Inertial recoil compensators cost 1,000 credits per kilogram.

Cradle Guns

Multiply the pulse energy in MJ by the mass per MJ to find the mass of the recoil system.

In Table 113, cradle recoil compensators cost 25 credits per kilogram for plasma guns and 35 credits per kilogram for fusion guns.

Fire Control

Cradle guns select one or more heavy weapon fire-control systems. Man-portable weapons use stocks and sights like other small arms.

Rate of Fire

Most weapons require several seconds to reload or recharge between shots. For plasma and fusion weapons, the time required to cool the firing unit is a significant limitation on the weapon's rate of fire. Conventional plasma and fusion guns fire at the rate of 12 rounds per minute.

Rapid-Pulse

Rapid-pulse high-energy weapons fire considerably more frequently than ordinary weapons—up to 240 rounds per minute. Fusion guns have a longer containment period before releasing the plasma bolt and have a maximum rate of fire of 120 rounds per minute.

Plasma Guns: The largest weapon that is capable of rapid-pulse fire is 20 MJ at TL11. Each TL above 11 increases the maximum pulse energy for a rapid-pulse weapon by 5MJ. The maximum rate of fire is 240 rounds per minute for pulses less than 5MJ. The maximum rate of fire for pulses over 5MJ is 1,200 divided by the pulse energy in MJ.

Fusion Guns: The largest weapon that is capable of rapid-pulse fire is 30MJ at TL14. Each TL above 14 increases the maximum pulse energy for a rapid-pulse weapon by 5MJ. The maximum rate of fire is 120 rounds per minute for pulses less than 5MJ. The maximum rate of fire for pulses over 5MJ is 600 divided by the pulse energy in MJ.

Power Source

Plasma and fusion guns require a power source.

Explosive Power Generators

Explosive power generators are particularly efficient power sources for plasma and fusion guns. The cartridge provides both the electrical power and the plasma required to initiate a pulse.

Action: Multiply the pulse energy of the gun by the action mass multiplier to find the mass of the action. See Table 114.

In Table 115, rapid pulse guns require heavier actions. Increase the mass of the action by the multiplier from the table.

Receivers cost 6 credits per kilogram.

Cartridge: Multiply the pulse energy by the cartridge characteristics to find the mass and cost of a cartridge. Once cartridge is consumed per bolt fired.

In Table 116, Mass is in kilograms per megajoule of pulse energy. Price is in credits per megajoule of pulse energy.

Cartridge-fed weapons require either a loader (to load cartridges from the ammunition storage into the action) or a box magazine. Box magazines are typically used in man-portable weapons while loaders are used for towed and vehicle-mounted weapons.

A loader masses 30 times the mass of an individual EPG cartridge and costs 10 credits per kilogram. A box magazines mass is calculated using the following formula.

Equation 56: Magazine Mass

$$Mass_{mag} = \frac{Mass_{ammo} \leftrightarrow (N_{rounds} + 4)}{3}$$

$Mass_{mag}$ is the mass of the empty magazine (in kilograms). $Mass_{ammo}$ is ammunition mass in grams. N_{rounds} is the number of rounds in the magazine.

Box magazines cost 10 credits per kilogram of empty mass.

Direct Electrical Input

Energy: The amount of electrical energy (in MJ) required per shot is equal to the weapon's muzzle energy multiplied by the weapon efficiency at the gun's TL. Energy storage must be provided for this amount of energy. See Table 117.

The input power (in MW) can be found by multiplying the electrical energy per shot by the rate of fire (in rounds per minute) and dividing by 60.

Fuel: Plasma and fusion guns require a source of hydrogen for the plasma bolt. This is normally supplied from the same fuel source as the reactor that supplies the gun's electrical power.

Equation 57: Energy Weapon Fuel

$$Fuel = \frac{E_{pulse} \leftrightarrow N}{Mod_{fuel}}$$

Fuel is fuel required in cubic meters of liquid hydrogen. E_{pulse} is the pulse energy in MJ. N is the number of pulses for which fuel is required. (Fuel is usually provided for hundreds or thousands of pulses.) Mod_{fuel} is the fuel consumption modifier, from Table 118.

Carriage and Shield

Carriage

If the gun is not vehicle mounted or man-portable, it requires a carriage. Divide muzzle energy (in MJ) by 2 to find the mass of the carriage for a plasma or fusion gun in metric tons. The carriage mass may not be less than the mass of the gun itself.

Rapid-fire guns with a rate of fire above 24 rounds per minute require heavier carriages. Multiply muzzle energy (in MJ) by the rate of fire (in rounds per minute) and divide by 48 to find the minimum carriage mass for these weapons.

Carriages cost kCr 2 per metric ton.

Gun Shield

Multiply the pulse energy in MJ of the weapon by 0.1 to find the mass of the gun shield in tons.

Gun shields cost 1 kCr per metric ton.

Gun Crew

High-energy weapons require a crew of two if they towed cradle guns, or one otherwise.

Range

Equation 58: Plasma Weapon Range

$$R_{pshort} = 100 \leftrightarrow \sqrt{E_{pulse}}$$

Fusion Gun

Equation 59: Fusion Weapon Range

$$R_{fshort} = 150 \leftrightarrow \sqrt{E_{pulse}}$$

Damage

Equation 60: Energy Weapon Damage

$$D = 40 \leftrightarrow \sqrt{E_{pulse}}$$

Recoil

Recoil is calculated only for man-portable weapons. Compute the single-shot recoil number. Higher numbers indicate higher recoil felt by the firer and make sustained, accurate fire more difficult.

Equation 61: Single-Shot Recoil

$$Mod_{rss} = \frac{-150 \leftrightarrow \sqrt{E_{muzzle}}}{Mass_{loaded}} \leftrightarrow Mod_{recoil}$$

Mod_{rss} is the single-shot recoil number. E_{muzzle} is the weapon's muzzle energy in joules. $Mass_{loaded}$ is the loaded mass of the weapon in kilograms. (For belt or cassette fed weapons, use the empty mass $Mass_{empty}$ instead.) Mod_{recoil} is the recoil modifier for the weapon's recoil compensation system from **Table 112: Man-Portable Recoil Systems.**

If the weapon is a rapid pulse plasma gun, compute the burst recoil number using a burst size of 10 shots (or the total amount of ammunition carried in the weapon's magazine, whichever is smaller). N_{burst} is the number of rounds fired in the burst.

Equation 62: Burst Recoil

$$Mod_{rburst} = Mod_{rss} \leftrightarrow \frac{N_{burst}}{2}$$

Price

Total the prices of all of the weapon components.

Set-Up Time

Towed guns require 50 seconds per metric ton of mass to set up for direct fire. Vehicle-mounted direct-fire weapons do not need to be set up and can fire whenever the vehicle is motionless. The ability of the vehicle to fire while moving is determined by the gun's stabilization system.

Volume

The volume of the gun, for purposes of transportation or mounting it in a vehicle, is equal to half of its mass in tons.

Battlefield Missiles

By convention, unguided self-powered projectiles are referred to as "rockets." Self-powered projectiles that are equipped with a guidance system are referred to as "missiles." Since missiles are one-use disposable weapons, they do not require the extensive chassis and airframe that are used for vehicles and aircraft.

Warhead and Guidance

Determine the technology level for the weapon. Select or design a warhead for the missile, optionally including a guidance package.

Mass

Determine the rocket or missile's launch mass; the sum of the masses of all components must be equal to (or less than) this amount. Many weapons, particularly those launched from aircraft, have mass limits imposed by the launch platform. The missile's performance is based on its average mass. Average mass is the launch mass, less half of the mass of the fuel.

Propulsion

Select a design speed for the rocket or missile. This determines the amount of thrust required in kilonewtons.

Equation 63: Missile Thrust

$$T_{req} = \frac{Mass_{avg} \leftrightarrow \sqrt{Vel_{design}}}{Mod_{tech}}$$

T_{req} is the required thrust in newtons. (Divide by 1,000 to find thrust in kilonewtons.) $Mass_{avg}$ is the average mass in kilograms. Vel_{design} is the design velocity in kilometers per hour. Mod_{tech} is the technology modifier from Table 119.

Select a thrust agency that provides the required amount of thrust. (See the "Thrust Agencies" section on page 65.)

Fuel

Compute the amount of fuel consumed per hour of thrust provided. Divide the total fuel carried by the fuel consumption, to compute the thrust duration in hours (usually a small fraction).

Range

The range of the missile, in kilometers, is equal to the thrust duration (in hours) multiplied by its average velocity (in kilometers per hour).

Maneuver Points

Only guided weapons (missiles) have maneuver points. Compute maneuver points based on the missile's average speed, and treat all missiles as streamlined (not airframe) vehicles, using the rules in the atmospheric performance rules of the "Thrust Agencies" component chapter (page 65). Maneuver points represent the missile's ability to turn, and the energy required to perform the turn, determined by the missile's speed. When attacking aircraft, missiles with more maneuver points are harder for the pilot to successfully evade.

Starship Weapons

This section covers spacecraft missiles, space missile launchers, lasers, particle accelerators, and meson guns.

Spacecraft Missiles

Select a warhead for the missile. At the present time, the only suitable warhead for space combat is a detonation laser missile. Standard spacecraft missiles are one half of a displacement ton, 7 cubic meters, and have a design mass of 7 metric tons.

Warhead and Guidance

Determine the technology level for the weapon. Select or design a warhead for the missile, optionally including a guidance package.

Mass

Determine the rocket or missile's launch mass; the sum of the masses of all components must be equal to (or less than) this amount. Many weapons, particularly those launched from aircraft, have mass limits imposed by the launch platform. The missile's performance is based on its average mass. Average mass is the launch mass, less half of the mass of the fuel.

Propulsion

Select a design acceleration for the missile, in meters per second per second ($1G = 10m/s^2$).

Equation 64: Missile Thrust

$$T_{req} = \frac{Acc_{design}}{Mass_{avg}}$$

Install a propulsion system that provides the desired amount of thrust.

Guidance

Spacecraft missiles must have the equipment required for at least one of the following three guidance modes. If a missile has guidance units, communicators, and sensors that qualify it for more than one guidance mode, the mode may be changed by the missile operator at any time the operator is in communication with the missile.

Controlled: Controlled missiles are "flown" into the target by missile operators on the launching ship. In addition to a command guidance unit, controlled missiles require a communications receiver to be able to receive the commands from the operator. Laser and tight-beam radio communicators are most often used.

Semi-Independent: Semi-independent missiles are operated by a gunner on the firing ship, just like controlled missiles. However, semi-independent missiles have a communications transceiver (instead of a receive-only system) and a sensor. The missile transmits sensor data back to the firing ship, allowing targets to be engaged beyond the sensor range of the launching ship and allowing the on-board guidance processor to control the missile during final approach, negating range penalties to the missile's remote operator.

Fully Independent: Fully independent missiles use a smart seeker guidance system and a sensor system to home in on their targets without intervention by the missile gunner. An initial course and speed are programmed into the missile at launch time. The missile establishes this vector. Also part of the initial programming is a sensor turn-on time; at the appointed time, the missile begins using the sensor to attempt to recognize a target. Once a target is recognized, the missile maneuvers to attack it.

Fuel

Compute the amount of fuel consumed per hour of thrust provided. Divide the total fuel carried by the fuel consumption to compute the thrust duration in hours.

Rating

Spacecraft missile performance is rated in terms of maximum acceleration in gravities (one standard gravity is 10 meters per second per second) and total fuel in gravity-hours. (One gravity-hour of fuel is the fuel required to sustain an acceleration of one gravity for one hour.)

Maximum Acceleration: Divide the acceleration (in meters per second per second) by 10 and drop fractions to determine acceleration in gravities.

Fuel in G-Hours: Multiply the acceleration (in meters per second per second) by the thrust duration in hours and divide by 10 (drop fractions) to determine the total fuel in G-hours. Fuel for primitive rockets consumes such a large fraction of the total mass of the rocket that these rules seriously underestimate the total change in velocity. After all, as the fuel burns, the vehicle accelerates more for the same amount of thrust. For primitive rockets (including rocket-powered missiles), the total change in velocity in meters per second possible is given by:

$$\Delta V = \ln(M_f / M_{tot}) \leftrightarrow \frac{3600}{FC \leftrightarrow FD}$$

M_f is the mass of the fuel, M_{tot} is the total mass of the vehicle (fuel and everything else), and FC is the listed fuel consumption, in m^3/kN/hour. For reference, a launch from the Earth's surface to low earth orbit requires slightly under 10km/sec total delta-V. More detailed treatment of primitive rockets will be handled in the future.

Space Missile Launchers

This section describes launch canisters, launch systems, and standard space launchers.

Launch Canisters

Missiles may be stored in pressure-tight canisters, ready for launching. These launchers are normally reloaded by replacing the entire canister (which uses standardized connectors) in port, after a battle. Launch canisters require a total volume of 110% of the volume of the missile contained inside, they mass 0.1 metric ton per cubic meter of launcher, and they have a price of 100 credits per cubic meter. Launch canisters can be installed in spacecraft socket turrets (in which case the launch system has the same streamlining as the turret), or they can be mounted directly on the superstructure of an unstreamlined vehicle or spacecraft.

Launch Systems

A reloadable launch system requires a total volume (including the ready-fire missile) of twice the missile contained inside the launcher. The launcher masses 0.5 metric tons per cubic meter of launcher and costs 700 credits per cubic meter.

The launcher can be reloaded in an hour by a crew of one. If an autoloader is provided, the launcher can be reloaded automatically after firing. The time required for the autoloader to reload the missile (in minutes) is equal to the missile mass in tons. Installing an autoloader doubles the mass, volume, and cost of the launcher.

A magazine must be provided for storage of missile reloads. The magazine requires a total volume (including the missile) of 150% of the volume of the missiles contained inside, at a mass of 0.25 metric tons per cubic meter and a cost of 100 credits per cubic meter. Missiles may also be stored as cargo, at 105% of the volume of the missile, but reloading requires two hours and a crew equal to half the missile's mass in tons.

Standard Space Launchers

Due to the available surface area, and allowing for the overhead of the turret itself, a standard three-ton socket turret holds five launch canisters, two reloadable launchers, or one launcher with an autoloader. A standard six-ton socket turret holds 10 launch canisters, five reloadable launchers, or two launchers with autoloaders. Magazines for additional missiles are provided within the ship's hull on military ships.

Bay installations are less standardized and typically contain autoloading launchers, a magazine, and fire direction equipment. No pointing mechanism is required for turret or bay missile launchers, but standard turret missile packages usually are designed as drop-in replacements for standardized turrets (which may have pointing mechanisms installed for compatibility with other weapon systems). Bay missile launchers do not require pointing mechanisms and normally don't include them.

Lasers

Lasers operate on a basic principle known as "stimulated emission," which derives from quantum mechanics. Basic physics teaches us that if an electron in an atom absorbs energy, it jumps to a higher "state" or orbit around the atom. When the electron drops back down to its normal state, it gives off the energy in the form of a photon. Quantum mechanics teaches that electrons can only occupy specific states and hence can only accept and give off certain quantities of energy. Stimulated emission happens when an electron in an excited state is struck by a photon of exactly the energy that the electron has absorbed. That photon "stimulates" the electron into giving off another photon in perfect sync with the original photon.

Lasers work by creating a large population of atoms or electrons in an energetic state. When one of these atoms gives off a photon, it triggers a chain reaction, eventually causing all the other atoms to give off photons, exactly in sync with the original.

Sequence

Design your laser weapon using the following steps.

Define Laser Specifications

Choose Tech Level: If TL13+, decide if you want a tunable laser or x-ray laser. Tunable lasers are more flexible, as their wavelengths can be changed (for example, to use in atmosphere), but they can't get down to x-ray wavelength. X-ray lasers have the best possible range but don't penetrate atmosphere well.

Choose Focal Array Diameter (D) And Type: The greater the focal array diameter, the better focusing (and hence longer range) but the larger the weapon. The focal array diameter is specified in meters during the design sequences; small arms lasers may be listed later in centimeters. Heavy focal arrays are installed in vehicles or spacecraft, and they include all the appropriate support systems (power, cooling, and so forth) already built in. Light focal arrays are intended for use in personal weapons or smaller vehicles and may need to have additional support systems added later in the design. If the laser has a heavy focal array, further choose whether you want it to be trainable (the focal array is built so that it can be mounted in a turret or similar mount and pointed at a target) or fixed (the focal array is mounted rigidly and aimed by pointing the entire vehicle).

Choose Discharge Energy (DE): This is how much juice comes out the working end of the laser. The maximum discharge energy possible is TLx50; beyond that, the optics in the laser overheat and fail catastrophically (the thing explodes . . . in your face).

Choose Grav Focused or Non-Grav Focused: Grav focused lasers become available at TL9 and are the only way to get long-range space combat lasers before X-Ray lasers become available at TL13. The gravitic focusing unit generates a small pulse of gravity at the same time as the laser fires. Since gravity can bend light waves, this small pulse provides the additional focusing beyond what is physically possible with optics alone.

Calculate Focal Array Characteristics

Focal Array Area: The area of the focal array is:

$$A_{FA} = \frac{\pi D^2}{4}$$

Focal Array Volume: The volume of the focal array depends on the area, tech level, and discharge energy. **Table 120: Focal Array Modifiers** lists the multipliers by TL for both heavy and light arrays.

$$Vol_{FA} = A_{FA} \leftrightarrow DE \leftrightarrow Modifier$$

Focal Array Mass: The mass of a focal array is its volume times 1 ton per m^3.

Focal Array Price: Light focal arrays cost MCr0.5 per m^3, fixed heavy focal arrays cost MCr0.1 per m^3, and trainable heavy focal arrays cost MCr0.2 per m^3.

Focal Array Length: For spacecraft-mounted weapons, calculate the length of the focal array. Divide the volume by the focal array area. The spacecraft mount must be of the right dimensions to allow mounting of the weapon.

Determine Input Energy (IE)

Input energy is the amount of energy you have to put in to get your chosen discharge energy out the back, and it depends on the efficiency of the laser. Gravitic-focused lasers have a constant efficiency of 0.2; non-grav-focused laser efficiency varies by TL and is listed in **Table 121: Non-Gravity Efficiency**.

$$IE = DE/Efficiency$$

Calculate Focal Value

The focal value determines how tight the beam can be held. Gravitic focusing is used to give better focal values than otherwise possible with purely optical focusing. The specific equation for focusing factor depends on TL, focal array type, whether the laser is grav-focused, and whether the laser is an x-ray laser.

For non-grav focused lasers, the focal value F = Focal Array Diameter at all TLs.

Table 122: Laser Range and Focal Values lists the focal value for grav focused lasers (TL9+) as well as the frequency bands available at that TL for both grav-focused and non-grav focused lasers. Tunable lasers may use any frequency band of equal or lesser TL. (This becomes important when considering atmospheric effects.) Simply insert the focal array diameter, in meters, into the equation listed.

For X-Ray lasers below TL20, use **Table 123: X-Ray Laser Range and Focal Value**. At TL20, regular tunable lasers reach the same capability as X-Ray lasers, so they use the same table.

Calculate Performance

Now you determine the range and combat effectiveness of the weapon.

Calculate The Laser's Effective Range (Reff): The effective range is the distance at which the laser can maintain a 1cm beam. Beyond that, the beam starts to spread out and its effectiveness drops. Range factors are listed in **Table 122: Laser Range and Focal Values,** above. For tunable lasers, there's a different effective range for each frequency band (one best for atmospheric bombardment, one for space combat). Tunable lasers can theoretically calculate their performance in each waveband, but that's not necessary. To determine the best rating in space, use the range factor for the highest waveband available. To determine the best rating in an atmosphere, use Visible Light for TL8+. TL7 lasers use the same rating either way. Atmospheres absorb laser energy, depending on the wavelength, and therefore the effective range is modified according to **Table 124: Laser Atmospheric Range**. Multiply the theoretical effective range by the factor in the table to determine the actual effective range in the atmosphere: Effective Range = Focal Value x Range Factor.

Choose or Calculate Short Range (SR): For heavy weapons, the short range depends on the fire control chosen and is usually chosen such that the short range is equal to the effective range. For small arms, the short range depends on the configuration of the weapon.

Heavy Weapons: Select a beam pointer from the "Electronics" component chapter (page 69), with a range equal to your desired short range.

Small Arms: Choose your configuration now, although the fittings won't be added until later. The choices are listed in **Table 125: Small Arms Configurations.** Multiply the configuration modifier by 200—that's your short range. Note that the short range is a function of the firer's ability to aim the weapon, not necessarily how far the beam will go.

Calculate Damage Value: The damage value for a laser depends solely on its intensity at any given range. Standard **Traveller** range bands are listed in **Table 126: Traveller Range Bands.**

For each range desired, calculate the following.

Intensity: The intensity of the beam at any given range depends on the discharge energy, and the ratio of the actual range to the weapon's effective range:

$$I = \frac{DE}{\left(R/R_{eff}\right)^2}$$

Damage Value: Damage value against vehicles is 2.5 times the square root of the intensity:

$$DV = 25\sqrt{I}$$

Personnel Damage: Determine the damage done against personnel targets, in number of dice rolled, by multiplying the DV by 20.

Supply Energy Requirements

There are two ways to supply the energy needed for each shot. The first way is direct power input: You build electrical power in an accumulator, then release the pulse to fire the laser. The second option is via chemical laser cartridges.

Direct Power Input: This is the method most commonly used for large vehicle and spacecraft mounted lasers. Dealing with the toxic waste gases from huge chemical cartridges is difficult., and it's impossible to carry power plants large enough to effectively power the laser. You need to provide an accumulator bank capable of storing the required energy for a single shot, and then supply power to charge the accumulator fast enough for the rate of fire you want.

Choose Rate Of Fire: Select how often you want to be able to fire the weapon. Rates higher than one shot every 10 seconds require extra cooling and ventilation to avoid damage to the focal array. Multiply the focal array volume, mass and price by the factor given in **Table 127: Laser ROF Modifier**.

Design Accumulator: You need an accumulator large enough to handle the input energy for a single shot. For large ship and vehicle mounted weapons, the accumulator is added into the overall weapon size; man-portable lasers usually have the accumulator in a separate backpack.

Calculate Power Required: In order to achieve the rate of fire you calculated, you have to be able to supply power fast enough. Power required is Rate of Fire x Energy Per Shot / Length of Turn.

Chemical Laser Cartridges: Another method of providing a laser pulse doesn't depend at all on a power source. Rather, a cartridge containing special chemicals produces a population of energized atoms to undergo inversion and generate the laser pulse. Thus, a single cartridge can provide the equivalent of the required input energy needed for a single pulse.

Choose Cartridge Size: **Table 128: CLC Output** lists the equivalent energy provided per kilogram for CLC cartridges at different tech levels. Note that this energy is not useful for powering electrical devices; it's merely a measure of the equivalent energy of the laser pulse produced. Divide the Input Energy by the value listed to determine how big a cartridge is needed per pulse. CLC chemicals have a volume of 0.1 liters per kg or 1 cubic centimeter per gram.

Choose Cartridge Dimensions: Much like projectile weapons, cartridges are not necessarily interchangeable. Also, the cartridge dimensions affect the size of the magazine. Most CLCs are cylindrical, with a length three times the diameter. Calculate the diameter of the cartridge:

$$D = 0.752\sqrt[3]{\text{Volume}}$$

Some designers choose to round the diameter up to a round number, then recalculate the length based on that. The formula for length is:

$$\text{Length} = 4\,\text{Volume}/\pi D^2$$

Rate of Fire: The rate of fire for a CLC weapon is limited by the purge cycle, which is the rate at which it can burn and then dispose of the chemicals. The chemicals are combined in the *combustor,* which is where the reaction takes place, and then they are drawn out by the *evacuator.* Unlike direct-power lasers, the maximum ROF depends on this.

Base Combustor/Evacuator Volume: All CLC weapons have a base evacuator volume of 55 liters per MJ of input energy per CLC cartridge. This volume is large enough to provide a rate of fire of one shot per second.

Choose Actual C/E Volume: You may choose to install a larger or smaller combustor/evacuator. Combustor/evacuators mass 1kg per liter and cost Cr500 per liter. This includes the weight and volume of a closed cycle cooling system.

Calculate Actual ROF: The actual rate of fire, in shots per second, is the actual volume divided by the base volume.

Ammunition Feed: Just like projectile weapons, a cartridge-fed laser requires the equivalent of a receiver/magazine assembly for small-arms lasers, or an electric action with autoloader for heavy weapons. Any laser with a heavy focal array is automatically a heavy weapon; lasers with light focal arrays may be designed either way at the designer's option.

Small Arms Lasers: The receiver, which extracts the cartridge from the magazine, holds it in place in the combustor, then ejects the spent cartridge. It has a volume 80 times the volume of the cartridge, weighs 1kg per liter, and costs Cr2000 per liter. The magazine may be either a cassette or box magazine (identical to those described in the "Small Arms" section [page 29]).

Cassette Magazines: A cassette feed system masses 2 kilograms (plus the mass of the ammunition contained in the cassette), and the cost of the empty cassette is equal to 500 times the cost of a single round of ammunition. Due to the overhead of the power and feed systems, cassettes typically hold 1,000 or more rounds.

Box Magazines: The mass, in kilograms, of a box magazine is given by the equation below, where Mass_{CLC} is the mass of the CLC in kilograms. Box magazines cost 10 credits per kilogram of empty mass.

$$\text{Mass}_{\text{mag}} = \frac{\text{Mass}_{\text{CLC}} \leftrightarrow (N_{\text{rounds}} + 4)}{3}$$

Heavy Laser Autoloaders: The volume of the action and autoloader is 35 times the volume of a single CLC round. The assembly masses 1kg per liter (1 t/m^3) and costs Cr10 per liter (kCr10/m^3). The magazine may be any size desired. Empty magazines mass 0.01 times the mass of all the rounds they hold, and a volume in cubic meters equal to the mass in tons of the rounds divided by 5. Price is kCr5 per ton. Reload time is loaded weight (in tons) times five.

Tunable Lasers: CLC lasers may be designed to work at different wavelengths, just like direct-power lasers. However, the wavelength of a CLC is controlled by the specific chemical reaction taking place in the combustor, which depends in turn on the specific type of chemicals in the cartridge. Therefore, for a CLC laser to work at different wavelengths, it requires different ammunition for each. The actual size and price of each cartridge is identical; you just have to make sure you have the right ones with you. A tunable combustor/evacuator assembly is the same size as a regular one but costs twice as much.

Crew

Vehicle- or spacecraft-mounted weapons may be designated to be crewed or uncrewed. Uncrewed lasers must be fired remotely. All crewed lasers require a workstation. Heavy lasers have a minimum crew of one, although more may be assigned to help with ammunition. Small-arms lasers, naturally, have a crew of the operator.

Furnishings and Supporting Hardware

Weapons that are mounted on a starship or vehicle can skip this entire section; all others proceed.

Carriage: If the weapon is intended to be a towed battlefield weapon, or otherwise movable, it needs a carriage.

Carriage Mass: The mass of the carriage is equal to the mass of the laser (including accumulator or ammunition).

Carriage Price: The carriage costs MCr0.002 per ton.

Armor: The carriage has a basic armor rating of 1. If you choose, you may enclose the laser in a cylindrical chassis, per the vehicle or spacecraft design rules, and armor the chassis. Note that this increases the mass of the laser and hence the mass of the carriage as well.

Mounts: Small-arms lasers may be mounted on bipods or tripods to increase their accuracy. See the small-arms rules for designing mounts.

Small Arms Cooling Systems: While CLC-driven lasers have an integral cooling system, direct-input lasers don't. The volume of the cooling system in liters is the Input Energy (in MJ) times 10. The cooling system masses 2kg per liter and costs Cr1,700 per liter. At least half the cooling system must be in the weapon, and 20% in the backpack. The remainder can be distributed as the designer chooses.

Small Arms Body and Stock: All small arms weapons require a body to hold the laser and a stock for the firer to hold.

Body: Add up the volume of all the components that go in the "empty" weapon itself and not in the backpack: focal array, cooling system, combustor/evacuator, and/or receiver. The volume of the body is 0.05 times this value. To *ruggedize* a laser body so you can mount a grenade launcher, double the volume. If you actually want to put a bayonet lug on, quadruple it. The body masses 1kg per liter and costs Cr100 per liter.

Weapon Length: Add the volume of the weapon and the body, take the cube root, and multiply by the configuration multiplier, which is 4.3 for direct input weapons and 3.4 for CLC weapons. The result is the weapon's basic length in centimeter.

Bayonet Lugs: You must have ruggedized the body to the 4x level to install a bayonet lug, which costs and masses nothing.

Grenade Adapter: A grenade adapter allows lasers to fire rocket-assisted multipurpose (RAM) rifle grenades. The adapter adds 5cm to the length of the body and costs Cr50.

Stocks: If the weapon's final length (without the RAM grenade adapter) is greater than 40cm, it's assumed to already be laid out as a two-handed weapon and you only need to add a bullpup stock. If it's shorter than that and you want it to function as a two-handed weapon, you need to add a stock. Stocks are listed in **Table 152: Stocks**. The weapon's final length is the base length so far, plus the length of the stock, plus the length of the grenade adapter (if added).

Sights: Light focal arrays may be fitted with either small-arms sights or direct fire controls for heavy weapons (see the "Electronics" component section on page 69). **Table 154: Optic Sights** lists optical sights for use with lasers.

Small Arms Backbacks: Direct electrical input lasers require a backpack to contain the accumulator, a power supply (and fuel if needed), and 20-50% of the cooling system. Add the volume of those components up to get the volume of the backpack. The empty casing masses 0.3kg per liter of enclosed volume and provides the equivalent of armor 1 to its contents. Cost is Cr3 per liter. If you want a higher armor value, multiply casing mass and price by the amount you wish to increase the armor. (If you want armor 3, multiply everything by 3.)

Particle Accelerators

A particle accelerator can be thought of as a mass driver for subatomic particles—the basic principle is the same. Using powerful electromagnetic fields, a PAW (Particle Accelerator Weapon) hurls ions or subatomic particles to near the speed of light and focuses them into a tight beam to retain its energy density over extreme distances.

There are two basic types of particle accelerators, each with its own realm. The first is the charged particle accelerator weapon (CPAW). A CPAW accelerates charged particles. In an atmosphere, charged particle beams hold together fairly well, as the flow of like charges in the same direction acts much like an electrical current, generating a magnetic field that acts to keep the beam together. However, in space the particles, which are all the same polarity, repel each other much like two north poles of a magnet. As a result, the beam pretty much disintegrates almost immediately after it's been fired, making the CPAW worthless as a space weapon.

The other type of particle accelerator is the Neutral Particle Accelerator Weapon, or NPAW. An NPAW works fairly well in space, as it's unaffected by magnetic or electrical fields. But since there's nothing to give it coherence in an atmosphere, it rapidly breaks up as the atmosphere ionizes and absorbs the beams.

PAWs work simply by using a device (such as a screen of foil or a high-powered laser) to create charged particles, then electromagnetically accelerates them down a long tunnel. At the end of the tunnel, the charged ions are released. An NPAW neutralizes the ions by returning the missing electron or removing the extra electron added during the ionization step. Note that this means that an NPAW can also function as a CPAW if desired—simply don't neutralize the beam. If you wish, you may rate an NPAW for both space combat and planetary combat (as a CPAW).

Design Sequence

Trace the following steps to design your particle accelerator.

Define the Tunnel

Choose the basic characteristics of the tunnel.

Choose Tunnel Length (L): The length, in meters, together with the diameter, determine how far the tunnel can focus the beam.

Choose Tunnel Diameter (D): Choose tunnel diameter. The tunnel diameter may not be greater than 1/8 tunnel length, and diameters less than the maximum reduce the amount of damage the weapon inflicts, compared to a full-bore weapon of the same energy.

Select Discharge Energy (DE): Choose how much energy you want coming out of the end of the tunnel with each shot. The maximum DE in MJ is tunnel length in meters squared.

Calculate Tunnel Characteristics

Using the values chosen in step one, and **Table 129: Accelerator Tunnel Characteristics**, to determine the effective features of the tunnel.

Tunnel Area (A): The muzzle area of the tunnel is fixed by the tunnel diameter: $A = (D^2/4$.

Effective Tunnel Length (L_{eff}): The effective length of the tunnel depends on the actual length and a modifier based on TL from Table 129. $L_{eff} = L \times LM$.

Effective Focal Area (AF): The focal area determines how well the weapon can keep the beam focused, and it depends on the type of weapon (CPAW or NPAW) chosen. $A_F = A \times FM$.

Damage Modifier: If you chose a tunnel diameter less than 1/8 the tunnel length, you need to calculate a modifier for the damage determined later. The modifier is $DM = (8 \times D/L)^2$. For tunnel diameters equal to 1/8 length, the modifier comes out to be 1.

Calculate Performance

Now you determine the range and combat effectiveness of the tunnel.

Theoretical Effective Range: This is the range at which the delivered energy intensity would still be the same as it is at the bore of the weapon. Theoretical Effective Range = Effective Tunnel Length x Effective Focal Area x 1,000.

Actual Effective Range: For NPAWs, the actual effective range in a vacuum is equal to the theoretical effective range. CPAWs are affected by atmosphere or the absence of atmosphere. (Remember, they don't do well in a vacuum.) Use **Table 130: Atmospheric Range Modifiers**. Note that weapons could theoretically be rated for all atmospheres, but in practice that may be too tedious. If the weapon will only be used on a specific planet, only rate it there. Actual Effective Range = Theoretical Effective Range x Range Modifier.

Short Range: Choose a beam pointer from the "Fire Control" component section (page 69) to set the short range of the weapon. The weapon's short range is usually the actual effective range because that's the longest range at which it does its maximum damage.

Range Bands: Choose the range bands that will be used in combat. Standard **Traveller** range bands are listed in **Table 126: Traveller Range Bands.**

Calculate Damage Value: The damage value depends on the intensity of the beam at a given range or the energy per area delivered. At the effective range, the intensity is equal to the weapon's discharge energy divided by $1cm^2$. For each range of interest, calculate intensity and damage.

Intensity: Intensity is Discharge Energy / $(Range/Effective Range)^2$.

Damage: DV is 5 times the square root of the intensity, times the damage modifier calculated above.

Calculate Tunnel Size

Determine how much space the weapon takes up and how much it costs.

Tunnel Volume: The tunnel volume is the actual area times the actual length.

Tunnel Mass: The mass of the tunnel is its volume times the mass multiplier from Table 129, above.

Tunnel Cost: CPAWs cost MCr0.09 per cubic meter of tunnel volume. NPAWs cost MCr0.1 per cubic meter of tunnel volume.

Supply Energy Requirements

You need to provide an accumulator bank capable of storing the required energy for a single shot, then supply power to charge the accumulator fast enough for the rate of fire you want.

Calculate Input Energy Per Shot: The input energy needed for one shot is 5 x Discharge Energy. (All PAWs have efficiency of 20%.) You need an accumulator big enough for this.

Choose Rate Of Fire: Select how often you want to be able to fire the weapon. Rates higher than four shots per minute require increased cooling to handle the huge amounts of energy going through the accumulators and the tunnel. See **Table 131: Particle Accelerator ROF Modifiers** and multiply the PAW's volume, mass, and price by the factor listed there.

Calculate Power Required: In order to achieve the rate of fire you just calculated, you have to be able to supply power fast enough. Power required is Rate of Fire x Energy Per Shot / Length of Turn.

Calculate Crew Requirements

Determine crew requirements: crew = 0.01 x Tunnel Volume x Computer Multiplier. Each crew member requires a normal workstation (from the "Electronics" component chapter on page 69).

Design the Carriage

Starship- or vehicle-mounted weapons don't require a carriage. However, if the weapon is intended to be a towed battlefield weapon, it needs a carriage.

Carriage Mass: The mass of the carriage is equal to the mass of the PAW.

Carriage Price: The carriage costs MCr0.002 per ton.

Armor: The carriage has a basic armor rating of 1. If you choose, you may enclose the PAW in a cylindrical chassis, per the vehicle design rules, and armor the chassis. Note that this increases the mass of the PAW and hence the mass of the carriage as well.

Planetary Bombardment Range

When bombarding a world from space, the weapon's performance is based on an "effective bombardment range," which is the actual range to the surface modified by the atmosphere in between the weapon and the surface. Since all worlds are different, this range has to be recalculated for each world. Divide the actual range by the appropriate atmosphere modifier in **Table 130: Atmospheric Range Modifiers,** above. Use this range only when determining if damage-hit probability still depends on the actual range to the target. If you're designing a weapon to be used for frequent planetary bombardment, you might consider copying the table into the weapon description so it's always handy.

Circular PAWs

Most military PAWs weapons are linear, that is, the accelerator tunnel is a straight line. The reason for this is simple: Even if one or two of the accelerator rings get knocked out, the weapon can still fire (albeit at reduced power). However, there is another option, one that is used today for research facilities (which are generally not too worried about combat damage).

A circular PAW accelerates charged particles around a ring tunnel instead of accelerating them down a long tunnel and out the end. By running the pulse round the tunnel for several laps, you can get the same particle speed it would take a much longer, straight tunnel to produce. This has several drawbacks, though. First of all, the faster the particles go, the more energy it takes just to keep them going in the circle, reducing the amount of energy you can add in each successive lap. Second, a hit that knocks out even one of the accelerator rings cripples the weapon. The benefit is that you can make a smaller weapon with the same damage rating. Use the following modified sequence.

Define The Tunnel

Similar to the standard sequence, you choose the size of your weapon, and then rate it.

Choose Torus Radius (R): This is basically the radius of the circle.

Calculate Path Length of the Torus (L): This is the distance the particles travel on one lap around the torus.

Choose Tunnel Diameter (D): The tunnel diameter can be no greater than 1/8 x path length, and tunnel diameters less than the maximum reduce the amount of damage the weapon inflicts compared to a full-bore weapon of the same energy.

Calculate Energy per Lap (E_{lap}): The maximum energy that can be added in a single lap is L^2.

Choose Number of Laps (N): Decide how many laps around the loop you want each shot to make before it's fired. More laps mean more energy.

Calculate Tunnel Characteristics

Using the values chosen above, and **Table 129: Accelerator Tunnel Characteristics,** determine the effective features of the tunnel.

Tunnel Area (A): The muzzle area of the tunnel is fixed by the tunnel diameter. $A = (D^2/4$.

Effective Tunnel Length (L_{eff}): The effective length of the tunnel depends on the actual path length and a modifier based on TL from Table 129. $L_{eff} = L \times LM$.

Effective Focal Area (A_F): The focal area determines how well the weapon can keep the beam focused, and it depends on the type of weapon (CPAW or NPAW) chosen. $A_F = A \times FM$

Damage Modifier: If you chose a tunnel diameter less than 1/8 the tunnel length, you need to calculate a modifier for the damage determined later. The modifier is $DM = (8 \times D/L)^2$. For tunnel diameters equal to 1/8 length, the modifier comes out to be 1.

Calculate Performance

Now you determine the range and combat effectiveness of the tunnel.

Theoretical Effective Range: This is the range at which the delivered energy intensity would still be the same as it is at the bore of the weapon. Theoretical Effective Range = Effective Length x Effective Focal Area x 1,000.

Actual Effective Range: For NPAWs, the actual effective range in a vacuum is equal to the theoretical effective range. CPAWs are affected by atmosphere or the absence of atmosphere. (Remember, they don't do well in a vacuum.) Use **Table 131: Atmospheric Range Modifiers.** Note that weapons could theoretically be rated for all atmospheres, but in practice that may be too tedious. If the weapon will only be used on a specific planet, only rate it there. Actual Effective Range = Theoretical Effective Range x Range Modifier.

Calculate Effective Discharge Energy: The discharge energy depends on the number of laps, and the maximum energy per lap:

$$DE = E_{lap}\sqrt{N}$$

Short Range: Choose a beam pointer from the "Fire Control" component section (page 69) to set the short range of the weapon. The weapon's short range is usually the actual effective range because that's the longest range at which it does its maximum damage.

Range Bands: Choose the range bands which will be used in combat. Standard **Traveller** range bands are listed in **Table 126: Traveller Range Bands.**

Calculate Damage Value: The damage value depends on the intensity of the beam at a given range, or the energy per area delivered. At the effective range, the intensity is equal to the weapon's discharge energy divided by 1cm^2. For each range of interest, calculate intensity and damage.

Intensity: The intensity of the beam at any given range depends on the discharge energy and the ratio of the actual range to the weapon's effective range.

$$I = \frac{DE}{(R/R_{eff})^2}$$

Damage: DV is 5 times the square root of the intensity, times the damage modifier calculated above.

$$DV = 5DM\sqrt{I}$$

Supply Energy Requirements

You need to provide an accumulator bank capable of storing the required energy for a single shot, then supply power to charge the accumulator fast enough for the rate of fire you want.

Choose Rate Of Fire: Select how often you want to be able to fire the weapon. Rates higher than four shots per minute require increased cooling to handle the huge amounts of energy going through the accumulators and the tunnel.

Calculate Input Energy Per Shot: The input energy needed for one shot is 10 x Lap Energy. You need an accumulator big enough for this.

Calculate Power Required: In order to achieve the rate of fire you just calculated, you have to be able to supply power fast enough to recharge the accumulators. Power required is Rate of Fire x Energy Per Lap x Number of Laps per Shot / Length of Turn.

Calculate Tunnel Size

Determine how much space the weapon takes up, and how much it costs.

Tunnel Volume: The volume of the tunnel plus the cradle holding it I

$$\pi^2 \leftrightarrow R \leftrightarrow D^2$$

Tunnel Mass: The mass of the tunnel is its volume times the mass multiplier from Table 129.

Tunnel Cost: CPAWs cost MCr0.09 per cubic meter of tunnel volume. NPAWs cost MCr0.1 per cubic meter of tunnel volume.

Calculate Crew Requirements

Determine crew requirements: crew = Tunnel Volume x Computer Multiplier / 100.

Design the Carriage

Starship- or vehicle-mounted weapons don't require a carriage. However, if the weapon is intended to be a towed battlefield weapon, it needs a carriage.

Carriage Mass: The mass of the carriage is equal to the mass of the PAW.

Carriage Price: The carriage costs MCr0.002 per ton.

Armor: The carriage has a basic armor rating of 1. If you choose, you may enclose the PAW in a cylindrical chassis, per the vehicle design rules, and armor the chassis. Note that this increases the mass of the PAW and hence the mass of the carriage as well.

Planetary Bombardment Range

When bombarding a world from space, the weapon's performance is based on an "effective bombardment range," which is the actual range to the surface modified by the atmosphere in between the weapon and the surface. Since all worlds are different, this range has to be recalculated for each world. Divide the actual range by the appropriate atmosphere modifier in **Table 131: Atmospheric Range Modifiers.** Use this range only when determining damage. If you're designing a weapon to be used for frequent planetary bombardment, you might consider copying the table into the weapon description so it's always handy.

Meson Guns

Meson guns are an extremely advanced version of the particle accelerator. Instead of firing charged subatomic particles at the target, a meson gun collides these particles together. The product of such high energy collisions is a new particle called the meson. Mesons have two properties that make the weapon so useful: First, mesons don't interact with normal matter. That means that they go right through armor and anything else in the way, in a straight path. The second feature is that mesons quickly decay, producing radiation and ionizing particles. By carefully accelerating the mesons to relativistic speeds, the decay can be timed to occur at a chosen distance. That chosen distance is hopefully inside an enemy ship.

Design Sequence

Trace the following steps to build a meson gun.

Define Tunnel

Choose the basic features of the weapon.

Choose Tunnel Length (L): The length, in meters, together with the diameter, determine how far the tunnel can focus the beam.

Select Discharge Energy (DE): Choose how much energy you want coming out of the end of the tunnel with each shot.

Calculate Tunnel Characteristics

Using the values chosen above and **Table 132: Meson Tunnel Multipliers,** determine the effective features of the tunnel.

Effective Tunnel Length: The effective length of the tunnel is L_{eff} = Actual Length x Length Multiplier.

Tunnel Volume: The volume occupied by the tunnel is Vol = Actual Length x Discharge Energy x Volume Multiplier.

Tunnel Area (A): The area of the tunnel bore is A = Tunnel Volume / Actual Length.

Tunnel Mass: The mass of the tunnel is Mass = Tunnel Volume x Mass Multiplier.

Tunnel Cost: The cost of the tunnel is Cost = MCr0.1 x Tunnel Volume.

Calculate Performance

Now you determine the range and combat effectiveness of the tunnel.

Effective Range: This is the range at which the delivered energy intensity would still be the same as it is at the bore of the weapon. Effective Range = Effective length x 1,000km.

Short Range: Choose a beam pointer from the "Fire Control" section (page 69) to set the short range of the weapon. The weapon's short range is usually the actual effective range because that's the longest range at which it does its maximum damage.

Range Bands: Choose the range bands which will be used in combat. Standard **Traveller** range bands are listed in **Table 126: Traveller Range Bands.**

Calculate Damage Value: The damage value depends on the intensity of the beam at a given range, or the energy per area delivered. At the Effective Range, the intensity is equal to the weapon's discharge energy divided by $1cm^2$. For each range of interest, calculate intensity and damage.

Intensity: Intensity is Discharge Energy / $(\text{Range/Effective Length})^2$. Round $(R/EL)^2$ to the nearest 0.5 before dividing DE.

Damage: DV is 5 times the square root of the intensity.

Supply Energy Requirements

You need to provide an accumulator bank capable of storing the required energy for a single shot, then supply power to charge the accumulator fast enough for the rate of fire you want.

Calculate Input Energy Per Shot: The input energy needed for one shot is 5 x Discharge Energy (all MGs have efficiency of 20%). You need an accumulator big enough for this.

Choose Rate Of Fire: Select how often you want to be able to fire the weapon. Due to the need for intense cooling between shots, rates higher than one shot every twenty seconds aren't possible.

Calculate Power Required: In order to achieve the rate of fire you just calculated, you have to be able to supply power fast enough. Power required is Rate of Fire x Energy Per Shot / Length of Turn.

Calculate Crew Requirements

Determine crew requirements: crew = 0.01xTunnel Volume x Computer Multiplier. Each crew member requires a normal workstation (from the "Electronics" component chapter on page 69).

Design the Carriage

Starship or vehicle mounted weapons don't require a carriage. However, if the weapon is intended to be a towed battlefield weapon, it needs a carriage.

Carriage Mass: The mass of the carriage is equal to the mass of the meson gun.

Carriage Price: The carriage costs MCr0.002 per ton.

Armor: The carriage has a basic armor rating of 1. If you choose, you may enclose the meson gun in a cylindrical chassis, per the vehicle design rules, and armor the chassis. Note that this increases the mass of the meson gun and hence the mass of the carriage as well.

See Table 132.

Deep Site Meson Mounts

As a result of their ability to fire through normal matter, meson guns are a favorite weapon of planetary defense forces all over the galaxy. By burying a large meson gun and support facilities deep below the surface, and connecting it via secure links to sensor sites scattered all over the planet, you have a weapon which is virtually immune to counterattack. Not only are they very difficult to detect, but only another meson gun can attack them, and a planetary meson gun is generally bigger than anything a starship can mount.

Deep site meson guns are mounted inside a large spherical cavity and equipped with a CG carriage to allow them to aim in any direction desired. Adjoining the cavity is another cavern containing all the support facilities needed.

Weapon Cavern

Divide the length of the weapon by two to get the radius of the weapon. The site must be a sphere with a radius of 1.1 times the weapon radius. Volume of the site is then

$$\text{Vol}_{\text{site}} = \frac{4}{3}\pi R^3_{\text{site}}$$

Lift Carriage

To allow the weapon to aim in any direction, you need to not only counteract the bending stresses on the extremely long and thin tunnel but also be able to move it. In order to ensure maximum control, the entire volume of the weapon cavern needs to be lined with CG generators. Install CG capable of providing 10kN of lift per cubic meter of cavern.

Support Systems

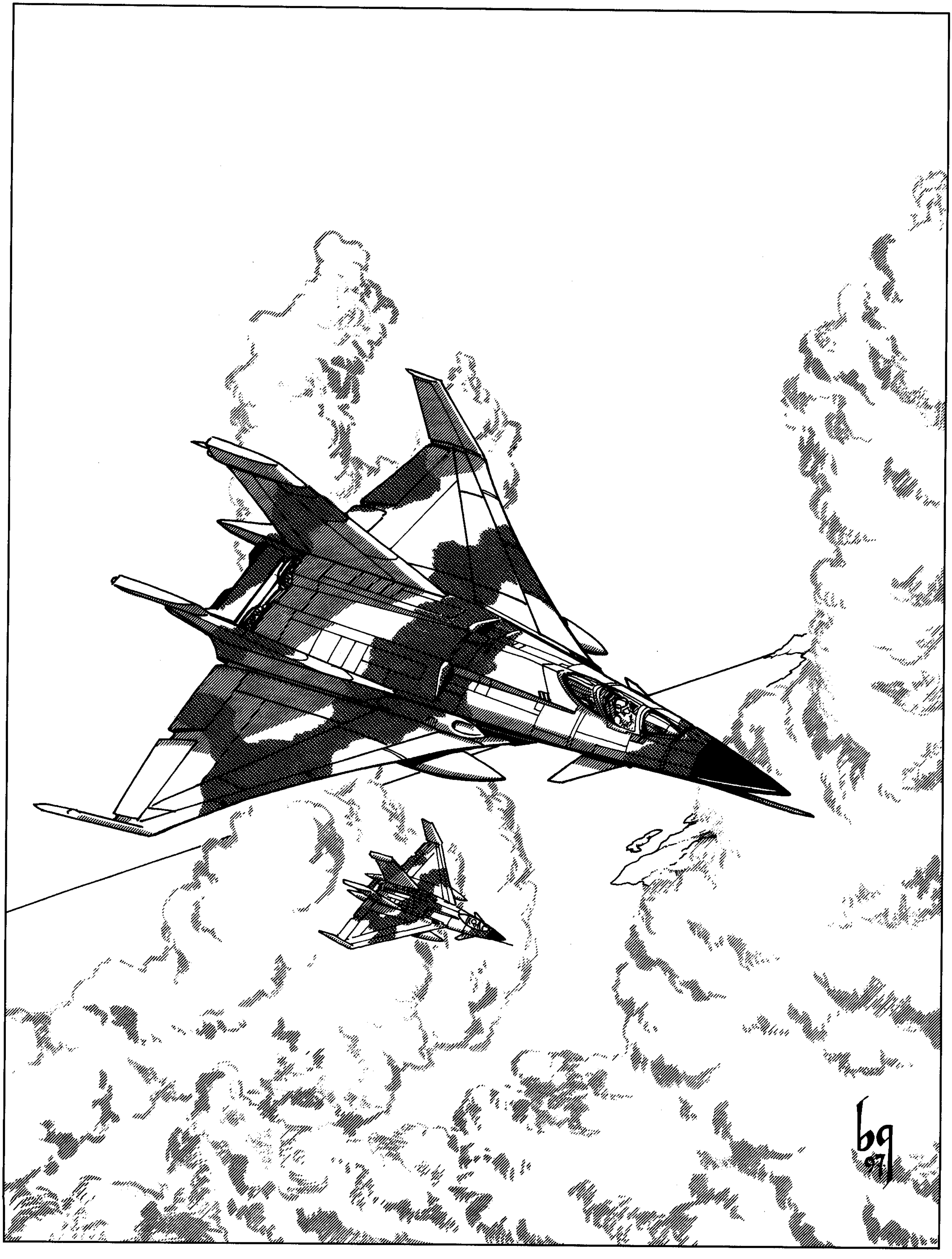
Fire control, crew, and power requirements are the same as for any other meson gun. In addition, you need to provide a power plant, life support, and accommodations for the weapon crew, plus a crew to run all those things. Add this volume in as well.

Surface Access

Twin high-speed elevators provide access to the surface. Choose the depth of the site, then multiply by a cross-section of 36 meters to get the shaft volume. Price of this is MCr0.001 per vertical meter of shaft.

Tunneling Costs

Finally, take the total volume you need to tunnel out, and multiply by Cr100 per cubic meter.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3: DEFENSE DESIGN

Now that you've designed spaceships, flying craft, ground vehicles, and weapons of all sizes, you should think about protecting your investment of time and credits. The most powerful ship in the cosmos is pirate fodder is it doesn't have a decent defensive system in place. This chapter should provide you with all the facts you need to take care of your possessions.

Electrostatic Armor

Electrostatic armor is an early attempt to create something resembling the "force fields" beloved of science fiction writers. A low-power static field is created around the target and linked to a high-energy accumulator. When something within certain parameters is detected entering the field, all the energy in the accumulator is dumped, (hopefully) vaporizing the object.

This discharge has no effect on lasers or PAWs (especially since they'll hit the target at the same time as they're detected), and it's difficult to provide enough power to completely vaporize heavy kinetic penetrators used by large-caliber projectile weapons. It's most effective with plasma streams from HEAP rounds and, of course, plasma and fusion weapons. The ESA system provides the equivalent of additional armor, to be added to the base armor value of the target's hull. For HE, HEAP, and plasma/fusion attacks, add the full armor value. For KEAP attacks, only add half. No AV is added for any other attack.

An ESA system consists of two parts: a field generator to create the static field and an accumulator bank to store the charge used.

Field Generators

The size of the field generator, as well as the effective AV, depend on the discharge energy and the size of the vehicle. The factors are listed in **Table 133: ESA Field Generator.** The effective AV is the power, times the armor value from Table 133, times the size multiplier from **Table 134: ESA Size Multiplier.**

For your convenience, a few predesigned field generators that are most useful for vehicles are listed in **Table 135: Predesigned ESA Generators.** These designs all assume a vehicle size of less than 14,000, so if you install them on larger vehicles, remember to multiply the AV by the AV multiplier.

Accumulators

Each ESA generator must have accumulators installed to provide the desired pulse of energy. These may be designed using the standard accumulators from the "Power Systems" component section (page 81).

Rate of Fire

An ESA's rate of fire (ROF) depends on how rapidly it can recharge its accumulators. Multiply the power input from the power plant (in MW) times the length of a combat round (in seconds), and divide by the discharge energy in MJ. The result is how many times in a combat round the ESA can add its protection to the vehicle.

Conversely, you can choose a rate of fire in discharges per round, multiply that by the discharge energy (in MJ), and divide by the length of a combat round (in seconds). That gives you the power you need to dedicate to the ESA to get your desired ROF.

Force Fields

Classic SF "force fields" or defensive screens come about at high tech levels as a result of an increased ability to manipulate subatomic particles and forces. The Third Imperium didn't acquire force field technology until the late 1000s, when several Ancient artifacts were discovered. Based on those, Imperial scientists were able to generate crude duplicates and gain some understanding of the technology involved. In a *Milieu:0* campaign these should be infinitely rare, and only in the form of inexplicable alien artifacts.

Early versions are effectively opaque to all radiation and matter from both the inside and the outside. Since this includes light, they're commonly referred to as "black globes." However, this particular feature presents some serious tactical problems—the enemy can't see in or shoot at you, but you can't see, shoot out, or maneuver either! The solution is to rapidly turn the field on and off, called "flickering." This allows limited maneuvering, and by timing weapons fire to the "off" periods, normal weapons fire.

Later technological advances produced a force field which is unidirectional, absorbing everything from one direction only (the outside) while allowing the ship inside to maneuver and fire freely. Since the globe absorbs incoming energy, sensors and incoming communications are still blocked. However, these new shields can also be tuned to allow certain frequencies through—by choosing frequencies not really useful in space combat, you can continue to scan, track, and communicate. Another feature of these advanced force fields is the ability to radiate energy out almost as easily as it's absorbed, hence the common name of "white globes." This is actually a critical feature, as you have to do something with the energy that's absorbed.

So what to do with all the energy absorbed? Black globes store this energy in an accumulator bank, which can then be used to power the ship's own weapons, or the generator itself. The size of the accumulator bank is critical, as the globe discharge catastrophically when it overloads. White globes, on the other hand, can discharge the energy nearly continuously, so there's much less chance of an overload.

Force fields cannot be used in an atmosphere or anywhere they would constantly be touching matter. They attempt to drain the matter of all its kinetic energy and almost instantly overload.

Field Generators

Select a generator from **Table 136: Force Field Generators.** The power given in the table is the power needed to create a small globe. If you need to create a larger one, multiply the power (only) by the factor in **Table 137: Force Field Size Multipliers.** Volume and mass remain the same regardless of field size.

Deployable Sensors

Deployable sensor arrays increase the effective size of the vehicle. If the force field is intended to protect the vehicle while the antennas are deployed, they must be designed for a volume at least as large as shown in **Table 138: Minimum Volume,** even if the vehicle is smaller.

Accumulator Design

After installing a globe, you also need to provide an energy store for it. Both black and white globes require accumulators. Black globes need enough capacity to store incoming energy faster than you can use it up with other systems, while the white globe has to cycle incoming energy through storage before it can be re-radiated.

The amount of storage provided is up to the designer. For black globes, think about how much damage you expect to be hit with each turn, and how rapidly you can use that energy up in other systems. White globes can discharge incoming power in a single turn, but you need to have sufficient accumulators to hold one turn's worth of damage. Considering that most spinal mounts have energies on the order of several thousand MJ, you probably want to be thinking in terms of millions of MJ for black globes.

For your convenience, the TL15+ portion of the accumulator table from the "Power Systems" section is repeated here. Multiply the storage capacity of the accumulator by the energy to be stored to get the volume in cubic meters. The table also includes several predesigned storage banks.

One cubic meter of accumulators masses 2 tons and costs MCr0.01.

Also note that jump drives contain accumulators as part of their design, and you may use those as well. 35% of the jump drive volume is accumulators, so multiply the jump drive volume by 0.35 and divide by the appropriate TL capacity from the table to determine how much charge you can store in the jump drive.

See Table 139.

Meson Screens

A meson screen is yet another example of the technology available once you acquire a solid understanding of the strong and weak nuclear forces, and the ability to manipulate them. A meson screen generator produces a field which slows and prematurely detonates high energy mesons before they penetrate far enough into the field to reach the ship or whatever is protected within.

To design a meson screen, choose the power input desired. From there, you can calculate the protection factor based on the tech level of the screen and the size of the ship. Volume: 20m^3/MW; mass 0.75t/m^3; antenna area 10m^2/MW; price 0.1MCr/m^3; crew is mass divided by 100, times Computer Multiplier (CM), with a minimum of 1. Each crew member requires a normal workstation as part of the screen installation.

Meson screens are rated by the Protection Value (PV) they provide against incoming meson fire.

For your convenience, **Table 142: Predesigned Meson Screens,** lists several "standard" screen designs. The protection value listed is for a ship smaller than 1,000T$_D$. For larger ships, divide it by the square root of the size modifier factor (also listed in **Table 141: Meson Screen Size Modifiers** for your convenience). See Table 140 as well.

Equation 65: Meson Screen Protection Value

$$\mathrm{PV} = \mathrm{TLMod} \leftrightarrow \sqrt{\mathrm{Power}/\mathrm{SizeMod}}$$

Nuclear Dampers

Like meson screens, nuclear dampers are a form of protection that depends on the ability to understand and manipulate the strong and weak nuclear forces, which affect the stability of atomic nuclei. A nuclear damper sets up interference patterns that create a series of positive and negative nodes. In the negative nodes, the forces are reduced (and hence the stability), while the positive nodes increase the forces. This allows you to both enhance and degrade nuclear reactions, both fission and fusion. The usefulness of this ranges from allowing damper boxes, used to store radioactive materials without danger of radiation or decay, to enhancing the strong nuclear force in fusion plants, allowing more efficient fusion reactions. This is why fusion plants exhibit such a drastic reduction in minimum size at TL12 as well as the ability to use regular hydrogen instead of deuterium.

As a defense, nuclear dampers can be used in one of two ways. Enhancing the strong force with a positive node prevents fission warheads from detonating by elimination the spontaneous emission of particles in a supercritical mass. This also protects against early fusion warheads, which require a fission trigger to detonate. However, more advanced fusion warheads are "pure" fusion and can only be stopped by reducing the strong nuclear force.

Damper Projectors

Unlike weapons, nuclear dampers have only one range, determined by the input power of the damper. **Table 143: Nuclear Damper Design,** lists the factors used to determine the size, range, and price of a nuclear damper. The "Min Power" column indicates the smallest power a damper can be designed to at that TL. All nuclear dampers mass one ton per cubic meter. You must also install a beam pointer with a range equal to the damper range.

Dampers used in space combat require a range of at least 30,000km to defend against detonation-laser missiles. For your convenience, **Table 144: Predesigned Nuclear Dampers,** includes a few ready-to-use dampers.

Damper Screens

In addition to the normal damper projectors, which are aimed at a given target, you can also install damper screens that effectively set up a single node, centered on the ship. By making this node large enough, you can protect against any incoming nuclear missiles. However, the power requirements to make the field large enough to protect against detonation lasers a tenth of a light-second away are prohibitive. The calculations below provide a field extending about 1,000 meters from the screen emitters.

To design a damper screen, choose the power input desired. From there, you can calculate the protection factor based on the tech level of the screen and the size of the ship. Volume is 20m^3/MW; mass 0.75t/m^3; emitter area 10m^2/MW; price 0.1MCr/m^3; crew is mass divided by 100, times Computer Multiplier (CM), with a minimum of 1. Each crew member requires a normal workstation as part of the screen installation. Damper screens are rated by the screen value (SV) they provide against incoming nuclear missiles.

Equation 66: Damper Screen SV

$$\mathrm{SV} = \mathrm{TLMod} \leftrightarrow \sqrt{\mathrm{Power}/\mathrm{SizeMod}}$$

See Tables 145 and 146.

Reactive Armor

Beginning at TL7, explosive reactive armor, or ERA, becomes available. ERA is a series of angled blocks or tiles placed over the outside of a vehicle. Each block consists of an explosive charge sandwiched between two metal plates. When a HEAP warhead strikes the outer plate, the charge detonates, and the resulting explosion blows the outer plate away from the vehicle. Since the plate is moving at an angle to the penetrator stream, it deflects part of the HEAP charge away from the vehicle as well.

Armor Value

ERA has no effect on solid penetrators, particle accelerators, or meson guns. It does work on HE and HEAP warheads as well as plasma/fusion bolts. ERA never adds its armor value unless it detonates. The ERA goes off whenever struck by a round with more than a damage rating of 10. From then on, one-twentieth of the ERA on that vehicle face is missing (having been exploded). Each time a round hits that vehicle side after that, roll 2d6. If the number rolled is equal to or less than the number of times the armor has detonated on that surface, the round hits bare armor; if it is greater than that number, the round hits an intact part of the ERA.

Note that reactive armor is worthless at the weapon velocities common in space combat.

Multiple Detonations

Whenever a tile detonates, there's a chance it sets off a neighboring tile as well. **Table 147: Explosive Reactive Armor,** lists a detonation number for each type of ERA. If the number or less is rolled on 2d6, another tile has detonated (and may set off a third, and so forth).

Multiple Layers

Up to three layers may be added, but each additional layer only adds half its armor value. The detonation number for multiple layers is the sum of all the detonation numbers.

Volume

Decide which faces are covered with ERA—normally it's only applied to one or two. The volume of ERA is then equal to 1cm times the surface area of that face (from the chassis design section), times 20.

Sandcasters

Sandcasters launch tiny reflective/ablative crystals, commonly called "sand," as a defense against lasers. These crystals are distant relatives of the tiny transparent spheres used to make street signs, painted strips and the like reflective. Such a sphere bounces a beam of light back in the direction of the source, with a small amount of spread.

The advanced crystals used in "sand" work similarly. When the laser first hits the crystal, part of the energy is reflected back in the general direction of the firing ship, and the rest is absorbed. As the beads absorb more of the pulse, they heat up and melt fairly quickly. But in free fall a liquid keeps its spherical shape, so the liquid bead continues to reflect a portion of the energy away. Eventually, the bead starts boiling, the energy absorption jumps dramatically, and it flashes into vapor. This vapor continues to absorb more of the laser pulse until it ionizes and forms a plasma. How much the vapor absorbs, and how easily it ionizes, depends on the composition of the bead.

Once it's a plasma, it may be very transparent or very absorbent, depending on the composition and the laser wavelength. Proper selection of crystal composition causes the plasma to be very opaque at common weapon-grade laser wavelengths. At higher TLs, the efficiency of the sand continues to increase. It's been mentioned more than once, by combat veterans, that "a laser interacting with sand is one of the best light shows ever . . . but it's also one I never want to see again."

Sand is dispensed in small canisters, and a cloud is placed between the ship and any enemy vessels which may fire on the ship. A single canister of sand provides the listed "effective AV" against laser attacks coming from a single enemy ship—defending against multiple ships requires multiple clouds of sand. As the sand absorbs an attack, its AV is reduced until it's gone. After each attack, the defender may choose to automatically replenish the sand.

Note that you have to at least have detected an enemy ship to be able to properly position the sand cloud. If the enemy isn't detected before he shoots, you won't be able to have sand in place. However, after the first hit, you'll know where the enemy is and be able to launch sand to protect against further attacks.

Sand Canisters

The protective value of a cloud of sand depends on how much sand is involved. While the standard canister size is 0.5m^3, **Table 148: Sand Armor Values** lists the armor value provided per m^3 of sand at each TL. If you choose to create a different size canister, multiply the canister volume by the AV listed.

Canister Dispensers

The canister dispenser contains both the mechanisms to dispense canisters as well as the magnetic or gravitic field generators used to control the cloud of sand. The size of the dispenser depends on the number of canisters carried and the tech level. Multiply the number of canisters times the canister size times the factor in **Table 149: Sand Launcher** to determine the size of the dispenser itself. This does not include the volume of the canisters contained within the launcher, which also needs to be added.

Standard Launchers

Table 150: Standard Sandcaster Turrets lists sandcaster launchers that can be placed in a standard 42m^3 socket (after the pointing mechanism has been removed).

Tractors and Repulsors

At very high tech levels, the science of gravitics reaches the point where you can project artificial gravity "beams." These beams can either be positively polarized (they pull something toward you, called "tractors") or negatively polarized (they push something away from you, called "repulsors"). Since tractors can only pull something toward you, they can't stop it from hitting you once it gets there. Combining tractors and repulsors produces a "manipulator."

Table 151: Tractors and Repulsors lists the amount of force at the projector available per cubic meter of installation. The range modifier is used to calculate the strength of the field at a given range—divide the strength of the projector by the product of the range and the range modifier.

All gravitic projectors mass one ton per cubic meters. Additionally, you need to install a workstation for the gunner operating the projector as well as a beam pointer to aim the projector.

4: WEAPON ACCESSORIES

Now that you've studied the design sequences, it's time to fill them with all the gadgets that make them work. You'll find the mechanical workings for weapon accessories, hulls, thrust agencies, electronics, life support and accommodations, and power systems. This is an engineer's walk through the candy store, so enjoy!

Small Arms

This section includes information on stocks and sights.

Stocks

Most small arms require some type of stock. Weapons that are mounted in vehicles and fired remotely do not require stocks. Select a stock from **Table 152: Stocks.**

Type

Stocks refer to rifle and pistol grips. Carbine stocks are generally fitted to rifles with short barrels (up to 80% of the ideal barrel length for the cartridge) or to sport versions of rifles. They are not considered sturdy enough for use on full-length military rifles. Weapons that are to be used exclusively from a tripod or vehicle require only a pistol grip instead of a full stock.

In Table 152, length is in centimeters, mass is in kilograms, and price is in credits.

Shock Absorbers

Shock absorbers can be built into stocks at TL5+, to absorb some of the recoil of the weapon. Shock absorbers can only be build into fixed rifle stocks until TL9, when folding shock-absorbing stocks become available. Prices and mass are in addition to the basic stock. See Table 153.

Sights

Sights fall into three categories: optic, laser, and advanced.

Optic

The design sequences assume basic iron sights on all small arms. Optic sights may be fitted instead of iron sights. These are rugged military versions of telescopic sights, which improve accuracy but do not provide the same long-range benefits of high powered (but delicate) civilian telescopic sights. Optic sights may not be used in combination with advanced sights. See Table 154.

Laser

A laser sight may be substituted for or added to any other sight. A laser sight allows rapid and accurate aiming, which allows the user to fire more aimed shots in a shorter period of time. The sight may only be used up to it's maximum listed range. See Table 155.

Advanced

Advanced sights may also be added. These sights add to the basic (iron sight) range of the weapon. Advanced sights may not be added to one-handed weapons. Advanced sights may not be used with optic sights. See Table 156.

Aircraft Weapon Mounts

Aircraft weapon mounts may be installed on spacecraft, grav vehicles, airships, helicopters, and of course, aircraft. These rules refer to all types of vehicles that carry aircraft weapon mounts as "aircraft." Except for gun mounts, the capacity of aircraft weapon mounts is listed in metric tons carried. Mounts that have a percentage capacity have the listed percentage of the aircraft's empty mass or the listed capacity in tons, whichever is greater. Fixed-wing aircraft may not carry more than 25% of their maximum mass as external stores. (External stores are weapons that are carried on hardpoints and launch rails.)

Example: An aircraft with an empty mass of one ton would have a fuselage hardpoint rated at two tons, so a 100-ton aircraft would have a fuselage hardpoint rated at 10 tons. An aircraft with two tons of external stores must be designed for a maximum mass of at least eight tons. Note, however, that the total actual mass of the aircraft may be less than the design maximum mass of eight tons.

Gun Mounts

The capacity of gun mounts is in terms of "Recoil Energy" (RE). The RE of a gun is the mass (in metric tons) of the gun carriage required for the weapon. Note that the carriage is not installed in an aircraft mount; the mass of the carriage represents the recoil energy of the weapon. Gun mounts that have a percentage capacity are capable of mounting weapons with a recoil energy up to the listed percentage of the aircraft's empty weight or the listed capacity, whichever is greater. Any ammunition for guns must be included in the aircraft's loaded mass.

Example: A half-ton aircraft with a TL5 fixed gun mount could mount a weapon with a recoil energy of up to 0.20. A 100-ton aircraft could mount a weapon with a recoil energy of up to 20.

Hardpoints

Hardpoints are locations or pylons on the wings or body of the vehicle where external weapons such as bombs, missiles, or various types of pods may be attached. Wing hardpoints include the cost and mass of adding stub wings to support the hardpoints on vehicles (such as helicopters and grav vehicles) which do not ordinarily have wings.

Hardpoints may be dry or plumbed.

Plumbed Hardpoints

Plumbed hardpoints have hook-ups to the aircraft's fuel system, allowing a fuel pod to be attached. Ordinary, or dry, hardpoints do not have this fuel plumbing and cannot carry fuel pods or tanks.

Bomb Racks

Ordinarily, hardpoints can mount only one bomb, missile, or pod. Bomb racks may be installed on hardpoints to allow a greater number of bombs to be carried on one of them. *Triple bomb racks* carry three bombs (of course), and *multiple bomb racks* carry six. Bomb racks do not have a listed capacity, but the total mass of the rack and the bombs installed on the rack may not exceed the capacity of the hardpoint.

Wingtip Launch Rails

Wingtip launch rails are special hardpoints designed to carry a single missile—usually a light air-to-air dogfight missile. Only one missile may be carried on each wingtip, and the missile may not mass more than 0.1 tons.

Bays

Internal bomb bays and retractable missile bays allow the aircraft to carry ordnance internally. Each ton of bombs or missiles carried requires one ton of mass designated for the ordnance bay. The bay itself has no mass when empty. The mass and cost per ton of ordnance bay is listed on the table.

Drag

Most types of aircraft weapon mounts cause drag, which reduces the speed of the aircraft. Drag quantities that are listed in parentheses only apply when weapons are loaded.

Example: A wingtip launch rail causes no drag unless it is loaded with a missile, in which case each rail causes one point of drag. A fully-loaded multiple bomb rack, installed on a inboard wing hardpoint causes a total drag of 5 (one for the loaded hardpoint and four more for the loaded bomb rack).

In Table 157, Drag amounts in parentheses apply only when the mount is in use. Mass is in metric tons. Price is in kilocredits (kCr, 1,000 credits).

Restrictions

Fixed-wing aircraft can have, at most, 25% of their designed maximum takeoff weight as external stores. There is no limit for helicopters. Ornithopters may not have wing hardpoints. Helicopters may have wing hardpoints; stub wings are included in the design (at no extra cost or weight) if wing hardpoints are specified. Helicopters that have fuselage hardpoints may not carry external loads.

5: HULLS AND STREAMLINING

Most vehicle design sequences (with the exception of the aircraft and airship sequences) require you to design a shell, or hull, to contain all the rest of the systems. There are three things you need to specify to create a hull. The first is the overall *size* of the hull. This determines how much volume is available for everything else, from armor to cargo bays. The next is the *shape* of the hull. Together, the size and shape of the hull set how much of the available volume will be taken up by armor and internal structure, and how much surface area is available for mounting external features. The final characteristic is the *streamlining.* All hulls are assumed to consist of some kind of interior skeleton which supports an external skin or shell. The shell serves to keep the insides of the vehicle in, the outside out, and it acts as armor against weapons.

Definitions

A few terms must be clarified to help you interpret the information presented in this section.

Acceleration

The acceleration of vehicles is defined in terms of "Gs," each of which represents one standard *gravity of acceleration.* The Imperium has defined the standard gravity to be 10.0m/s^2. For comparison, the surface gravity on Earth is 9.8m/s^2.

Configuration

Configuration is the shape of your hull. See **Figure 1: Hull Configurations** for examples. Spacecraft may use any of the configurations listed. The configuration of a hull affects how much internal structure it needs, how much surface area is available, and how much armor is required to get a certain rating. **Table 160: Hull Shape Modifiers** lists the various modifiers for each configuration, based on the reference shape which is a sphere. The table presents several versions of each configuration, with different proportions. For example, under "cylinders" the short cylinder is as long as it is wide, the medium cylinder is twice as long as it is wide, and the long cylinder is 3.5 times as long as it is wide.

Displacement

Based on long-standing tradition dating back to the Ramshackle Empire, spacecraft are customarily recorded in official documents according to their "displacements." This refers to how many tons of liquid hydrogen (LH_2)—the most common fuel—they would displace. One ton of liquid hydrogen has a volume of 14m^3, which is referred to as one *displacement ton,* or T_D. However, this is a rather large unit and is often inconvenient during design. It also has little if any relationship with day-to-day life and can be hard to visualize. So "displacement" is reserved for official documents and designs are actually carried out using m^3.

Surface Area

An important limitation in designing a any vehicle is how much surface area is available on the hull. Sensors, weapons, heat radiators, and drives all require a place on the surface of the hull, and once you run out of area, you can't add anything more.

Stealth

By carefully shaping the hull, it's possible to provide some control over how the hull reflects energy back to a sensor.

Each level of stealth reduces the signature of the hull for active sensors. Specific effects are explained in the "Sensors" component section (page 72) and in the "Space Combat" rules in the **Traveller** core rules book.

Armor Materials

Table 158: Hull Materials lists the various materials available by tech level, which you can use to build a hull or a chassis.

Toughness is a measure of the material's strength and resistance to damage. Density is how much one cubic meter of the material masses. Price is the cost of one cubic meter, and it represents both the cost to purchase the raw material and the labor involved in working it into the right shape.

Soft Steel: A soft alloy of iron and carbon.

Hard Steel: A somewhat harder alloy of iron and carbon.

Composite Laminate: Composed of layered metal/ceramic fibers and binders.

Light Ceramic Composite: A more advanced form of composite, *LCC* is more expensive than composite laminate but offers better strength for the weight—most useful for high-performance applications where cost is a secondary consideration.

Crystaliron: An iron alloy with perfect crystal structure combined with carefully controlled impurities, providing maximum toughness and hardness for an iron alloy.

Superdense: A material whose molecular structure has been partially collapsed by intense artificial gravity fields, increasing both density and strength.

Advanced Composites: Less durable than TL 12 superdense but lighter and cheaper. Advanced composites are normally used in civilian and commercial structures, where armor factor is less important than cost.

Bonded Superdense: Armor with internal electron bonds, further strengthened by a small induced electrical current. Note that unlike other armors, bonded armors have a power requirement listed in the table. This power requirement represents the induced current used to strengthen the material. If all power is lost, the armor's strength reverts to that of normal superdense.

Enhanced Bonded Superdense: Benefits from refinements in material technologies that allow improvements to be made on standard bonded superdense materials, at TL15.

Collapsed Crystalline: Incorporates refinements in bonded superdense technology, with advances in crystalline carbon materials discovered at TL16.

Coherent Superdense: Bonded superdense with the current dynamically controlled by the computer, based on sensor readings, to polarize subatomic forces in the hull and maximize resistance in the area of a weapons hit.

Enhanced Coherent Superdense: The ultimate extension of 'conventional' technologies, this material incorporates improvements in coherent superdense material production available at TL18.

Basic Hull Size

To avoid complex calculations for volume, surface area, internal structure, and so on, this book uses a simple system based on a spherical shape. Values for other shapes are then derived from that spherical reference ship by means of simple multipliers. Use **Equation 67: Basic Hull Factors** to compute the characteristics of a spherical hull, or select a predesigned hull from **Table 159: Basic Hull Size.**

Hull Configuration

Configuration is the shape of your hull. See **Figure 1: Hull Configurations** (page 103) for examples. The configuration of a hull affects how much internal structure it needs, how much surface area is available, and how much armor is required to get a certain rating. **Table 160: Hull Shape Modifiers** lists the various modifiers for each configuration, based on the reference shape of a sphere. The table presents several versions of each configuration, with different proportions. For example, under cylinders, the short cylinder is as long as it is wide, the medium cylinder is twice as long as it is wide, and the long cylinder is 3.5 times as long as it is wide.

Streamlining

Streamlining specifies how much attention was paid to airflow over the hull, which affects the ship's performance in an atmosphere. **Table 160: Hull Shape Modifiers** lists the cost factors for adding different types of streamlining to each configuration, if it's possible. (Otherwise the table says "N/A.") Once the overall type of streamlining is determined, the speed regime is selected from **Table 161: Streamlined Hull Speed Regime** (for streamlined configurations or **Table 162: Airframe Hull Speed Regime** (for airframe configurations.

Airframe

With this design, atmospheric performance and the airflow over the hull were prime considerations in the design of the hull. All protuberances were kept to a minimum. The hull has full atmospheric maneuverability and generates lift so it can take off from worlds with a surface gravity greater than its G-Rating. Compute the speed of the hull in an atmosphere using the "Atmospheric Performance" rules (page 68) and the vehicle's acceleration. Airframe hulls are normally equipped with contragravity units, so minimum speeds can be ignored and the (extremely long) runways for takeoff and landing are not required. If contragravity units are not installed, compute the takeoff and landing rolls, and ensure that the vehicle's thrust is sufficient to give it a speed above the minimum speed for the airframe. Airframe hulls that are capable of hypersonic flight may skim gas giants for hydrogen fuel.

Streamlined

With this design, airflow over the hull was considered as an afterthought. Sharp edges were rounded off, and protuberances were covered by a fairing. However, the hull does not generate lift. Compute the speed of the hull in an atmosphere using the "Atmospheric Performance" rules (page 68) and the vehicle's acceleration. Streamlined hulls are normally equipped with contragravity units, so they can take off and land on any world with ease. Streamlined hulls capable of hypersonic speeds may skim gas giants for hydrogen fuel.

Unstreamlined

The hull was not designed to operate in an atmosphere. Sharp edges, antennas, bracing, and all kinds of other things stick out from the hull at various places. This hull is extremely vulnerable to wind turbulence and shouldn't land on any planet with greater than a trace atmosphere. If you do, you run the risk of damage or loss of control due to wind turbulence. Unstreamlined hulls are not normally designed for any type of planetary landing but can be capable of landing on airless worlds at the designer's option. Hulls intended for planetary landings are normally equipped with contragravity units. Unstreamlined hulls may not skim gas giants under any circumstances.

Design Sequence

Follow the steps below, in order, to design your hull.

1. Hull Size

The first step is to choose the desired hull size. Look up your desired hull size in **Table 159: Basic Hull Size**. This table lists the diameter and surface area for a spherical hull shape. The structural factor is used to determine the amount of internal structure needed. You may also calculate these factors using **Equation 67: Basic Hull Factors.**

(a) $$\text{Diameter} = \sqrt[3]{\frac{6 \leftrightarrow \text{Volume}}{\pi}}$$

(b) $$\text{Area} = \pi \leftrightarrow \text{Diameter}^{2}$$

(c) $$\text{SF} = \frac{\sqrt{\text{Vol}^{3}}}{225{,}000}$$

2. Hull Configuration

After choosing the size of the hull, your next most important choice is the shape of the hull. Each shape has different surface areas compared to the default sphere, as well as different costs to manufacture and modify. **Figure 1: Hull Configurations** shows the different configurations available while **Table 160: Hull Shape Modifiers** lists the various factors which apply.

A. Available Surface Area

Multiply the surface area of a sphere by the surface modifier to find out how much surface you have.

B. Streamlining Cost Modifiers

These factors modify the price of the hull's external shell, calculated further below, based on what type of streamlining you choose. If a cost modifier is listed as "N/A," then that form of streamlining is not available for that configuration.

i) USL

Choosing USL does not streamline the craft at all, and no streamlining modifiers may be chosen.

ii) SL

Choosing SL allows ordinary streamlining to be added to the hull, using the characteristics from **Table 161: Streamlined Hull Speed Regime.**

iii) AF

Choosing AF allows airframe streamlining to be added to the hull, using the characteristics from **Table 162: Airframe Hull Speed Regime.**

C. Dimension Modifiers

The length of your hull is equal to the reference sphere's diameter times the length modifier. The same goes for width and height.

3. Streamlining Modifications

Adding streamlining to the hull changes several of its characteristics. The type of streamlining that can be added is determined by the configuration. The waste volume and area, as well as the total cost of the streamlining, depend on the speed regime selected for the hull.

A. Wings

If the configuration of the hull is AF, the surface area is increased by 30%. This extra area represents the added surface of the wings. For supersonic and above, the square root of the wing area times two is the total wingspan (the width of both wings together). For subsonic airframes, the square root of the area times three is the total wingspan. Add this to the width calculated above for the body itself.

B. Waste Volume

If the hull is 1,000 cubic meters or less, multiply the waste volume factor from the appropriate streamlining table by the total volume of the hull to find the volume rendered unusable due to the streamlining. If the hull is over 1,000 cubic meters, compute the waste volume as if for a 1,000-cubic-meter hull.

C. Waste Area

If the hull is 1,000 cubic meters or less, multiply the waste area factor from the appropriate streamlining table by the total volume of the hull to find the area rendered unusable due to the streamlining. This represents the area taken up by hatches, control surfaces, and so forth. If the hull is over 1,000 cubic meters, compute the waste area as if for a 1,000-cubic-meter hull.

D. Price Multiplier

Multiply the streamlining cost modifier from step 2B, above, by the additional price multiplier from the speed regime table. This is the final streamlining cost modifier used to compute the price of the hull shell.

E. Minimum Speed

If the hull has wings, there is a minimum speed below which the wings fail to generate enough lift to keep the hull aloft. Note this minimum speed, as the vehicle must generate sufficient forward thrust to exceed this speed or the vehicle will not be able to fly.

F. Maximum Speed

The streamlining selected determines the hull's maximum speed at altitude in an atmosphere.

G. Thrust Efficiency

Thrust efficiency determines how efficient the hull is at moving through an atmosphere. This value is used when evaluating the hull's atmospheric performance.

4. Armor

The next step is to calculate how much volume is taken up by the skin and armor plating of the hull. To simplify things, volume of the armor is the thickness of armor desired times the area of the hull. For all but the tiniest hulls, this is close enough for game purposes. First, choose the armor material desired from **Table 158: Hull Materials.**

A. Armor Thickness

To determine how thick the hull needs to be, based on a desired armor rating, divide the armor rating by the material toughness. This gives you a hull thickness in cm. The absolute minimum armor rating required is 20 for spacecraft, 1 for grav vehicles, and an absolute minimum thickness (regardless of actual armor value) of 0.25cm for ground vehicles.

B. Armor Volume

Divide the thickness by 100 to get thickness in meters, then multiply by surface area to get the total volume taken up by the armor. Remember, this comes out of the available volume.

C. Armor Mass

The mass of the armor is the density times the volume.

D. Armor Cost

The cost of the armor is the volume, times the price, times the streamlining price modifier listed in **Table 160: Hull Shape Modifiers**.

5. Internal Structure

Now that you've got everything else, you can calculate the volume taken up by the internal structure which supports everything.

A. Structure Volume

The volume of the internal structure depends on the volume of the hull, the maximum acceleration of the ship, and the toughness of the material used. Multiply the structural factor by the maximum acceleration, then divide by the toughness. This gives you the volume of the internal structure.

B. Structure Mass

The mass is simply density times volume.

C. Structure Price

The price of the internal structure is the volume times the material price. Do not multiply this by the streamlining price modifier used for armor; internal structure is independent of streamlining.

6. Stealth

If desired, the hull may be shaped for stealth. For each level of stealth desired, multiply the armor price by 5. However, in order to keep the stealth characteristics of the shape, everything placed on the surface of the hull has to be specially contoured and shaped as well. For any surface features other than drives and radiators, multiply the volume of the component by 1.1 and the surface area needed by 1.25 to account for extra contouring and shaping needed.

7. Hull Coatings

A normal starship hull at TL10+ is equipped (at no extra cost) with a color-changing coating. Normally used by merchants for advertising purposes, in combat situations the coating is set to moderate (99%) black to reduce emitted signature. The signature calculated elsewhere for vehicles assumes the hull is set to moderate black. "Bare metal" (or painted non-black) hulls get a discount on hull price of MCr 0.01 per m^2. At TL8-9, all hulls are bare metal (with no discount). A TL 8-9 hull may be permanently painted black at a cost of MCr 0.01 per m^2. At TL11+, the color-changing coating can be enhanced to a "military black hull." This costs MCr0.01 per m^2 of hull. At TL13+, military ultrablack hulls become available, costing MCr 0.1 per m^2 of hull.

6: THRUST AGENCIES

This section covers components for rocket thrust, atmospheric thrust, fuels, space performance, and atmosphere performance.

Rocket Thrust

Rockets can be propelled through advanced drives, contragravity, primitive rockets, nuclear rockets, exotic drives, and solar sails.

Advanced Drives

Advanced drives use either HEPlaR (High-Efficiency Plasma Recombustion) or reactionless thrusters.

High-Efficiency Plasma Recombustion

The most efficient reaction thruster available, HEPlaR adds a heat exchanger/recombustion chamber to any existing fusion (not Fusion+) power plant. Hydrogen injected into the chamber is heated to a plasma state, then magnetically accelerated further to produce a high-velocity stream of reaction mass. HEPlaR thrusters require input power.

Reactionless Thrusters

One of the many effects of the TL11 mastery of gravitics is the invention of reactionless thrusters, also known as thruster plates. Where "contragravity" at earlier tech levels can only interact with the local gravitational field (and is hence limited to working near a planetary surface), thruster plates actually use the curvature of space in a different manner, basically by "grabbing" on to it. However, thruster plates have a limitation as well. Rather than degrading slowly with local gravity, like contragravity, thruster plates work normally until the curvature reaches a threshold. Below that threshold, quantum-gravitic effects drastically cut the effectiveness, by a factor of a hundred or more. That cutoff level turns out to be around 2,000AU for a normal, Sol-like star. Thus, thruster-plate equipped ships can't maneuver effectively in deep space although they can still hold position and make minor course changes. Ships intended to routinely work out beyond the cutoff are generally designed with some form of auxiliary propulsion that isn't similarly affected (fusion rockets or HEPlaR are the most popular).

Power Requirements

Unlike primitive drives, HEPlaR and thrust plates don't produce power—they need power to operate. Power plants and power plant fuel are handled later. See Table 163.

Contragravity

At TL9, the burgeoning science of gravitics allows vehicle designers to manipulate the local gravity field and create a lifting force. Most of the force is directed parallel to the gravity field (straight up and down), but a fraction can be diverted horizontally to provide thrust as well as lift. The thrust factor column in **Table 164: Contragravity Drives** indicates the portion of the drive's lift that can be used for propulsion. If you need greater thrust, some other form of auxiliary propulsion needs to be added to the vehicle. Also note that in level flight, the lift must equal the weight, and hence the maximum thrust available, in kN, will be equal to 10 x Thrust Factor x Loaded Mass.

Contragravity is used mainly by grav vehicles for lift and propulsion. However, spacecraft often also mount contragravity to assist in takeoff and landing, especially on worlds where the local gravity is greater than the ship's main maneuver drive's rating.

Primitive Rockets

Primitive rockets rely on chemical combustion to produce an extremely hot, high pressure gas which is then vented through a nozzle to provide a high-velocity exhaust stream. The thrust generated by a chemical rocket depends on the external atmospheric pressure as well as the nozzle design—a rocket engine designed for launch from the ground does not generate the same amount of thrust in a vacuum. For simplicity, the numbers below are all based on a vacuum.

Solid Rockets

Solid rocket fuels consist of a puttylike mixture of a propellant and an oxidizer, with some form of hollow core where the rocket is ignited. By properly shaping this core, you can control how the rocket burns. It's possible to vary the thrust over time. (For example, to have thrust decrease as the rocket burns, to keep constant acceleration.) For simplicity, we assume that solid rockets produce a constant thrust. **Table 165: Solid Rockets** lists the performance of solids at different tech levels.

Solid rockets are handled somewhat differently than liquids. Where liquids have a thrust chamber that determines how much thrust you can produce—with the amount of fuel carried determining how long you can thrust—solid fuel basically *is* the thrust chamber. The same amount of rocket fuel can produce very high thrust for a very short time, or very low thrust for a longer time, depending on how it's arranged, but it's still the same amount of fuel. The product of thrust and time is called "impulse," which is a constant for a given amount of fuel.

Unlike other drives, Table 165 lists impulse instead of thrust. By changing how you arrange the fuel, you can increase or decrease how long it takes for the fuel to be consumed and thereby decrease or increase the thrust it produces while burning. For example, a 1,200kN's rocket can produce 1,200kN for one second or 1kN thrust for twenty minutes. Decide on the thrust you want (in kN) and how long you want to produce it (in seconds). Multiply the two together to determine the total impulse you need, and divide by the impulse per cubic meter listed in the table. That tells you how much propellant you need.

Hybrid Rockets

One drawback to solid rockets is inherent in their nature: Once you ignite the propellant, the rocket burns until it's all gone. You can neither throttle it nor stop it. The hybrid rocket is an attempt to overcome this. A hybrid rocket is a sort of mix between a solid and a rocket. One component, usually the propellant, is solid and cast identically to a regular solid rocket. The other component, usually the oxidizer, is a liquid and is fed into the solid propellant core to allow combustion. By controlling the amount of oxidizer injected, you can control the thrust of the rocket. For simplicity, hybrid rockets are included with solids and are designed the same way.

Liquid Rockets

A liquid rocket carries its propellant and fuel as two separate liquids, which are combined in the thrust chamber to produce thrust.

Liquid Hydrogen and Liquid Oxygen

A more advanced version of the liquid rocket is the liquid hydrogen/liquid oxygen rocket. Somewhat more technically advanced, liquid hydrogen (LH) and liquid oxygen (LOX) are more difficult to store and handle but provide better performance than less complicated fuels like kerosene.

Hypergolic

Hypergolics are another type of liquid fuel. Getting the fuels ignited isn't always a simple task in liquid rockets, especially in space or hostile environments. Hypergolics deal with this problem by choosing fuels that react spontaneously to each other and ignite (often explosively) without any need for outside ignition methods. This simplicity is offset by the fact that they're chemically unstable, very reactive, and highly toxic to boot.

High Density Liquid

Most liquid rockets use fairly light fuels and hence require larger fuel tanks. In an attempt to cut down on the tank size, engineers started experimenting with more dense fuels (primarily the oxidizer).

See Table 166.

Nuclear Rockets

Nuclear thermal rockets (NTR) pass a liquid propellant—usually liquid hydrogen—through a reactor core, heating them and expelling the superheated steam. These are very simple and remarkably clean drives, as long as the reactor core is in good shape. An NTR can use just about any chemically inert fluid as a working medium without major problems or even redesign. However, note that most fluids are significantly denser than hydrogen. You'll get more thrust, but the increased mass of the propellant outweighs that and may drive the ship over its maximum mass.

Advanced NTR, at TL8, is simply a more effective version of the normal NTR.

Gas Core NTR

Instead of using a solid reactor core and passing the working fluid through channels in that, the gas core NTR uses a gaseous core nuclear reactor.

Fusion

Appearing experimentally at TL8 and perfected at TL9, a fusion rocket is simply a fusion reactor designed to "leak" fusing hydrogen plasma, under control, out one end. Although it's extremely fuel efficient, it can also be a rather dangerous drive. The exhaust stretches for a few hundred kilometers and is somewhat radioactive. Using these in an atmosphere or in a crowded orbital approach corridor is usually viewed as an act of war!

Crew and passengers of any ship passing through the wake within 200km of the ship suffer serious radiation sickness unless wearing radiation-protective equipment, and they require medical treatment over the next few months for a full recovery. Onboard electronics, unless hardened against EMP, suffer spontaneous errors or resets. See Table 167.

Exotic Drives

If you're an inventor as well as an engineer, you might have a few exotic drives of your own in mind. This section covers ion drives, Daedalus drives, and the Bussard ramscoop.

Ion Drive

Ion drives are very efficient, low thrust drives currently being considered for use as stationkeeping thrusters or for long-duration space missions. A noble gas such as xenon is stripped of electrons (creating an ion, hence the name), accelerated through a series of charged grids, and expelled out the back of the drive. An electron emitter returns the "stolen" electron to the ions as they leave, ensuring that a static charge doesn't build up on the ship.

Daedalus Drive

First proposed by the British Interplanetary Society as the drive for their Daedalus interplanetary probe, this drive produces "pulses" rather than a steady thrust. Hydrogen fuel in the form of deuterium/helium-3 ice pellets are injected into an ignition chamber and hit by multiple high-power lasers arranged around the outside. This causes a minute thermonuclear explosion which pushes the ship forward. However, the exacting manufacturing requirements for the fuel pellets drive an exorbitant price.

Bussard Ramscoop

One of the biggest problems for primitive societies in traveling interstellar distances at sublight speed is the fuel requirements of any primitive drive. If you want to travel between stars at sublight speeds and want to spend years instead of hundreds of years doing it, you need to get up to a healthy fraction of the speed of light. Fuel is a definite limiting factor there. The Bussard ramscoop is a way to get "free" fuel. Space isn't really a perfect vacuum (although it's close enough for you and me); there are actually a few atoms per cubic centimeter scattered around—mostly hydrogen. And hydrogen is useful for a fusion drive, so you just need to gather it up. Rather than building a physical scoop several thousand kilometers across (which is what you'd need), the Bussard ramscoop uses superconducting magnets at the base of the scoop to generate a wide magnetic field instead. The hydrogen gathered is then used to fuel a standard fusion drive.

One limitation to the Bussard ramscoop is its minimum velocity: To be able to scoop enough fuel to power the fusion drive, the ship has to be moving at about 1% of the speed of light, or 30,000m/s. To get up to that speed, it can either use a booster of some kind, which drops away after the combination has reached the ram speed, or it can carry enough fuel to run the fusion drive like a regular fusion drive. See Table 168.

Solar Sails

Solar sails are large, extremely lightweight reflective surfaces that rely on the physical pressure of light to generate thrust. As you can imagine, they are an extremely leisurely way to move around a solar system and are not usually used for any commercial or military vessels. However, the *Terra's Cup* solar sail races are probably the biggest tourist draw in the Terran system, with a course that starts in orbit around Terra, loops in around Venus, and then out past Saturn and Jupiter before returning to Terra's moon, Luna. Rich yachtsmen and syndicates from dozens of parsecs around make the pilgrimage every 25 years to participate, and they spend much of the time in between plotting and scheming on how to win next time.

In the habitable zone of a star, solar sails generate 0.005kN thrust per square kilometer of sail. One square kilometer requires 10 cubic meters for storage when stowed. See Table 169.

Atmospheric Thrust

Atmospheric thrust is generated through propellers and jets or helicopter rotors.

Propellers and Jets

Table 170: Aircraft Thrust Agencies gives thrust agencies in kN of thrust per cubic meter of thruster. (1kN is the thrust required to accelerate 1 metric ton at 1 meter per second per second: 0.1G or one-tenth of a standard gravity.) Figures include all components required to produce thrust: the engine, engine mount, propellers, ducts, nozzles, engine cooling, and so forth as applicable. All of these engines burn hydrocarbon distillates (HCD) and can provide 2kW (0.002Mw) of electrical power per kilonewton of installed thrust. Designs that require more electrical power should install supplemental power supplies.

All thrust agencies mass one ton per cubic meter and provide 2kW of electrical power per kN of installed thrust. Thrust is the thrust output in kilonewtons per cubic meter of thruster. Price is the price in millions of credits per cubic meter of thruster. Power is the electrical power output (in addition to thrust) per cubic meter of thruster. Fuel is the fuel consumed per kilonewton of thrust for an hour of continuous operation. Airframe is the fastest airframe that the thruster can be installed on.

Ramjet engines must reach a speed of 800kph before the engine starts; SCRAMJet engines must reach a speed of 1,200kph before the engine starts.

Jet Thrust Options

See Table 171.

Afterburners

Reheat, or afterburners, can be added to any turbojet, turbofan, or high-bypass turbofan at TL6 or above. Afterburners inject additional fuel into the hot exhaust, which provides additional thrust. Adding afterburners multiplies the engine volume, cost, and mass by 1.1. When in use, the afterburners multiply thrust 1.5 and multiply fuel consumption by 2.

Advanced Zero-speed to Hypersonic (AZH)

AZH engines include a wide variety of exotic engine types that are designed to function at all speed and altitude ranges, from the low-speed, low-altitude regime (for takeoff and landing) to hypersonic speeds at high altitudes, all the way to suborbital and orbital-insertion profiles. AZH engines support all of these flight regimes at no additional volume, mass, or cost.

To support this wide range of operating conditions, AZH engines have three operating modes: turbojet, ramjet, and rocket. The values listed on the table are for an AZH engine operating in turbojet mode. When operating in ramjet mode, the AZH engine thrust is multiplied by 1.66 and fuel consumption is multiplied by 4. When operating in rocket mode, AZH engine thrust increases 2.5 times over turbojet mode and fuel consumption is multiplied by 9. AZH rocket mode requires a supply of hydrogen-oxygen rocket fuel (HRF), separate from the normal supply of hydrocarbon distillates (HCD) used in turbojet and ramjet modes. Each ton of hydrogen-oxygen rocket fuel occupies 3.33 cubic meters of volume.

Atmosphere Type

Table 170: Aircraft Thrust Agencies gives the characteristics of the thruster in a standard atmosphere. These thrust agencies are usable in thin, standard, and dense atmospheres (including the tainted variants of each, if the taint is compatible with engine operation). Different atmospheres affect the thrust and fuel consumption of the thrusters. Thin atmospheres reduce the thrust of all propeller thrusters (including turboprops) by 50%. Other power plants are unaffected. Dense atmospheres increase the fuel consumption of all jet thrust agencies (including turboprops) by 50%.

Helicopter Rotors

Helicopters rely on overhead rotors for both lift and thrust, much the same way that grav vehicles use contragravity for lift and thrust. The rotors, along with the required gearboxes, transmission assemblies, and drive shafts needed to convert engine power into lift are termed "rotor assemblies." Like contragravity generators, helicopter rotors require a separate source of power.

Choose a rotor assembly from **Table 172: Rotor Assemblies.** Install a total lift equal to or greater than the maximum takeoff weight of the aircraft. The helicopter's thrust is equal to the lift multiplied by 0.10. If additional thrust is desired, install additional thrust agencies (usually turbojet or turbofan). The table gives the characteristics of rotor assemblies per kN of lift.

Fuels

Different types of drives require different kinds of fuel. Most chemical rockets, whether liquid or solid, need both a propellant and an oxidizer. The oxidizer provides the oxygen necessary to burn the propellant, creating a large volume of very hot gas. For simplicity, the numbers listed in the table are for the oxidizer and propellant combined, in the proper proportions, even though they're stored separately.

Note: There's a difference between hydrogen rocket fuel (HRF) and liquid hydrogen (Lhyd)—one is liquid oxygen/liquid hydrogen for chemical rockets, and the other is pure liquid hydrogen for HEPlaR, fusion plants, jump drives, and so on.

Basic fuel tanks require volume equal to the amount of fuel, cost nothing, and mass nothing when empty. More options are available in the "Miscellaneous Components" chapter (page 14). See Table 173.

Space Performance

Vehicles that travel in space must use thrust devices which operate in the space environment, such as rockets or advanced thrusters. The speed that a vessel can achieve in space is limited only by the vessel's acceleration and the amount of time the drives can maintain that acceleration.

Compute a space vehicle's acceleration, in meters per second per second, by dividing the mass of the vehicle, in tons, by the total thrust, in kilonewtons. Spacecraft acceleration is typically expressed in Gs. Divide the acceleration in m/s^2 by 10 to determine acceleration in Gs.

Atmospheric Performance

The key factors in atmospheric performance are weight and drag, thrust, glide ratio, acceleration, and speed.

Weight and Drag

Consider the effects of weight and upon aircraft, grav vehicles, and spacecraft.

Aircraft

For aircraft, the maximum takeoff mass was determined at the beginning of the design sequence. Ensure that the sum of the masses of all of the components—including external stores, fuel, cargo, ammunition, and ordnance in internal bays—is less than this amount. For fixed-wing aircraft with external hardpoints, no more than 25% of the aircraft's maximum takeoff mass may be carried on the external hardpoints.

Fixed-wing aircraft that carry stores on external hardpoints also have a maximum internal load (or "clean" mass). This is the mass of the aircraft without any external ordnance but with a full internal fuel load and all ammunition and ordnance that is carried internally.

Some aircraft may have additional configurations. Calculate the mass for these configurations. (For example, a dual-role fighter may have an "air superiority" configuration with only four air-to-air missiles and a maximum air-to-ground configuration with all of the hardpoints loaded with heavy bomb racks.)

For aircraft that have external hardpoints, total the number of drag points for each configuration.

Grav Vehicles

For grav vehicles, calculate the total loaded mass. Grav vehicles that have external hardpoints also calculate drag points as per aircraft. Note that the main turret already has a reduction in speed associated with it, so it incurs no drag points here. Some grav vehicles may have additional configurations; if so, calculate the mass for those configurations as well.

Spacecraft

For spacecraft, calculate the total loaded mass. A spacecraft turret or bay incurs one drag point per $10m^2$ of surface area. Grapples incur one drag point per 25 cubic meters of carried craft. Some spacecraft may have additional configurations; if so, calculate the mass for these configurations as well.

Thrust

Total the thrust of all of the vehicle's engines to find the total thrust in kilonewtons (kN). Remember that helicopter rotors provide a thrust equal to 10% of the lift. Also remember that the thrust available from contragravity is limited by the "thrust factor" multiplied by the total lift generated (which can't be greater than the vehicle's weight).

Glide Ratio

All fixed-wing aircraft, airframe grav vehicles, spacecraft, and compound helicopters with Main + Tail Rotors or X-Wings have a base glide ratios of 5, adding 1 for every 5% of the airframe devoted to maneuver enhancement. STOL aircraft double their glide ratio. Compound helicopters are not considered STOL for this purpose.

Subtract 1 from the glide ratio for every drag point the aircraft has (exclude drag points due to the STOL airframe option).

All ornithopters have a glide ratio of 20. All other helicopters may autorotate to unpowered landings and do not have a meaningful glide ratio.

Acceleration

For each configuration of the vehicle, divide the total thrust by the total mass. If the aircraft includes afterburners, perform the calculation twice (with and without afterburners). If the aircraft includes AZH engines, perform the calculations for each mode the engine operates in. The result is acceleration in meters per second per second.

Streamlined Configurations

Multiply the acceleration by the efficiency factor of the airframe from **Table 161: Streamlined Hull Speed Regime** to find the effective thrust. Use this value to compute the vehicle's maximum speed.

Aircraft and Airframe Configurations

Multiply the acceleration by the efficiency factor of the airframe from **Table 162: Airframe Hull Speed Regime** and divide by the local gravity in Gs to find the effective thrust. Use this value to compute the vehicle's maximum speed.

Aircraft

VTOL aircraft must have an acceleration of at least five meters per second per second (0.5G) or they are treated as STOL aircraft. VTOL aircraft with an acceleration of less than five meters per second per second at their maximum takeoff weight, but an acceleration of five meters per second per second or greater in their clean configuration are called STOVL (Short Take-Off, Vertical Landing) aircraft, as they require a short takeoff roll to become airborne.

Speeds

Maximum

Acceleration is expressed in meters per second per second. In no case can the vehicle's atmospheric speed exceed the maximum speed of the airframe. Helicopters (except compound helicopters) cannot exceed 320kph. If the maximum speed is below the minimum speed for the airframe, the vehicle cannot fly; a redesign is called for (remove mass or add thrust). Note that vehicles that have installed sufficient lift to counteract the entire weight of the vehicle have no minimum speed requirement. (This includes most airships, grav vehicles, spacecraft, and all helicopters.) See Table 174.

Cruising

An aircraft's cruising speed is 75% of its maximum speed.

Minimum

Note the aircraft's minimum speed from **Table 162: Airframe Hull Speed Regime**. Most spacecraft, grav vehicles, VTOL aircraft, and helicopters do not have a minimum speed. Vehicles that depend on wing lift for flight have a minimum speed.

Terrain-Following

Terrain-Following Flight: Terrain-following flight is defined as flying a fixed, and usually very small, distance above the ground and obstacles on the ground. Any vehicle may perform terrain-following flight. The maximum safe terrain-following speed is determined by the vehicle's terrain-following avionics. If none are installed, the maximum safe terrain-following speed is 120kph. Terrain-following speed may not exceed 25% of the vehicle's maximum speed.

NOE Flight: Nap-of-the-Earth (NOE) flight is defined as flying around obstacles, not over them, and is conducted at an even lower altitude than terrain-following flight. In order to perform NOE flight, a vehicle must be capable of hovering. Only grav vehicles, spacecraft, helicopters, and VTOL aircraft can perform NOE flight. The maximum safe NOE speed is the maximum NOE speed allowed by the vehicle's terrain-following avionics (or 40kph if none are installed). NOE speed may not exceed 25% of the vehicle's maximum speed.

Maneuver Points

Maneuver points represent the vehicle's available energy and ability to perform dogfighting maneuvers in atmospheric flight. In combat, the vehicle with more maneuver points has an advantage over a vehicle with fewer points. Streamlined hulls, which lack aerodynamic control surfaces, are less maneuverable than airframe vehicles, particularly at low velocities. Determine a vehicle's maneuver points using **Table 175: Maneuver Points**, from the maximum atmospheric speed computed above.

Takeoff and Landing Rolls

All aircraft (including ornithopters) except for helicopters and VTOL aircraft, and most airframe vehicles, have takeoff and landing rolls.

Equation 68: Takeoff Roll

$$R_{to} = 0.19 \leftrightarrow S_{\min} \leftrightarrow \sqrt{W_{to}}$$

R_{to} is the takeoff roll in meters, S_{min} is the airframe's minimum speed in kph, and W_{to} is the actual takeoff weight of the aircraft, in kilonewtons.

Equation 69: Landing Roll

$$R_{la} = 0.19 \leftrightarrow S_{\min} \leftrightarrow \sqrt{W_{la}}$$

R_{la} is the takeoff roll in meters, S_{min} is the airframe's minimum speed in kph, and W_{la} is the actual landing weight of the aircraft, in kilonewtons. The landing roll (in meters) is never less than the aircraft's minimum speed (in kilometers per hour).

7: ELECTRONICS

This section covers fire control, computers, systems controls, communications, space sensors, vehicle sensors, countermeasure devices, passive sensor jammers, and passive sensor decoys. Before moving into that material, however, there are two minor pieces of electronics-related information to mention:

Electronics Pods: Any of the electronic systems that follow may be installed into streamlined pods for external mounting on aircraft or lift vehicle hardpoints. The mass of the pod is 10% of the total mass the pod can carry, leaving 90% of the mass for components. Pods may have an antenna with an area up to 1m^2 per 1,000kg of total pod weight.

Antenna Replacement: For all systems that don't provide separate costs for antennas, the cost of replacing a destroyed antenna is 25% of the total system cost.

Fire Control

This section covers components for direct fire, point defense, indirect fire, weapon stabilization, bean pointers, and master fire directors.

Direct Fire

All direct fire requires a sight or rangefinder. See Tables 176 and 177.

Point Defense

Ballistic computers may be modified to allow the weapon to perform in a point-defense role. Double the mass, volume, and price of a ballistic computer to add point defense capability.

When a weapon equipped with a point-defense fire control system fires on a ballistic projectile, the modifiers due to the target's movement are halved.

Indirect Fire

Indirect fire sights are required to be able to conduct indirect fire. See Tables 178-180.

Beam Pointers

Beam pointers provide the built-in fire control capabilities for heavy lasers, particle accelerators, and meson guns. Choose a beam pointer from **Table 181: Beam Pointers** based on your TL and the desired short range of the weapon. Note that "short range" and "effective range" are not the same thing—one defines the distance at which you can point the weapon accurately while the other defines the distance at which the weapon retains its maximum damage effectiveness. It is quite possible, especially with high-tech weapons, to have an effective range longer than the short range of the weapon.

Master Fire Directors

Master fire directors provide centralized control for spacecraft weapons. See Table 182.

Computers

If a computer is desired, choose one from the list available in **Table 183: Computers**. Any vehicle intended to travel into orbit must have at least one computer, and any jump-capable spacecraft must have a minimum of two. These are all space-rated, fault-tolerant, internally redundant multiprocessing units, unlike anything in a home or office.

Computer Multiplier (CM)

The computer multiplier is used during crew calculations to model the reduction in workload computer processing provides.

Computing Power (CP)

The computing power is a measure of how much "horsepower" the computer has for handling multiple complex problems simultaneously. To find the CSC computer rating from computer power, multiply computing power by 5.

Fiber Optic

Fiber optic computers become available at TL7 and are specially hardened systems that use optical circuitry, instead of electronic, to reduce vulnerability to radiation damage. Starships usually have at least one of their computers fiber-optic, and military ships may have several. Multiply the volume, mass, power, and price of a normal computer by 2.

Flight Computers

Flight computers are simplified version of full computers, optimized to perform specific routine flight functions. They may be used in place of standard computers but do not reduce maintenance needs like regular computers. Multiply volume, power. and mass by 0.1, and price by 0.001.

See Tables 183 and 184.

Controls

This system deals with the control system, workstations, navigation aids, flight avionics, and terrain-following avionics.

Control System

Control systems include control consoles from which the crew of a ship controls its systems and the interior circuitry linking the ship's electrical and mechanical systems to those controls. Installed computers must be from the same tech level as the controls, and avionics and navigation aids may not be installed from a tech level higher than that of the controls. The size of the controls depends on the size of the ship, the type of controls, and the level of automation desired.

Automation Level

There are three different levels of automation available. *Low automation* means there is no interconnection between different ship's systems, and all functions can only be performed under the direct control of the crew. While this provides the most security (even if one system is broken into, you can't go anywhere else, and failures stay isolated), it also requires the most crew for the ship. *Standard automation* provides basic communications links between different systems, allowing data to be passed back and forth, but it still limits how much influence one system has on another. Standard systems are also able to perform the most routine operations without the direct control of the crew: a basic "autopilot" and similar functions. *High automation* means everything is highly interconnected, processors are shared, and any system can control any other. This allows the control system to perform many operations without needing control inputs from the crew: an advanced autopilot. Naturally, this allows the smallest crews but makes the ship the most vulnerable—damage to one system, or electronic intruders breaking in, can spread to other systems. Theoretically a hostile individual could take complete control of the ship.

Military ships, with their need for damage resistance and security, usually use standard automation, as do exploration vessels and merchant ships venturing into risky territory. Civilian ships and merchants plying safe, well-known space go with high automation to maximize cargo space and minimize crew costs. Finally, in some eras and cultures low automation is used out of fear of computer viruses or because it is otherwise unacceptable to place a machine in a position of responsibility over sentient lives.

The basic controls listed below are for standard automation (basic communications links between different systems). For low automation, multiply the values listed by 0.95. For high automation, multiply them by 1.10.

Linked Controls

Any "linked" control system allows the vehicle's computer(s) to assist in the control process. Instead of having the commands sent directly from the operator's control panel to the system in question, all panels are connected to the ship's central computer. This computer can then interpret the commands, calculate the desired response, and send it out to the system. Note this also means that a reconfigurable panel (dynamic or holographic) can be used to control virtually any system on the (if the computer's security system allows it).

However, this also poses some vulnerability and security questions. Any system an authorized user can get into, a skilled-enough unauthorized user can get into as well. Or an authorized user with a malicious intent (or just plain incompetence) can access other parts of the system. Once you're into a system, you have a chance of eventually getting into connected systems. So if all your controls are integrated, someone who has access to one control panel can theoretically perform any function available on the system, if he or she is good enough.

Mechanical

Basic mechanical control systems consist of a series of mechanical linkages, pulleys, cables, and so forth to transfer the operator's control inputs to the various subsystems. Basic mechanical control systems can only be used with basic mechanical control panels.

Electronic

Electronic control systems are what's commonly known as "fly-by-wire" in the real world. The operator's actions are translated by the control panel into electronic signals, which are then sent to the appropriate subsystem, decoded, and acted upon.

Computer

Computer control systems use a small, special-purpose computer to process the control inputs and generate the outputs, which are then sent to the appropriate subsystem. In effect, the operator's control actions describe to the computer what the operator wishes to accomplish, and the computer calculates the electronic control signals required to do what the operator has described.

Dynamic

At higher technology levels, sufficient computer power becomes available in the control panel to allow the operator to define the way the controls should respond as well as where and how they are to be located for maximum convenience. Gravitic technology allows improved sensory feedback from the computer to the operator. Control operation becomes a dialogue between the computer and the operator, and as before the computer calculates the electronic signals required to perform the activities that the operator has described.

Holographic

Holographic data presentation techniques are used to improve the amount of information that the controls can present to the operator, and to increase the versatility of the controls. Holographic linked controls represent the ultimate in interactive data presentation using conventional computer technology.

Synaptic Linked

The next major advance in control technology is a control system that uses synaptic processing to "learn" correct responses from the operator. As such controls gain "experience" with an operator, they are able to correctly anticipate the operator's actions and needs. In high-automation systems, these controls use techniques they've learned from their operators and can become quite sophisticated.

Aircraft Controls

The numbers in **Table 185: Control Systems** are for spacecraft and vehicles, which are rated based on their volume. The aircraft design sequence works in terms of mass instead of volume. Multiply the values below by 140 to get power and price per ton of aircraft mass. Aircraft controls require 0.014t per ton of aircraft mass.

Mass and Volume

All controls require a volume of 0.001m^3 per cubic meter of hull, and mass 0.0001t per cubic meter of hull. See Table 185.

Workstations

All craft need some form of operator controls. At higher TLs, most if not all craft include a computer as part of their onboard controls. Different types: crew stations/workstations include multiple control panels as well as space for crew member. Short duration craft only require crewstations, but any vehicle or craft intended for more than six hours of continuous use, or for interplanetary flight, must install workstations instead.

Crewstations

All crew members aboard short-duration craft require a crewstation.

Workstations

Workstations are required for engineering, electronics, maneuvering, master fire directors, and command crew members. If two or more command crew are called for, the vehicle requires a bridge. Bridge workstations are twice the size of normal workstations, to allow room for easy movement and communication, personnel changeovers, and conferences on the bridge. Electronics, maneuvering, master fire directors, and command crew all get bridge workstations while engineers always get normal workstations.

Bridge workstation volume is 14m^3 at TL7+. Normal workstation volume is 7m^3 at TL7+. Neither is available prior to TL7. Cramped crewstation is 2.5m^3, while open crewstation is 3.5m^3. See Table 186.

Navigation Aids

These are instruments that tell you where you are in the world, but not necessarily in which direction you are pointed or how fast you're going. In many cases, what is extraordinary accuracy (for navigational purposes) is nearly useless for practical flying. Knowing where you are to within 500m is great if you're lost, but it won't help you set down on a 100m-wide runway if (due to weather conditions, for example) you can't see out. A good current-day example of a navigational aid would be a GPS system.

Navigation aids are the precision instruments of their times; hence, they are extraordinarily expensive when first introduced. For any TL after the initial TL, multiply price by 0.1. See Table 187.

Flight Avionics

Flight avionics guide pilots while maneuvering over the ground and making takeoffs and landings, especially in difficult weather or at night. These are instruments that tell the pilot what the vehicle is doing in relation to the ground. For example, they can indicate how high the vehicle is, which direction it's pointing, how fast it's going, and whether or not there is something in the way. If you're going to be flying by VFR (Visual Flight Rules—clear weather only), you don't need these. Otherwise, don't leave them out of the design: These are the "instruments" for IFR (Instrument Flight Rules—nonvisual flying conditions). In many cases, knowing where you are (in a local sense) gives you navigational information, but that's not the real purpose of these instruments. Good current-day examples of flight avionics are an artificial horizon, the ILS (Instrument Landing System), or weather-detecting radar.

While in the real world there is considerable overlap between flight avionics and navigational aids (knowing that you're 15 miles from a certain VOR beacon, on radial 240, is almost as good as a GPS fix), for game purposes assume that there's no overlap. In other words, if your craft has flight avionics but not navigational aids, then there are no instruments to tell the pilot where he is. If for some reason the vehicle becomes lost, the pilot's Navigation skill could be used to figure it out, though.

TL6 or better flight avionics are required for a spacecraft to land on the surface of a planet. Each level of avionics includes all features listed at lower TLs. See Table 188.

Terrain-Following Avionics

These are automatic systems that allow the vehicle to fly at insane speeds, very close to the ground, without managing to actually hit the ground or other terrain features. They would use the flight avionics to sense things that need to be avoided, and then fly the vehicle (or at least, help the pilot fly the vehicle) over or around them. Good current-day examples of terrain-following avionics are the terrain-following autopilots of the F-111 or the Tornado. See Table 189.

Communicators

See Tables 190-193.

Space Sensors

Sensors detect targets either by receiving the energy the target gives off (passive sensors) or by transmitting their own energy and reading the reflections from the target (active sensor). Sensors can be further broken down into scanners, which look at a wide area for targets, and trackers which concentrate their attention on small areas to get detailed information about a target, including fire control information. A scanner is a wide-field sensor, optimized for scanning the whole sphere to look for enemy targets, or for providing coarse tracking of already-detected targets. A tracker is optimized for precision tracking of one or more already-detected targets, to provide a fire-control solution, and allow weapons fire.

Trackers operate in two main ways. First, they can maintain detection on a previously detected target, even if no scanner is available. In this mode, they use their full sensitivity rating. However, a single mode sensor (tracker only, not tracker/scanner combination, available at TL10+), which only operates in a single mode, can only track a single target this way. Second, they can be used to provide targeting solutions for previously detected targets. The target must have already been detected by a scanner which is in communication with the tracker. (It can be on the same ship or another ship via comm link.) In this mode, the tracker's sensitivity is reduced by 1.5.

Detecting Targets

The chance of detecting a target with a given sensor depends on three factors. The signature of the target indicates how much energy the target gives off or reflects. The sensitivity of the sensor represents the minimum signal strength the sensor can reliably detect. Finally, the range determines how much of the energy from the target actually reaches the sensor. In an atmosphere, some of the energy is absorbed as well, but that's an added complication not considered here.

These three factors are put together by adding the sensitivity and signature of the target and subtracting a factor for the range. For passive sensors, the range factor is simply the range band number. For active sensors, the energy is diffused twice—once on the trip from the sensor to the target, and then again on the trip back from the target. Hence, you subtract twice the range band number. **Table 194: Range Factors** lists the range factors for most space detection ranges.

The range scale and signatures are based on logarithm progressions and are a very simplified model of the way real-world sensor issues are analyzed. After adding the factors together (sensitivity + signature – range factor for passives; sensitivity + signature – 2 x range factor for actives), compare the result to the following table.

So, if a Type S with a sensor rating of 6.5 was trying to detect a destroyer with a signature of 1 at a range of 5,000,000km, the total would be (6.5) + (1.0) – 6.0 = 1.5, a very easy task for a skilled operator.

Once a target has been detected, add 1 to the sensor rating of a ship continuing to track it. If a given target has been detected within the past ten turns, add 0.5 to the sensor rating.

Weapons fire requires a more precise lock. First, the target must be within the maximum range of the tracker. Second, the sensitivity of a sensor is reduced by 1.5 for determining if a weapons fire-control solution can be obtained on an already-detected target. So, a tracker with a rating of 7.5 firing at a target at a range of 500,000km would have a easy task to obtain a fire-control lock.

As a minor complication, each ship is given two signatures for passive sensors: a "reflected" signature, representing reflected sunlight, and an "emitted" signature, representing emitted infrared radiation from the ship's radiators and hull. At any instant, only the higher of these two—usually the emitted signature—should be used, but circumstances will modify this (shutting down the power plant, for example, or hiding in the shadow of a planet).

Sensor Options

There are three options for sensors: single-function, science-grade, and folding array.

Single-Function Sensors

At TL10+, single-function sensors—scanner-only or tracker-only—require 0.75 times as much area. Single-function scanners have no minimum diameter requirement while the diameter for trackers is unchanged. Prior to TL10, all sensors are single-function.

Science-Grade Sensors

Any sensor may be manufactured to "science grade". This increases volume (but not area) 20% and cost by a factor of 2.

Folding Arrays

If a ship is too small to mount a sensor with the desired diameter, the sensor may be designated as a folding array. The sensor elements are mounted on a folding framework, which allows the sensor to be stowed when maneuvering or not in use. Folding arrays double the volume of the sensor.

Passive Sensors

Passive sensors are spacecraft sensors that attempt to detect enemy craft through radiation coming from the target itself, either reflected visible light or thermal radiation from a ship's hull or sensors, rather than actively, as a radar does. The sensitivity rating for passive sensors measures roughly the range at which they can detect a typical ($100T_D$) target; the actual detection is modified by the target's signature and various environmental conditions. Passive sensor signal strength is calculated by adding sensitivity and signature, and subtracting the range factor. Compare the result **to Table 195: Detection Probability**.

Like TL8 sensors, TL8 trackers are telescopes—single telescopes optimized for high angular resolution. TL9 trackers use several separate telescopes linked together as an interferometer to improve angular resolution, although this technology is not fully mature until TL10.

Sensitivity: Sensor sensitivity rating. Remember that trackers subtract 1.5 from their sensitivity when calculating the chance of obtaining a fire-control solution.

Area: Surface area required.

Diameter: Minimum diameter of the sensor. This must be less than or equal to the length of the ship's hull, or the sensor must be designed as a folding array.

Maximum Range: Maximum range at which the sensor allows a fire-control solution.

Typical Range: For reference, the typical range at which the sensor can detect a $100T_D$ sphere with a 150MW power plant.

Resolution: For reference, the smallest detail that the sensor can resolve at 50,000km range. Divide by 4 for a science-optimized sensor. Resolution depends on range—at half the range, the resolution is halved, and so forth.

At low tech levels (TL8-9) scanners are simply telescopes—typically two or more mounted to cover the whole sphere surrounding a ship—equipped with sensitive visible-light and infrared detectors. The whole telescope structure is cooled to ~150 K to enhance infrared sensitivity by reducing thermal background. Scanner telescopes are optimized for wide field of view rather than high angular resolution. See Tables 196 and 197.

At TL10+, trackers and scanners are usually combined into a single sensor, often abbreviated as PEMS (Passive Electromagnetic Sensor.) This sensor is usually an interferometric array, using many small antenna separated by large distances to synthesize a single high-resolution image—as opposed to the TL8-9 interferometers, which combine the light from separate telescopes using an arrangement of mirrors and beam-splitters. Each TL10 element separately detects light and the signals are combined electronically. As a result the sensor, like a 1990s phased array radar, can scan in any direction without moving parts and can instantly switch from wide-angle to high-resolution scanning. The sensitivity listed in the table is used when scanning; subtract 1.5 when in tracker mode to get a fire-control solution. See Tables 198-200.

Active Sensors

Active sensors, instead of relying on whatever energy is coming from the target already, send out pulses of energy themselves and look for the reflection. TL8-9 active sensors are radar only while TL10+ sensors use a wide range of the electromagnetic spectrum and are referred to as Active Electromagnetic Sensors (AEMS). Although they are capable of using a variety of frequencies simultaneously, they concentrate on the submillimeter radar and infrared bands.

These sensors are all dual mode, operating as both scanners and fire-control trackers; since these sensors are all phased-array radars there is essentially no advantage to making a single-mode sensor of either type. However, their lower sensitivity compared to passive sensors tends to make the smaller AEMS of little use for precision fire control. Active sensor signal strength is calculated by adding sensitivity and signature, and subtracting twice the range factor. Compare the result to **Table 195: Detection Probability.**

Sensitivity: Sensor sensitivity rating. Remember that trackers subtract 1.5 from their sensitivity when calculating the chance of obtaining a fire-control solution.

Area: Surface area required.

Diameter: Minimum diameter of the sensor—this must be less than or equal to the length of the ship's hull or the sensor must be designed as a folding array.

Maximum Range: Maximum range at which the sensor allows a fire-control solution.

Typical Range: For reference, the typical range at which the sensor can detect a $100T_D$ sphere. See Table 201.

The maximum number of targets such a sensor can allow fire on in a single turn is given by **Table 202: Active Tracker Targets.** Note that this is the maximum number of targets that can be tracked for fire control—active (and passive) scanners can detect an unlimited number of targets in a single turn.

LIDARs

LIDAR is the laser form of radar: Light Detection And Ranging. LIDARs operate only as trackers, either providing a fire-control solution to a target or maintaining contact on a target detected by another sensor. In combat, LIDAR detection probabilities are computed using the normal sensor rules but using the targets visual signature multiplied by 0.5. LIDAR may simultaneously track the number of targets listed in **Table 202: Active Tracker Targets.** See Table 203.

Converting FF&S1/QSDS/SSDS Sensors

To convert sensors ranges from FF&S1 (given in kilometers or hexes) or from QSDS/SSDS (usually given in hexes) use Table 204.

Vehicle Sensors

This section covers passive and active, as well as portable visible and infrared light, sensors for vehicles.

Passive Sensors

In addition to the large, expensive, cooled sensors used on starships, lower-performance sensors are available for use on vehicles and aircraft. Lacking the aggressive cooling used on large sensors, these are typically optimized for high-background situations and have reduced sensitivity for detecting spacecraft. **Table 205: Vehicle Passive Sensors** lists the volume for a given sensor at a given TL. TL8-9 sensors must be designated as either visible-light or infrared; visible-light sensors can detect space combat targets only through their reflected signature while infrared sensors use the target's emitted signature. TL10+ sensors operate simultaneously in visible and infrared.

Range: This is the typical range at which the sensor can detect an aircraft or large vehicle.

Space Sensitivity: This is the sensitivity rating the sensor would have used in space combat or anywhere both the target and sensor are in a vacuum. Note there would be a large penalty (about −1) if either target or sensor are in an atmosphere.

Resolution: This is the typical size of details that can be discerned at 5km range. See Table 205.

Active Sensors

Portable Visible and Infrared Light Sensors

These sensors, due to their short range, are more suited for use on vehicles, or even hand-carried, than on spacecraft. Active sensors illuminate the target with a beam of visible or infrared light while passive sensors simply use the background light available.

Countermeasures

Countermeasures include jammers, reflected signature masking, and thermal masking.

Jammers

Radio and active-sensor jammers may be purchased to try to interfere with an enemy's communications or sensor operations. Jammers subtract their rating from the sensor or communicator's rating. To build a jammer of a given rating, start with a radio or active sensor of the same rating. Multiply power and price by 2, and divide antenna area by 10.

Reflected Signature Masking

The design sequence in the "Hulls and Streamlining" section offers different options for hull coatings, which may increase or decrease the vehicle's signature (see page 62). These methods all depend on various types of coating placed on the hull.

Thermal Masking

All power plants generate heat, which must be radiated away to keep the inside of the ship within normal temperature ranges. These radiators are installed in the "Power Systems" section (page 81) and are normally arranged to radiate most of the heat into a few directions, to limit detection from other directions. By adding additional radiators beyond the minimum required, the crew can control which radiators are used and hence modify the heat signature of the ship. Basic thermal masking doubles radiator area and costs MCr0.1 per m^2 of radiator. Advanced thermal masking increases radiator area by a factor of 10, requires 0.1MW per MW of power plant output, and costs MCr1 per m^2 of radiator. At TL13+, extreme thermal masking becomes available. Extreme masking increases radiator area by a factor of 20, requires 0.1MW per MW of power plant output, and costs MCr10 per m^2 of radiator. Each of these forms of masking helps reduce the signature, calculated elsewhere.

Passive Sensor Jammers

Passive jammers attempt to use emitted radiation to confuse a target's sensors. While it is effectively impossible to prevent detection this way, it is possible to confuse a fire-control tracker, at least long enough to prevent a fire-control lock. Even for this application, however, PEMS (Passive Electromagnetic Sensors) jammers are generally only effective against jammers of a lower tech level.

PEMS jammers are designed using **Table 198: PEMS Arrays.** Area required is multiplied by 0.5; cost per m^2 is increased by x5. Power required is 2 MW per m^2.

Passive Sensor Decoys

Passive sensor decoys, like passive sensor jammers, cannot prevent detection, but they can prevent a fire-control lock. A deployed decoy subtracts 1 from the target ship's signature; only one decoy (actually a bundle of decoys) can be deployed per turn.

A decoy dispenser requires 0.001 m^3 per m^3 of ship's volume. It masses one ton per m^3 and costs MCr 0.1 per m^3. A decoy bundle sufficient to protect a ship for one 30-minute space combat turn requires 0.01 m^3 per m^3 of the ship's volume. It masses two tons per m^3. It costs MCr 5 per m^3.

8: LIFE SUPPORT AND ACCOMMODATIONS

This subject is certainly one of the most important to address, even if it may not be as glamorous as weapons and defense design!

Crew and Passengers

Ground vehicles and short-duration flying vehicles normally carry only the minimum crew necessary to operate them. Starships normally carry both operating crew and maintenance crew internally, while small craft designed to operate from a base or a mother ship only need to carry their operating crew. Ships carrying small craft must also carry the operating crew and maintenance crew for them. The size of the crew depends on many factors.

1. The Mission: Military vessels have larger crews, to prepare for combat losses as well as issues listed below. Small private vessels tend to have the smallest crew possible. Liners have to provide for the needs of passengers, research or exploration ships need scientists, and on and on.
2. Shift Needs: Military ships tend to man their sensors and communicators round-the-clock in normal space as well as having a full bridge crew. Merchant and private ships may have only a single watchstander on the bridge handling maneuvering, sensors, electronics, and so forth.
3. Tech Level of Controls and Computers: Computers provide a computer multiplier (CM), which can be used to reduce crew needs. Vehicles without computers, and low tech vehicles, use a CM of 1.
4. Level of Automation: Less automated ships naturally require more crew, and high tech electronics automates better. For low automation, and for vehicles without computers, use the crew multiplier (CM) as is. For standard automation, divide it by 3, and for high automation, divide it by 5.
5. Overall Size of the Crew: That sounds obvious—"The size of the crew depends on the size of the crew"—but this isn't as intuitive as it seems. What this means is that the more people you have doing work, the more people you need supervising the work. Long-standing studies show that a single person's "span of control" over the long run is somewhere between five and nine subordinates, depending on the degree and complexity of control required.

Passengers

Ships are rated for high passengers. Middle passengers, low passengers, and troops.

High Passengers (PH)

High passengers are the luxury passengers, who expect a large private stateroom, stewards at their beck and call, quality food, and entertainment. High passengers are also allowed $14m^3$ of personal luggage, which must be provided for in the cargo hold in addition to their carry-on luggage, stowed in the cabin.

Middle Passengers (PM)

Middle passengers still require a private stateroom but get less service and entertainment. Middle passengers are allowed $1m^3$ of personal luggage in the hold, in addition to their carry-on luggage, stowed in the cabin.

Low Passengers (PL)

Low passengers are carried in low berths. Their total luggage allowance is 10kg, which amounts to a $0.01m^3$ locker and is included in the volume of the low berth.

Troops (PT)

These are troops carried aboard who are separate from the ship's crew structure; this is for troopships and so on. Enlisted troops require at least a bunk each. One sixth of the troops are officers and should be placed in staterooms (maximum double occupancy for small staterooms, quadruple occupancy for large). One sixth of the officers (round down) are senior officers and require private staterooms. Cargo requirements depend on the troop's equipment.

Crew

Unless otherwise specified, round all calculations to the next lowest number unless the result would be zero. Set all crew categories with crew requirements less than one aside. At the end of the sequence, add all the fractions up and round down. If the result is greater than zero, you need that many "multipurpose" crew members.

Short-duration craft only require crewstations, but any vehicle or craft intended for more than six hours of continuous use, or for interplanetary flight, must install workstations instead.

Crewstations

All crew members aboard short-duration craft require a crewstation.

Workstations

Workstations are required for engineering, electronics, maneuvering, MFD (Master Fire Directors), and command crew members. If two or more command crew are called for, the vehicle requires a bridge. Bridge workstations are twice the size of normal workstations, to allow room for easy movement and communication, personnel changeovers, and conferences on the bridge. Electronics, maneuvering, MFD, and command crew all get bridge workstations while engineers always get normal workstations.

Maneuvering Crew (CMn)

The maneuvering crew are the people who fly or drive the vehicle and plot its course. The number required depends on how long the vehicle is intended to operate away from its home or base. For vehicles designed for short trips (six hours or less), only a single driver/pilot is needed. For trips longer than that, but less than 16 hours, ground vehicles require two drivers while aircraft, grav vehicles, and spacecraft require two pilots. Vehicles intended for round-the-clock operations require a pilot/driver for each shift. Vehicles intended for interplanetary travel also require a navigator. On small private ships (under $1{,}000T_D$), one person can handle both pilot and navigator tasks if desired. However, this can lead to task overload: Trying to pilot a ship and plot an emergency jump at the same time results in neither one being done properly.

Merchant ships are required by Imperial regulations to carry at least one pilot and one pilot/navigator. Military vessels, with their need for backup and round-the-clock shifts, have bridge crew equal to 3 x log (CM x ship size), rounding fractions up. For your convenience, **Table 206: Maneuvering Crew** lists the crew required for a given (CM x size) for the common vessel sizes.

Electronics Crew (C_{El})

The electronics crew operates on-board electronics systems: sensors, communicators, and computers. Small vehicles may

dispense with dedicated electronics operators, allowing the pilot to monitor sensors and communications, but this results in the possibility of overload during high-stress situations such as combat or in-flight emergencies.

Electronics Crew is CM x (number of installed electronics systems).

Engineering Crew (C_{En})

The engineering crew operates and maintains all onboard power plants and drives. Engineering Crew is CM x [power plant output (in MW)/30 + (mass of maneuver drives + mass of jump drives)/60]. Round fractions down.

A flight engineer is required in any aircraft with three or more engines, or more than 25kN of propeller thrust, unless a flight computer is installed.

Maintenance Crew (C_{Mx})

The maintenance crew performs maintenance on all vehicle systems, assists engineering in maintaining drives and power plants, and performs damage control duties. Vehicles that have short missions and operate from fixed bases may choose not to carry a maintenance crew. Maintenance crew is CM x (mass of drives + mass of power plants + mass of electronics + mass of weapons + mass of defenses + mass of carried craft)/500.

Maintenance crews for small craft, carried craft, and any craft operating for short periods from a fixed base can be left on the base or the mother ship and need not have provisions aboard the craft itself. Starships and long-duration small craft must carry their own maintenance crews as well as maintenance crews for any carried vehicles.

Gunnery Crew (C_G)

The gunners operate all weapons, master fire directors, countermeasures, and defensive systems. Add up the crew requirements for each weapon which will be manned during combat, defensive systems, and master fire directors. Aboard spacecraft, some of these requirements may be met by ship's troops (see below) instead of requiring gunners.

Vehicles carrying weapons that require loaders must also carry loaders. The driver of a vehicle may operate weapons in forward-firing fixed mounts. All others require a gunner. A gunner may fire multiple weapons as long as each is controlled from the same weapon station. All weapons mounted on the same face of the chassis or in the same turret may be controlled by a single station. Each small turret requires a station unless it is remotely controlled. A gunner may control any number of weapons but may only operate one weapon in a single turn. A bombardier or weapons officer is required for aircraft intended to launch air-to-ground attacks from above 2,000 meters altitude.

Flight Crew (C_F)

The flight crew mans carried craft (such as fighters, shuttles, grav carriers, and so on), and flight officers coordinate all flight operations. Many ships don't carry enough flight crews to man all their subsidiary craft at once. For example, a subsidized merchant has a $10T_D$ launch, but it's usually piloted by the ship's pilot instead of having a dedicated pilot. On the other hand, military vessels often carry full flight crews.

Flight crew is equal to the crews required for subordinate craft, plus one flight control officer per six craft (round down).

Ship's Troops (C_T)

Ship's troops are troops actually assigned to the ship, under the direct control of the ship's commander. They provide onboard security, boarding actions, assist with maintenance, and may also provide some gunnery crew. (But remember! If they're off doing ship's troop stuff, you can't fire weapons!) Suggestion: M x Disp/10, where M is some troop multiple ranging from 1 to 30. For every six troops, you may reduce maintenance crew by 1.

Command Crew (C_C)

The command crew is made up of the officers, section chiefs, and supervisors who coordinate all the activities of the other sections. Add up all the crew so far and divide by six, dropping fractions: $C_C = (C_{Mn} + C_{El} + C_{En} + C_{Mx} + C_G + C_F)/6$.

Small vehicles may choose to have the senior pilot or driver assume the role of commander. However, military vehicles often assign a separate commander, as the driver is often too busy driving to be watching for targets or coordinating with other vehicles and headquarters.

Stewards (C_S)

Normally only found on passenger aircraft, grav vehicles, and spacecraft, stewards perform housekeeping duties, cooking, administrative and financial work, serving and entertaining passengers, and so on. One steward per eight high passengers (minimum one if there are any high passengers), plus one per 50 middle passengers or crew members is the standard: $C_S = (C_C + P_H)/8 + (C_B + C_{El} + C_{En} + C_M + C_G + C_F + P_M)/50$ (minimum of one if there are any high passengers).

Frozen Watch (C_F)

These are crew members in suspended animation (or low berths), in case regular crew members are injured or killed during combat. Designer's choice: For warships, each "frozen watch" consists of total crew / total displacement (T_D)/1,000. The frozen watch requires regular low berths.

Medical Crew (C_M)

The medical crew monitors the health and safety of passengers and crew, diagnoses and treats illnesses or injuries, and suspends and revives low passengers. Add up all the crew, high, and middle passengers so far, and divide by 120, and add to that to low passengers and frozen watch divided by 20.

Crew Quality

The calculations above assume that the average skill level of the entire crew in the required areas is equal to Skill-2 and will do fine for generic ships. These are also the fixed requirements for military ships, regardless of the actual quality of the crew. However, if you're creating an NPC crew for a specific civilian or private ship and have generated skill levels for the NPCs, count them as (Skill Level/2) crew members. For example, if you need three Engineers according to these rules, and you have an Engineer-4 and Engineer-2 generated, they count as (4/2 + 2/2 = 3) three engineering crewpersons.

This rule applies to electronics, engineering, maintenance, steward, and medical crew only. However, note that reducing the number of crewpeople actually aboard decreases command crew requirements as a side effect. Also remember that fewer people can perform fewer tasks at the same time.

Accommodations

See Table 207.

Seats: Seats do not include any controls—see workstations or crewstations. Paying passengers require at least adequate seats. Troops must be cramped or better. Restricted seats are the bare minimum possible accommodation (jump seats and the like). Seats are for short-duration vehicles only (less than 24 hours). Increase the minimum seat size by one level for vehicles with duration over eight hours.

Ejection Seats: Adding ejection capability to any seat adds $0.2m_3$, at a mass of 0.1t and a cost of MCr0.1. The base chance of surviving such a trip is a roll of TL or less on 2D, subject to the following modifications: +3 if the ejection was deliberate and not in response to an emergency; –3 if the vehicle is too close to the ground or not upright; –1 per 50km/hr over 100 of vehicle speed. A successful roll means the occupant suffers 1D of wounds but makes it out of the vehicle in time. Failure means either the occupant doesn't get out in time or is killed by the stress of the ejection, or the parachute fails in some way, or the character sustained 6D of wounds as a result of the ejection (referee's decision).

Bunks: A bunk consists of a single bed, with storage space underneath for the crew member's personal belongings.

Low Berths: Low berths offer a form of suspended animation. At low tech levels, they use a form of cryogenic suspension and are often known as "cold berths." The individual is quick-frozen with supercooled liquids, as slow freezing would allow fatal ice crystals to form in the body's cells, basically ripping them apart. Revival techniques are equally primitive. By TL 11, however, the "gravisonic modulator" improves the safety and practicality of the process immensely. Sonic scanners map out the precise internals of the subject and then gravitic technology is used to modify the kinetic energy of various regions in the body independently, providing precise and accurate control over the freezing and thawing processes.

Normal low berths have a long preparation process, carefully mapping out tissue patterns and preparing for a safe revival. The preparation is done under the direction of a medical person, who ensures that the revival process can be done without significant problems, even under computer control and without medical support. However, most planetary regulations require a doctor's presence during revival anyway.

The emergency low berth sacrifices careful preparation for quick hibernation. Capable of holding four normal humans, it can drop its occupants into hibernation in less than sixty seconds, fully clothed and without any preparation. The down side is that the revival process is extremely tricky and requires careful monitoring by skilled personnel. They are only used in life-or-death situations, when a ship is rendered otherwise uninhabitable.

Military ships reverse the emergency low berth sequence—they trade off longer-than-normal preparation times in order to cut the revival time. By putting even more time and effort into the freezing process, trained medical personnel find and eliminate any potential problems in advance. Then, in the heat of battle, the frozen watch can be revived in under five minutes to replace casualties.

Low passengers and the frozen watch require a normal low berth. An emergency low berth can accommodate four humans or the equivalent mass of other species.

Staterooms: High and middle passengers require one stateroom apiece. Crew can be crammed in up to two per small and four per large stateroom at a time. "Hot-bunking" is possible (sleeping in three shifts per 24-hour period). Officers cannot be placed in bunks or more than double-occupancy staterooms.

Deck Plans: Bunks, staterooms only actually occupy half the listed volume; the remainder is taken up by common areas.

Life Support

This section describes environmental controls, consumables, and acceleration compensation and artificial gravity.

Environmental Controls

Enclosed Volume: For simplicity, most people use the overall hull volume when installing life support systems. You may choose to exclude armor and structure volume as well as fuel tanks. However, if the fuel tanks do not have life support or artificial gravity, they are more difficult to maintain (you need vac suits and so on) and can't be used for emergency measures (such as installing modular quarters).

Duration: Each type of life support lists a normal duration, which is the length of time the system is designed to be used under normal conditions. There's plenty of safety margin over that. Assume maximum capacity is double the designed load. For life support types designed based on ship volume rather than per person, assume the design load is the ship's normal complement of crew and passengers. The per-person life support requirements can be assumed to be handled by the accommodations.

Example: a Type III system on a scout/courier is good for two weeks normally, and it is assumed to be able to handle four people, which is eight person-weeks. Thus, in normal operations it could go for eight weeks with one person, four weeks with two, and so on. After that, the air starts smelling and the chances of a breakdown increase, to the limit of 16 person-weeks. In an emergency it could go for 16 person-weeks, although the chances of a failure are increased. Thus, you could rescue four shipwreck survivors and still go for two weeks (assuming you do your maintenance right).

It also makes the players take the time to see if they can salvage any life support gear from the wreck (extra filters, spare water or food—that sort of thing). If they don't, when they drop off the survivors, with their ship reeking, they can get asked by the guy delivering their recharges "Weren't there any filters you could salvage?" so that they'll kick themselves.

Increasing Duration: If you want to increase the duration of a given type of life support system over the listed "normal duration," the system becomes larger. Each increase equal to the listed normal duration requires 75% of the base life support. In other words, if I want double the normal duration, that's an increase of one, so the final life support size would be 1.75 times the base. If I wanted triple the duration, that's an increase of two, so the final size would be 2.5 times the base.

Overpressure: For use on worlds with tainted or contaminated atmospheres, or worlds with thin atmospheres. This includes compressors and filters to take in the outside air, filter contaminants out of it, and keep the inside of the vehicle at a higher pressure than the outside. Since the air inside is constantly flowing out, the contaminants don't leak into the vehicle. This does not work on worlds in very thin or less atmospheres.

Oxygen Tanks and Masks: These allow breathing at high altitudes, in thin atmospheres, or in poisonous atmospheres. They do not suffice for use in very thin or vacuum conditions. Normal duration is three hours.

Type I (Minimal): Minimal life support provides a sealed environment, heat, and light. The air supply is open loop, meaning there's no attempt to recycle it. Stored air provides fresh oxygen while minimal air processing (filters and chemicals) removes the worst of the waste products from the air. Water and food are not normally provided but may be carried aboard. Wastes (air, water, or body wastes) are dumped overboard or stored for later dumping. As time goes on, the air becomes increasingly unbreathable due to a buildup of impurities and biological waste products (carbon dioxide and so on) and the oxygen being consumed. Example: Sealed air/raft. Normal duration is three hours.

Type II (Basic): Basic life support provides heat, light, and short-term purified air. This is also an open loop system, but it provides better air processing to clean impurities out. Neither water nor food are included in the life support supplies, but small amounts may be carried in the passenger area. Wastes are vented or stored. As time goes on, the air again starts going "bad." Normal duration is 12 hours.

Type III (Standard): Standard life support is so named because it's the standard system used aboard spacecraft. It provides light, thermal control, closed-loop water recycling, and semi-closed loop air. Food is a carried consumable, and given the duration it must be separately provided rather than carried on in the passenger compartment like previous types. Water is recycled and basically unlimited. The air is purified and recycled, but the filters used to purify it have a limited life and slowly break down. Solid waste can be vented or stored; waste water is recycled. Food is limited to what is carried aboard. This is what most starships use. Normal duration is two weeks.

Type IV (Extended): Extended life support provides light, thermal control, and closed-loop air and water (indefinite). Air and water can be purified and recycled indefinitely. Food is a carried consumable (requiring dedicated storage volume). Normal duration is indefinite, limited only by food.

Type V (Endurance): Endurance life support provides full closed loop recycling for air, water, and food through use of hydro/aeroponics, aquaculture (fish), and even carniculture (meat). There are several different levels of Type V life support, each representing a major improvement over the previous but also a major cost and volume increase. These forms of life support are usually only used aboard space stations and generation ships. Normal duration is indefinite.

Type V-a: At this level, air and food are provided by low-level plant life. Think algae vats, which require processing to create food, at low TLs—rather . . . *unpleasant.* ("Please, sir, may I have some more gruel?") This has the lowest per-person requirements.

Type V-b: This level provides vats and gardens. You actually get real vegetables and fruits. Requires more space per person, but provides better morale.

Type V-c: This level includes small animals (chickens, fish, goats). It requires much more space per person, but you get meat. Or, at this level you can have a greater variety of food plants.

Type V-d: Large animals—now you've gone too far! Pigs in space, okay, but cows in space? This is practical only for large space stations or huge generation ships.

General Notes: Types I-IV are based on the overall ship volume and are assumed to be designed for whatever the design complement (crew + passengers) of the ship is.

Type V, Endurance, requires that Type IV life support be installed, based on the size of the hull (to handle the air, heat and water), and then a certain volume added per person to be supported (for the food farms). However, these are miniature ecosystems, which require both a minimum size and a steady load to remain stable. For every 5% change in the of people on board, the life support engineer must make a routine task to avoid an imbalance in the life system. Imbalances can manifest themselves in runaway plant growth, crop blight, and so on, at the referee's option. See Tables 208 and 209.

Min Cap: Due to their nature, endurance systems have to be built to support a minimum number of people.

Airlocks: Airlocks allow people to enter and leave the vehicle without either contaminating or losing the vehicle's air. Minimal airlocks are extremely cramped while standard airlocks allow room for a person to fit comfortably, or two people cramped. Decontamination facilities may be added to any airlock. Decontamination time averages around 10 minutes but depends on the nature of the contamination. For spacecraft, one standard airlock is required per 1,400m^3 of hull volume. See Table 210.

Note: There's nothing that says 10 airlocks on a spacecraft have to be 10 separate facilities. When laying out deck plans, you may combine them into larger airlocks.

Consumables

Endurance (Type V) life support is the only kind that can actually produce its own foodstuffs to keep the crew and passengers fed. All other kinds have to carry food for crew and passengers. Since everything below Type III (Standard) life support is used only for short-duration trips, you can simply assume that any food provided is included in the passenger volume. Types III and IV actually have to provide storage and possibly preparation space to feed those *ravening* adventurers and *slothful* high passengers.

Meal Types

Choose what kind of food you want to feed your crew and passengers, and how many meals you're going to need. Not only do you need to carry enough food for your full complement for the normal duration of the trip, but you probably ought to consider having extras for emergencies. The descriptions below list the per-meal sizes and costs for your reference or custom use. (Maybe not everybody gets the *good* meals, for example.) For simplicity, **Table 211: Standard Food Supply** provides different quality meals per person for a normal two-week Type III life support system, with a one-week supply of emergency rations.

Emergency: Emergency meals are the 57th-century equivalent of MREs (the US military's rations, "Meals, Ready to Eat," also disrespectfully known as "Meals, Rejected by Everybody"). These are packaged, precooked meals that can be eaten cold or reheated in a minimal galley. Although the food items are usually labeled, they may not always resemble what the say they are. Quality varies from not quite acceptable to nearly inedible. These rations are designed to keep you alive and well but not necessarily happy. Furthermore, the meals are nutritionally balanced so you can get by indefinitely on only a single meal a day, unless you're undergoing heavy physical stress. An example: the Imperial Navy and Marine SISR (Standard Imperial Survival Ration), called SISO by the rank and file for "Same in Same Out". Volume 1.5l; mass 1.5kg; cost Cr10 per meal. The shelf life is equal to the TL of the packaging, in years.

Meager: These are more prepackaged meals, along the lines of airline food or TV dinners. Strip the cover off, slap them in a microwave for 30 seconds, and you're done "cooking." Unlike emergency rations, these are actually created with the taste in mind, but that's usually where it stayed. Taste-wise, they're only slightly better than emergency rations, and they're not as nutritionally dense as emergency rations. This is the absolute minimum quality food crew members will tolerate (but not for long) as well as passengers on short-duration flights. Think bad airline food. Volume 1l; mass 0.5kg; cost Cr3 per meal. The shelf life is one year.

Normal: Normal meals are prepared from prepackaged materials that were prepared for storage (such as canned vegetables, frozen foods, and grain products). The quality of these meals depends on the person doing the cooking, and some form of galley (see below) is usually required. This is the minimum-quality meal that can be served to paying passengers on long-duration trips. Volume 2l; mass 1.5kg; cost Cr5 per meal. The shelf life is one month, unless special storage is available.

Good: These are normal, homecooked-style meals prepared from mostly fresh raw materials prepared for long term storage but not cooked. This requires cooking in some form of galley (see below). While not the highest quality, meals look like meals made of separate courses, and you can usually tell what the components are—provided they are prepared by a competent chef. Volume 2.5l; mass 1.5kg; cost Cr12 per meal. The shelf life is one week, unless special storage is available.

Excellent: These are gourmet meals made of high quality, fresher versions of the above. This requires a full galley and a fine cook (Steward-4+ or Cook-3+); otherwise, this tastes simply like a better version of good-quality meals. Volume 2.5l; mass 1.5kg; cost Cr25 per meal. The shelf life is three days, unless special storage is available.

Food Preparation Facilities

A wide variety of preparation facilities are available, and the choice depends on the size and nature of the ship. Furthermore, not everybody on board a ship may be served from the same galley. For example, a liner may have a large First Class Galley (= Full Galley), with a master chef providing excellent meals for the high passengers, and a smaller half-galley serving middle passengers and crew.

Minimal Galley
Basically just a small microwave or equivalent high-tech heating facility, a hot plate, some open counter space, and a sink at the edge of the crew lounge. The required space is included in the space used by the accommodations and life support systems; no additional volume is required.

Ordinary Galley
A small nook off of the crew or passenger lounge, dedicated to food preparation, cooking, and utensil storage. This is capable of preparing meals for six to ten in one sitting. It's suitable for preparing either meager through good rations. It usually opens onto one side of the crew or passenger lounge but is sometimes partitioned off. Volume 0.2m^3 per person served, minimum 4m^3; mass 0.3 t/m^3; cost MCr0.000125/m^3; power 0.0025MW/m^3; crew is one dedicated cook per 40 persons served. (For small ships, personal vessels or non-passenger ships, round down.)

Full Galley
A separate facility for food preparation, cooking, and utensil storage. It includes variable configuration ovens, toasters, stoves, and so forth. Generally manned by a dedicated cook (Steward 3+ or Cook 2+), who can create some truly spectacular meals. Volume 0.3m^3 per person served, minimum 12m^3; mass 0.3t/m^3; cost MCr0.00015/m^3; power 0.0025MW/m^3; crew is one dedicated cook per 20 persons served for Excellent meals, or one cook per 40 persons for others.

Additional Storage
Meager and emergency meals can be stored in any container with no special requirements. To preserve more than the minimal amount of normal or better meals, some way of preserving the raw materials is required. At low TLs that may be refrigeration, but the table below assumes a generic "preservative" technology without going into details of what it is at each TL. The storage volume may include cool storage, cold storage, and shelf storage—actually requiring refrigerators to be designed separately from freezers, separately from simple cabinets, would be way too complex and worthless. At TL8 or less, food storage equipment doubles the shelf life of normal or better quality meals. At TL9 and above, the shelf life is tripled. See Table 212.

Acceleration Compensation and Artificial Gravity

The human body can tolerate impressive amounts of acceleration—for a short time. Present-day fighter pilots can withstand forces of up to 9G for periods of several seconds, with the help of special suits. However, the tolerable acceleration decreases as the exposure increases: A few minutes at 3G fatigues a healthy person, and long voyages at more than 1.5G are extremely uncomfortable. Not only is high G due to acceleration bad, but extended periods of zero-G are also detrimental to physical health, with the main effects being a loss of muscle tone and bone calcium. Even exercise in zero-G can only slow these effects, not prevent them.

Low Tech

At low tech levels, there's no way to counteract the effects of acceleration, only cope with them. The effects of acceleration can be reduced slightly by immersing passengers and crew in a special buoyant fluid during high-G maneuvering.

A semblance of gravity can be provided by spinning the ship or portions of it. However, the ship or habitat section must *despin* in order to maneuver. There are several types of spin methods listed below, most of which don't require the entire ship to spin.

G-Tanks
A G-tank reduces the effects of acceleration by 1G. Passenger G-Tanks include adequate seats. Crew G-tanks include open crew-stations. If you want different accommodations, subtract the volume for the current accommodation and add in the new one. See Table 213.

Spun Hulls
The entire hull is spun about the long axis to produce "centrifugal" gravity. This may only be used with cylindrical or open frame configurations and spheres larger than about 14,000m$_3$, as the effects vary depending on the distance from the axis of rotation, and you want to keep living sections at approximately the same distance. Furthermore, Coriolis effects render the central part of hull (within about 10m of the axis) unpleasant for people and hence unusable for quarters or workstations, or anything requiring a long-term presence. This space is generally reserved for low-maintenance machinery, cargo, and fuel.

Spun hulls require no additional machinery.

Double Hulls
Again, limited to cylindrical configurations. In this variety, the ship actually consists of two cylindrical hulls, one inside the other. The outer hull spins while the inner hull (containing fuel, cargo, and so forth) doesn't. The outer hull, containing crew areas, must begin at least 10m from spin axis. Volume 1% of enclosed volume of outer hull; density 1t per m^3 of machinery; price MCr0.001 per m^3 of machinery.

Spin Capsules
The most common form of spin habitat in use at low tech levels is the spin capsule. Two or more habitat modules are placed at the ends of pylons, which rotate around a common axis. This common axis is usually, but not always, the long axis of the ship. The pylons must be at least 10m long. Moving between the habitats and the rest of the ship is by way of ladders or powered lifts in the pylons. The capsules are designed to retract or fold against the ship's hull during violent maneuvering. Any unstreamlined configuration may use spin capsules. Volume 5% of the habitat volume; mass 1t per m^3 of machinery; price MCr0.001 per m^3 of machinery.

Artificial Gravity & G Compensation

Artificial gravity inertial compensators create an artificial gravity field directed between the deck plates of a ship to provide a constant gravity field. The generators are also tied into the ship's computer, which varies the field strength to counteract the effects of a ship's acceleration, up to a maximum level. See Table 214.

9: Power Systems

This section describes components for power generations as well as fuels and power storage media.

Generation

Power generation requires consideration of radiator requirements, scale efficiencies, chemical power plants, fission plants, fusion plants, fusion plus, fuel cells, antimatter plants, photoelectric, and explosive power generators.

Radiator Requirements

All power plants require radiators to get rid of excess heat. The radiator sizes in the tables are for a vacuum installation, where you can only rely on radiative heating. In an atmosphere you can use convection to carry the heat away faster. Divide the listed radiator area by 2 in thin atmospheres, by 4 in standard atmospheres, and by 8 in dense atmospheres.

Scale Efficiencies

Building one large power plant is usually more efficient than building multiple small ones because of the way components scale with size. Think of it this way: If four 25HP engines were exactly the same size, added together as one 100HP engine, Detroit would only be building 25HP engines and adding as many as needed to each car. Instead, they build big engines for big cars because it's more efficient that way.

To model this in **Traveller**, adding power to a power plant takes less volume as it gets bigger. The output per m^3 of power plant is as listed in **Table 215: Power Plant Scale Efficiency,** for power plants up to 10 times the listed minimum volume. Once a power plant reaches 10 times the listed volume, the power produced per cubic meter above that volume is multiplied by 1.1. When you reach 100 times the listed minimum volume, the power per additional cubic meter is multiplied again by 1.1, and so on. For your convenience, this progression is listed in **Table 215: Power Plant Scale Efficiencies.**

Example: A TL12 fusion plant has produces 2MW/m^3, and has a minimum volume of 10m^3. For power plant sizes from 10 to 100m^3, the output is the listed 2MW/m^3. So a 50m^3 power plant has an output of 100MW. At 10 times the minimum volume, the output of additional volume increases. So the first 100m^3 still only produce 2MW/m^3, and a 100m^3 power plant produces 200MW. But additional volume produces 2.2MW/m^3. So if you build a 110m^3 power plant, the first 100m^3 produce 200MW (100m^3 x 2MW/m^3), but the last 10 m^3 produce 22MW (10m^3 x 2MW/m^3 x 1.1). This pattern repeats itself at 100 times minimum volume, where the power output becomes 1.21 (1.1 x 1.1), and so on.

Fusion Plus: This rule applies to all power plants except Fusion+. Since a Fusion+ plant is actually composed of numbers of identical cells instead of a monolithic plant, increasing the number of cells doesn't increase the efficiency.

Chemical Power Plants: The minimum size listed for chemical plants is for the purposes of scale efficiency rules only. There is no real minimum size for chemical power plants.

Chemical Power Plants

All these plants burn hydrocarbon distillates. They can all be fueled with alcohol distillates (which reduces power output to 75% of the listed value). Hydrogen fuel is available at TL7 or higher; there is no fuel consumption or power output penalty.

External combustion engines (only) may also burn wood or coal. Wood fuel reduces power output to 50% of the listed value, and fuel consumption triples. Coal fuel provides the listed amount of energy but increases consumption to 1.5 times the amount listed. See Table 216.

Fission Plants

Note that fission plants consume fuel quite slowly—unlike chemical systems, the fuel rates are listed for an entire *year* instead of an hour. See Table 217.

Fusion Plants

Note that fusion plants consume fuel quite slowly—unlike chemical systems, the fuel rates are listed for an entire *year* instead of an hour. See Tables 218-221.

Photoelectric

Photoelectric cells convert light into electricity. The table below lists requirements for cells that are applied directly to the surface of the vehicle and hence limited by the surface area of the chassis or hull. Placing solar cells on a deployed winglike array allows you to have much more area than the hull would allow but multiplies the mass of the solar arrays by ten times the vehicle's maximum acceleration. The arrays may also be retractable, in which case they require 1.1 times their volume in storage space within the vehicle, and the mass is increased by another factor of two.

Fuels

Different types of power plants require different kinds of fuel. Basic fuel tanks require volume equal to the amount of fuel, cost nothing, and mass nothing when empty. See Table 222.

Storage

Accumulators are used to store large amounts of energy for short periods of time. They are capable of very rapid charge and discharge but are not suitable for long-term storage. Accumulators include technologies such as capacitors, homopolar generators, and superconducting energy storage banks. Batteries can hold their charge longer and store more energy, but they can't provide the enormous pulses of power that an accumulator can. Battery technology generally stores energy in chemical reactants.

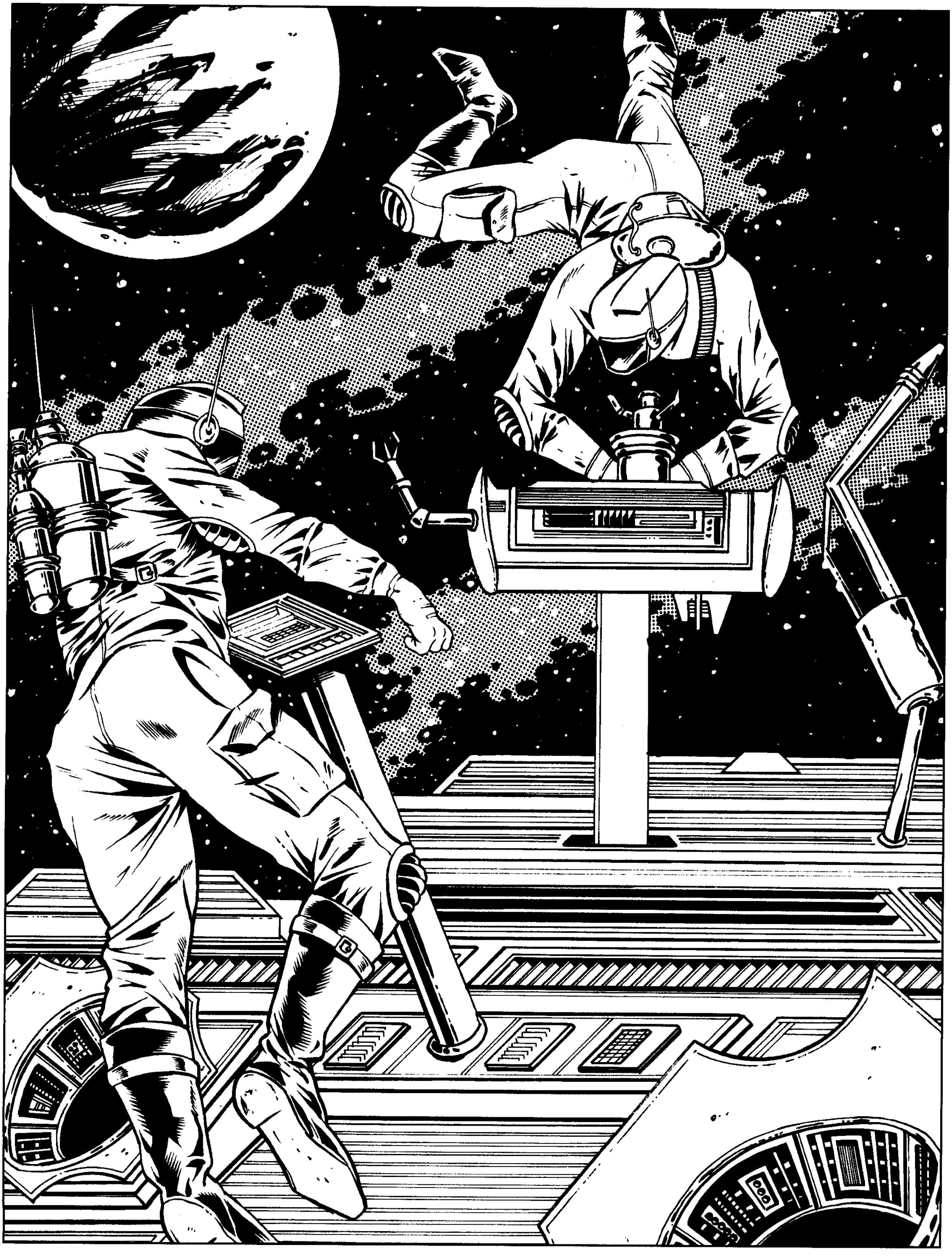
Note: The "accumulators" described as part of the "Vehicle Design System" in *Central Supply Catalog* are actually batteries.

Accumulators

Table 223: Accumulators lists the volume needed to store energy, not power. Accumulators are used for devices, usually weapons (or a camera strobe), which require their energy in one great big pulse rather than a steady flow (like a light bulb). Multiply the capacity of the accumulator by the energy to be stored to get the volume in cubic meters. One cubic meter of accumulators masses two tons and costs MCr0.01.

Batteries

Table 224: Batteries lists the output that a battery can sustain for one hour. If you want to drain a battery faster or slower, use **Table 225: Battery Discharge Rates.** This shows the output a battery can sustain for different time periods. Note that the battery must be specially designed to be able to provide very fast drain rates. This is shown by the price multiplier in the table. Only batteries that were designed in advance for high rates can discharge at those rates. If there is no multiplier, any battery can discharge at the listed rate. Also note that high discharge rates are only available at higher TLs. All of these batteries are rechargable and can be charged at half of the maximum drain rate.



TABLES

Table 1: Metric Units

Abbrev	Unit	Measure	Traditional Equivalent
m	meter	length	3.2808 feet
g	gram	mass	0.03527 ounces
N	Newton	force	0.2248 pounds
W	Watt	power	0.00134 horsepower
J	Joule	energy	0.7737 foot-pounds

Table 2: Metric Prefixes

Abbrev	Prefix	Multiplier	
a	atto	10^{-18}	0.000000000000000001
f	femto	10^{-15}	0.000000000000001
p	pico	10^{-12}	0.000000000001
n	nano	10^{-9}	0.000000001
u	micro	10^{-6}	0.000001
m	milli	10^{-3}	0.001
c	centi	10^{-2}	0.01
d	deci	10^{-1}	0.1
		10^{0}	1
da	deca	10^{1}	10
h	hecto	10^{2}	100
k	kilo	10^{3}	1,000
M	mega	10^{6}	1,000,000
G	giga	10^{9}	1,000,000,000
T	tera	10^{12}	1,000,000,000,000
P	peta	10^{15}	1,000,000,000,000,000
E	exa	10^{18}	1,000,000,000,000,000,000

Table 3: Asteroid Materials

Description	Toughness	Density (t/m³)	Price (Cr/m³)
Icy Bodies	0.29	1.1	50
Metallic Bodies	1.71	8.0	100
Stony Bodies	0.71	5.5	75

Equation 1: Standard Thrust Requirements

Thrust = Accel ↔Volume ↔10kN

Equation 2: Jump Drive Volume

$$Vol_{JD} = 0.01x(1+Jn)x\ Vol_{ship}$$

Equation 3: Jump Grid Area

$$\text{Grid Area} = \text{TotalArea}x0.005x(2+Jn)$$

Equation 4: Jump Fuel

$$\text{Jump Fuel} = 0.1xJnxVol_{ship}$$

Table 4: Jump Drive Table

TL	Max Jump	Mass (t/m³)	Price (MCr/m³)
9	1	3.0	0.3
11	2	3.0	0.3
12	3	3.0	0.3
13	4	3.0	0.3
14	5	2.5	0.3
15	6	2.0	0.3

Table 5: Turret Sockets

Total Socket Size (m³)	Useable Vol (m³)	Empty Mass (t)	Area (m²)	Diameter (m)	Height (m)	Power (MW)
14	13.59	0.41	4.83	2.48	2.89	0.14
28	26.71	1.29	7.69	3.13	3.65	0.28
42	39.46	2.54	10.07	3.58	4.18	0.42
56	51.90	4.10	12.19	3.94	4.60	0.56
70	64.06	5.94	14.12	4.24	4.95	0.70
84	75.94	8.06	15.98	4.51	5.26	0.84

Table 6: Bays

Total Socket Size (m³)	Useable Vol (m³)	Empty Mass (t)	Bay Area (m²)	Weapon Area (m²)	Length (m)	Width & Hght (m)	Power (MW)
350	332.62	17.38	59.0	27.3	10.00	5.90	1.75
700	644.81	55.19	91.2	45.4	12.00	7.60	3.5
1,050	941.53	108.47	121.8	59.4	14.00	8.70	5.25
1,400	1,224.79	175.21	150.4	69.4	16.00	9.40	7
3,500	2,693.17	806.83	270.9	130.7	21.00	12.90	17.5

Table 7: Vehicle Facilities

Description	Volume	Mass (t/m³)	Power (MW/m³)	Price (MCr/m³)
Internal Hangar (Minimal)	x2	0.2	—	0.0002
Internal Hangar (Spacious)	x4	0.2	—	0.0002
Docking Ring	x1.1	0	—	0.0002
Jettison Bay	x1.05	0	—	0.0003
Launch Tube	x25	0.5	0.01	0.00015
External Grapple (USL hull)	x0.1	1.0	—	0.001
External Grapple (SL Hull)	x0.3	1.0	—	0.002
External Grapple (AF Hull)	x0.5	1.0	—	0.003

See text for Area

Table 8: Labs and Workshops

Type	Volume (m³)	Mass (t)	Power (MW)	Price (MCr)
Electronics Shop	84	40	0.6	1.0
Machine Shop	140	120	2.0	1.0
Laboratory	112	50	5.0	0.8
Sickbay	112	50	5.0	0.8

Table 9: Fuel Purification Plants

TL	Volume (m³)	Mass (t)	Power (MW)	Price (MCr)	MinVol (m³)
8	0.7	1.5	0.01	0.0002	135
9	0.6	1.2	0.009	0.00019	120
10	0.55	1.1	0.008	0.00018	105
11	0.45	0.9	0.007	0.00017	95
12	0.4	0.8	0.006	0.00016	80
13	0.35	0.7	0.005	0.00015	65
14	0.25	0.5	0.005	0.00014	55
15	0.2	0.4	0.005	0.00015	40
16	0.15	0.3	0.005	0.00016	25
17	0.1	0.2	0.005	0.00017	15
18+	0.05	0.1	0.005	0.00018	5

All values are per m³ of fuel processed per six hours.

Table 10: Standard Purification Plants

TL	Capacity (m^3/6 hrs)	Volume (m^3)	Mass (t)	Power (MW)	Price (MCr)
8	700	490	1,050	7.0	0.140
8	1,400	980	2,100	14.0	0.280
10	700	385	770	5.6	0.126
10	1,400	770	1,540	11.2	0.252
12	700	280	560	4.2	0.112
12	1,400	560	1,120	8.4	0.224
14	700	175	350	3.5	0.098
14	1,400	350	700	7.0	0.196

Table 11: Maintenance Point Divisors

TL	Divisor
4-5	2
6-7	3
8-9	4
10-12	5
13-15	6
16-18	8
19-21	10
22+	12

Table 12: Visible Signature

Surface Area (m2)	Signature Reflected
1-9	-2
10-99	-1.5
100-999	-1
1,000-9,999	-0.5
10,000-99,999	0
100,000-999,999	0.5
1,000,000-9,999,999	1.0

Table 13: IR Signature

Effective Power (MW)	IR signature
0.000-0.009	-2.5
0.01-0.09	-2.
0.1-0.9	-1.5
1-9	-1
10	-0.5
100	0
1,000	0.5
10,000	1
100,000	1.5
1,000,000	2

Table 14: Active Signature

Surface Area (m^2)	Active Signature
0-9	-0.5
10-999	0
1,000-99,999	0.5
100,000-9,999,999	1
10,000,000+	2

Table 15: Facing Armor

Face	Increase per cm
Front or rear (each)	+10%
Sides (both)	+30%
Top or bottom (each)	+20%

Table 16: Armor Slope Effects

Armor Slope	Effective Thickness	Penalty (per face)
Moderate	x1.5	10%
Radical	x2.0	20%

Table 17: Main Turret Efficiency

TL	Multiplier
6	x4
7	x3
8+	x2

Table 18: Maintenance Point Divisors

TL	Multiplier
4-5	2
6-7	3
8-9	4
10-12	5
13-15	6
16-18	8
19-21	10
22+	12

Table 20: Envelope Cost

TL	Type	Cost (MCr/m^3)
3	non-rigid	10
4	non-rigid	7
4	rigid	50
5	rigid	57
6	non-rigid	11
7	rigid	71
8	non-rigid	14
9	non-rigid	18
9	rigid	143

Table 19: Airship Envelopes

		Lift in Standard Atmospheres (m^3/kN)				Lift in Dense Atmospheres (m^3/kN)			
TL	Type	H	He	Hot Air	Spd Mult	H	He	Hot Air	Spd Mult
3	Non-rigid	141	159	200	0.3	105	117	143	0.2
4	Non-rigid	128	143	175	0.5	98	108	130	0.4
4	Rigid	202	241	350	0.6	136	156	206	0.5
5	Rigid	176	205	280	0.7	124	140	179	0.6
6	Non-rigid	117	129	156	0.7	91	100	119	0.6
7	Rigid	157	179	233	1.0	114	127	159	0.9
8	Non-rigid	108	118	140	0.8	86	93	109	0.7
9	Non-rigid	100	109	127	0.9	81	88	101	0.8
9	Rigid	128	143	175	1.1	98	108	130	1.0

Table 21: Envelope Configuration

TL	Config	Type	Lift Mult	Min Spd (km/hr)	Max Spd (km/hr)	Cost Mult
3	Balloon	Non-rigid	x1.1	0	50	x0.8
4	Cigar	Either	x1.0	0	200	x1.0
8	Cyclo-Crane	Non-rigid	x1.2	0	300	x2.0
9	Magnus Sphere	Non-rigid	x1.4	0	300	x1.5
9	Airfoil	Rigid	x1.6	40	300	x1.3

Table 22: Airship Gondolas

TL	Type	Mass (t/t)	Cost (MCr/t)
3	Primitive	0.01	0.01
5	Standard	0.005	0.02

Table 23: Maintenance Point Divisors

TL	Divisor	TL	Divisor
4-5	2	13-15	6
6-7	3	16-18	8
8-9	4	19-21	10
10-12	5	22+	12

Table 24: Airframes

TL	Type	Aircraft	Mass (t/t)	Cost (MCr/t)	Min Spd (km/hr)	Min STOL (km/hr)	Max Spd (km/hr)	Efficiency
4	Simple	Either	0.010	0.01	150	75	320	0.85
5	Autogyro	Fixed	0.005	0.02	40		200	0.65
5	Fast Subsonic	Either	0.050	0.02	160	80	800	0.90
6	Transonic	Either	0.100	0.03	180	90	1,100	0.95
6	Supersonic	Fixed	0.200	0.04	280	140	2,800	1.00
7	Hypersonic	Fixed	0.300	0.10	350	175	5,000	2.75
7	Wing-in-Ground	Fixed	0.050	0.02	75		400	4.50
8	Advanced Hypersonic	Fixed	0.250	0.14	325	160	none	3.00

Table 25: Airframe Options

Option	Mass	Cost	Drag	Restrictions
VTOL	+10%	+50%		Not with Helicopter or STOL
STOL	+5%	+30%	10	Not with Autogyro, Helicopter, Wing-in-Ground, or STOL
Seaplane	+5%	+25%		Not with Amphibian or Floatplane
Amphibian	+5%	+25%		Mass < 350 tons, not with Seaplane or Floatplane
Amphibian		+25%		Mass between 350 and 400 tons, not with Seaplane or Floatplane
Amphibian	-5%	+25%		Mass > 400 tons, not with Seaplane or Floatplane
Floatplane	+5%	0.01/ton	20	Only with Simple or Fast Subsonic airframes.
Carrier Aircraft	See Text	See Text		None

Table 26: Rotor Assemblies

TL	Type	Mass (kg/kN)	Cost (Cr/kN)	Power (kW/kN)	MaxL (kN)
5	Light Main+Tail Rotor	2.0	40	25	20
5	Light Tandem Rotors	2.4	72	20	50
5	Light Coaxial Rotors	1.6	64	20	30
6	Main+Tail Rotor	3.1	31	25	600
6	Tandem Rotors	3.5	53	20	none
6	Coaxial Rotors	2.5	50	20	600
9	Lift Activator Disk	13.3	133	11	none
9	X-Wing	3.0	150	20	400
9	Ornithopter	3.6	180	40	10
12	Ornithopter	2.0	60	33	20

Table 27: Maneuver Enhancement

% of Aircraft	Points Added
5	1
10	2
20	3
30	4
40	5
50	6
70	7
90	8

Table 28: Maintenance Point Divisors

TL	Divisor
4-5	2
6-7	3
8-9	4
10-12	5
13-15	6
16-18	8
19-21	10
22+	12

Table 29: Facing Armor

Face	Increase per cm
Front or rear (each)	+10%
Sides (both)	+30%
Top or bottom (each)	+20%

Table 30: Armor Slope Effects

Armor Slope	Effective Thickness	Penalty (per face)
Moderate	x1.5	10%
Radical	x2.0	20%

Table 31: Ground Vehicle Propulsion

TL	Type	Volume (m³/MW)	Area (m²/MW)	Price (MCr/MW)	Speed Multiplier
4	Tracks	4.9	17	0.809	0.30
5	Tracks	3.6	14	0.504	0.40
6	Tracks	2.8	12	0.322	0.45
7	Tracks	2.1	10	0.2	0.50
8	Tracks	1.5	9	0.12	0.55
4	Wheels	2.8	12	0.14	0.40
5	Wheels	2.2	10	0.099	0.45
6	Wheels	1.8	8	0.063	0.50
7	Wheels	1.4	6	0.041	0.6
8	Wheels	1.0	5	0.025	0.7
5	Hover	4.1	25	0.02	0.2
6	Hover	3.2	20	0.017	0.3
7	Hover	2.5	15	0.013	0.4
8	Hover	2.0	10	0.01	0.5

Table 32: Main Turret Efficiency

TL	Multiplier
6	x4
7	x3
8+	x2

Table 34: Maintenance Point Divisors

TL	Divisor
4-5	2
6-7	3
8-9	4
10-12	5
13-15	6
16-18	8
19-21	10
22+	12

Equation 5: Bullet Base Area

$$Area_{base} = \frac{\pi}{4} \leftrightarrow Caliber^2$$

Table 36: Propellant Energy Density

TL	Conventional	ETC
2	0.5	—
3	0.6	—
4	0.7	—
5	0.8	—
6	0.9	—
7	1.0	—
8	1.1	—
9	1.2	2.4

Table 33: Speed Multipliers

Mass (t)	Speed Multiple
10	x1.2
20	x1.5
40	x1.9
80+	x2.4

Table 35: Energy Limits

TL	kJ/mm
4 or less	2000
5 - 6	3000
7 or more	4000

Equation 6: Conventional Propellant Volume

$$Vol_{propel} = \frac{E_{rated}}{ED_{propel}}$$

Table 37: Bullet Length

Type	Len_{bullet}
Shotgun	0
Pistol or Ball	Caliber
Rifle	2 x Caliber
Flechette	3 x Caliber

Equation 7: Minimum Cartridge Case Length

$$Len_{cc\min} = \frac{Vol_{propel}}{Mod_{ctype} \leftrightarrow Area_{base}}$$

Table 38: Cartridge Type Modifier

Type	Mod_{ctype}
Spherical Ball	0.15
Shotgun	0.20
Patched Ball	0.23
Conical Bullet	0.30
Straight	0.40
Necked or Caseless	1.60

Equation 8: Ammunition Mass

$$Mass_{ammo} = Mod_{atype} \leftrightarrow Len_{ccase} \leftrightarrow A_{base}$$

Table 39: Ammunition Type Modifier

TL	Type	Mod_{atype}
2	Spherical or Patched Ball (loose or paper cartridge)	0.003
2	Shotgun (shell or paper cartridge)	0.003
3	Conical Bullet (loose or paper cartridge)	0.005
3	Early Straight (metallic cartridge)	0.010
3	Early Necked (metallic cartridge)	0.013
5	Straight (metallic cartridge)	0.008
5	Necked (metallic cartridge)	0.010
8	Caseless	0.0075

Equation 9: Ideal Barrel Length

$$Len_{ideal} = \frac{E_{rated}}{Caliber^2} \leftrightarrow Mod_{rifling}$$

Table 40: Rifling Modifers

Type	Black Powder	Conventional	ETC
Smoothbore	20.0	4.0	3.0
Rifled	5.0	1.0	0.5

Table 41: Ammunition Price Modifier

Classification	Price Cr/g	Notes
Loose Powder and Bullet	0.005	
TL-2 Paper Cartridge	0.050	
TL-3 Paper Cartridge	0.010	
Shotgun	0.010	
Mass-produced	0.020	See text
Ordinary	0.040	See text
High-Powered	0.050	See text

Equation 10: Barrel Length Modifier

$$Mod_{blen} = \frac{Len_{barrel}}{Len_{ideal}} - 1$$

Table 42: Ammunition Options

TL	Code	Type	Cost
4	HP	Hollow-point	x 1
5	Flechette	Flechette	x 5
6	HE	High explosive	x 2
6	HEAP	High explosive armor piercing (Large Caliber)	x 3
6	Tranq	Tranquilizer	x 2
8	DS	Discarding sabot	x 2
9	HEAP	High explosive armor piercing (Small Caliber)	x 3

Table 43: Cartridge Case Features

Code	Meaning
R	Rimmed
SR	Semi-rimmed
B	Belted
E	Electro-thermal-chemical
C	Caseless
F	Flechette

Table 44: Historic Equivalents

Designation	Energy	Common Name	Weapons Used in
5.45x39mm	1,400		AKS-74
5.56x29mm	500	.22 SCAMP	Colt SCAMP
5.56x36mm	1,100	.221 Fireball	Remington XP-100
5.56x45mm	1,800	.223 Remington, 5.56 NATO	M16A1, FN-CAL, Galil ARM
5.7x17mmR	200	.22 Long Rifle	High-Standard .22, AR-7
6.35x15.5mmSR	100	.25 ACP, .25 Auto	Colt .25 Automatic
7.62x25mm	500	.30 Mauser, 7.62 Tokarev	Mauser M1896, Tokarev M1933
7.62x33mm	1,200	.30 Carbine	M2 Carbine
7.62x39mm	2,000	7.62 Short	SKS, AK-47, AKM-47, RPD, RPK
7.62x51mmR	2,600	.30-30	Winchester 94
7.62x51mm	3,400	.308 Winchester, 7.62 NATO	M-14, FN-FAL, L42A1, G-3, M60
7.62x54mmR	3,600	7.62mm Russian	SVD, SG-43, PKM, Vz-59
7.62x63mm	3,500	.30-06	Springfield M1903, M1 Garand
7.62x66mmB	5,100	.300 Winchester Magnum	Walther WA-2000
7.65x17mmSR	300	.32 ACP, .32 Auto	Welrod "Silent", Vz-61
7.7x56mmR	3,100	.303 British	Enfield, Vickers, Lewis, Bren
7.7x58mm	2,900	7.7mm Arisaka	Arisaka M99
7.92x33mm	2,000	7.92 Kurz	MP-44
7.92x57mm	3,700	8mm Mauser	Kar-98k, FG-42, MG-08, MG-34
8x21mm	400	8mm Nambu	Type 14 Nambu
9x17mm	300	.380 Auto, 9mm Short	Walther PPK, Ingram M11
9x18mm	400	9mm Makarov	P64, Makarov, Stechkin, PM-63
9x19mm	500	9mm Parabellum, 9mmP	Luger P-08, S&W M39, UZI
9x29mmR	300	.38 Special, .38 S&W	Colt Police Positive
9x33mmR	1,000	.357 Magnum	S&W M27, Colt Python
10.8x33mmR	1,100	.44-40	Winchester M1873
10.97x33mmR	1,600	.44 Magnum	S&W M29
11.2x32mm	1,500	.44 Automag	.44 Automag
11.43x23mm	500	.45 ACP, .45 Auto	Colt M1911A1, Thompson SMG
11.43x60mmR	2,300	.45 Martini	Martini-Henry Mk.I
11.56x33mmR	600	.45 Colt	Colt M1873
11.6x54mmR	2,200	.45-70	Springfield Trapdoor
11.6x63.5mmB	6,900	.458 Winchester Magnum	Winchester M70 African
11.6x74mmB	11,000	.460 Weatherby Magnum	.460 Weatherby Mk.V
12.7x83mmR	3,900	.50-140 Sharps	Sharps M1874 "Buffalo Rifle"
12.7x99mmB	16,900	.50 Browning	.50 Cal M2HB
12.7x108mmB	16,800	Type BZ	DshK M38/46
13.9x22mmR	1,500	.56/50 Spencer	Spencer .56
13.9x99mmB	23,500	.55 Boys	.55 Boys Mk.I
14.45x114mmB	30,600	Type BS-41	PTRS-41, KPV, "Crunch Gun"
15.7x76mmR	11,400	.600 Nitro Express	.600 Nitro Rifle "Elephant Gun"

Table 45: Barrel Mass per Centimeter

Type	Mass
Light	0.02
Heavy	0.03

Table 46: Barrel Cost per Kilogram

Type	Cost
Smoothbore	100
Black Powder	200
Light Rifled	200
Heavy Rifled	400

Equation 11: Actual Muzzle Energy

$$E_{muzzle} = E_{rated} \leftrightarrow (1 + \frac{Mod_{blen}}{2})$$

Table 47: Advanced Barrel Materials

TL	Mass	Price
8	x 0.75	x 5
10	x 0.60	x 6
12	x 0.50	x 7

Table 48: Stealth Options

TL	Type	Length	Mass	Cost
4	Silencer	40	1.00	200
4	Suppressor	10	0.25	50
4	Flash Hider	3	0.03	3
4	Long Flash Hider	7	0.07	7

Table 49: Muzzle Brakes and Recoil Compensators

TL	Type	Mod_{recoil}	Length	Mass	Price
6	Muzzle Brake	0.90	4	0.2	50
7	Muzzle Brake	0.85	4	0.2	50
7	Long Muzzle Brake	0.70	8	0.4	200
7	Recoil Compensator	0.90	0	0.0	300
8	Muzzle Brake	0.80	4	0.2	50
8	Long Muzzle Brake	0.65	8	0.4	200
8	Recoil Compensator	0.85	0	0.0	300
9	Muzzle Brake	0.75	4	0.2	50
9	Long Muzzle Brake	0.60	8	0.4	200
9	Recoil Compensator	0.80	0	0.0	300

Table 50: Locks

TL	Type	Mass	Price	Reload
2	Matchlock	0.3	30	25
2	Wheellock	0.6	100	20
2	Snaphaunce	0.5	200	15
2	Flintlock	0.5	50	15
3	Percussion	0.3	20	15

Table 51: Receiver Types

TL	Code	Action	Type
3	SS	Single-Shot (individually loaded)	Light
3	SAR	Single-Acting Revolver	Light
3	LA	Lever Action Repeater	Heavy
4	DAR	Double-Acting Revolver	Light
4	BA	Bolt Action Repeater	Light
4	PA	Pump Action Repeater	Light
4	SA	Semi-Automatic	Heavy
4	FA	Full Automatic	Heavy
5	SA	Semi-Automatic	Light
5	FA	Full Automatic	Light
6	AB	Automatic Burst	Light

Equation 12: Minimum Receiver Length

$$Len_{mrec} = Mod_{rtech} \times \sqrt{E_{rated}}$$

Equation 13: Low-Power Receiver Mass

$$Mass_{mlrec} = \frac{E_{rated}}{800}$$

Table 52: Receiver Technology

TL	Mod_{rtech}
4-5	0.55
6-7	0.50
8-9	0.45
10+	0.40

Equation 14: Standard Receiver Mass

$$Mass_{mlrec} = 1.25 + \frac{(E_{rated} - 1000)}{1000}$$

Table 53: Receiver Cost per Kilogram

Action	Price (Cr)
Single-Shot (individually loaded)	50
Revolver (either type)	150
Repeater (any type)	300
Automatic	200
Selective Fire	250
Multi-Selective Fire	300

Table 54: Advanced Receiver Materials

TL	Mass	Price
8	x 0.75	x 5
10	x 0.60	x 6
12	x 0.50	x 7

Table 55: Grip Magazine Capacity

TL	Max Length (mm)	Capacity Factor
4	30	80
5	40	90
6	50	100
7	60	120
8+	70	140

Equation 15: Multiple-Barrel Rate of Fire

$$ROF_{\max} = 500 \times (Num_{barrels} - 1)$$

Equation 16: Revolver Cylinder Capacity

$$Cap_{cylinder} = \frac{19}{\sqrt{Cal}}$$

Equation 17: Magazine Mass

$$Mass_{mag} = \frac{Mass_{ammo} \times (N_{rounds} + 4)}{3}$$

Table 56: ETC Power Source

TL	Mass (kg/rd)
9	0.027
10	0.019
11	0.013
12+	0.011

Equation 18: Basic Range

$$R_{basic} = (1 + (Mod_{blen} \leftrightarrow Mod_{bscale})) \leftrightarrow Mod_{config} \leftrightarrow \sqrt{E_{muzzle}}$$

Table 57: Configuration Range Modifiers

Configuration	Mod_{config}
Bullpup	0.9
Bolt-Action	1.1
One-Handed	0.4
Two-Handed	1.3
Smoothbore	0.5

Table 58: Ammunition Range Modifiers

Ammunition	Range
Discarding Sabot	x 1.20
HE and HEAP	x 0.75
Tranq	x 0.60

Table 59: *Traveller* Range Bands

DM	Name	Distance (m)
0	Contact	0 - 3
1	Very Short	4 - 15
2	Short	16 - 45
3	Medium	46 - 150
4	Long	151 - 450
5	Very Long	451 - 1500

Equation 19: *Traveller* Damage

$$D = \frac{\sqrt{E_{eff}}}{10.5}$$

Equation 20: KEAP Penetration Value

$$PV = PV_{base} + Mod_{pv} \leftrightarrow \left(E_{muzzle} - E_{base}\right)$$

Table 60: KEAP Penetration Modifiers

E_{muzzle} At Least	But E_{muzzle} Less Than	PV_{base}	Mod_{pv}	E_{base}
0.03	0.5	16	7	0.03
0.5	1	19	12	0.5
1	1.5	25	10	1
1.5	5	30	8	1.5
5	7	58	6	5
7	9	70	4	7
9	12	78	2	9
12		84	1	12

Equation 21: HE and HEAP Effective Energy

$$E_{eff} = E_{muzzle} + \left(\frac{Cal}{2} + TL - 7\right)^3$$

Equation 22: Single-Shot Recoil

$$Mod_{rss} = \frac{-0.15 \leftrightarrow \sqrt{E_{muzzle}}}{Mass_{loaded}} + Mod_{energy} \surd \leftrightarrow Mod_{recoil}$$

Table 61: Recoil Energy Modifier

E_{muzzle}	Mod_{energy}
0 - 1000	0
1001 - 2500	1
2501 - 5000	2
5001 - 10000	3
10001 - 20000	4
20001 - 50000	5
50000+	6

Table 62: Recoil-Compensating Actions

TL	Type	Mod_{recoil}
4	Semi-Automatic	0.95
4	Full Automatic	0.95
6	Automatic Burst	0.95
9	ETC	0.60

Equation 23: Burst Recoil

$$Mod_{rburst} = Mod_{rss} \leftrightarrow \frac{N_{burst}}{2}$$

$$Mass_{ammo} = \frac{\pi \leftrightarrow Cal^2}{50}$$

Table 63: Ammunition Cost

Classification	Price	Notes
Mass-produced	0.020	See text
Ordinary	0.040	See text

Table 64: Ammunition Options

TL	Code	Type	Cost
10	HE	High explosive	x 2
10	HEAP	High explosive armor piercing	x 3
10	Tranq	Tranquilizer	x 2

Table 65: Gauss Weapon Characteristics

TL	Maximum (m/s)	Mod_{blen}	Efficiency
10	2000	1.6	3.0
11	4000	1.3	2.4
12	6000	1.0	2.0
13	6000	0.8	1.8
14	6000	0.6	1.6
16+	6000	0.4	1.4

Equation 24: Barrel Length

$$Len_{barrel} = \frac{Vel_{muzzle}}{100 \leftrightarrow Mod_{blen}}$$

Equation 25: Muzzle Energy

$$E_{muzzle} = \frac{Mass_{ammo}}{2000} \leftrightarrow Vel_{muzzle}^{\;2}$$

Table 66: Receiver Mass

TL	Factor
10	6,250
11	8,333
12	10,000
13	11,111
14	12,500
15	14,286
16	16,667
17	20,000
18+	25,000

Table 67: Receiver Options

Type	Cost
Fully-Automatic	x 1.1
Select Fire or Burst	x 1.2
Very Rapid Fire	x 5.0

Equation 26: Receiver Length

$$Len_{rec} = \sqrt{1000 \leftrightarrow Mass_{rec}}$$

Equation 27: Battery Mass

$$Mass_{battery} = \frac{N_{rounds} \leftrightarrow E_{input}}{Mod_{btech}}$$

Table 68: Battery Mass Factor

TL	Mod_{btech}
10	100000
11	111111
12	166667
13	181818
14	250000
15	285714
16+	333333

Equation 28: Gauss Gun Input Power

$$Power = \frac{E_{input} \leftrightarrow ROF}{60}$$

Equation 29: Magazine Mass

$$Mass_{mag} = \frac{Mass_{ammo} \leftrightarrow (N_{rounds} + 4)}{3} + Mass_{battery}$$

Equation 30: Gauss Gun Basic Range

$$R_{basic} = 1.2 \leftrightarrow Mod_{config} \leftrightarrow \sqrt{E_{muzzle}}$$

Table 69: Configuration Range Modifiers

Configuration	Mod_{config}
Bullpup	0.9
One-Handed	0.4
Two-Handed	1.3

Table 70: Ammunition Range Modifiers

Ammunition	Range
HE and HEAP	x 0.63
Tranq	x 0.50

Table 71: *Traveller* Range Bands

DM	Name	Distance (m)
0	Contact	0-3
1	Very Short	4-15
2	Short	16-45
3	Medium	46-150
4	Long	151-450
5	Very Long	451-1500

Equation 31: *Traveller* Damage

$$D = \frac{\sqrt{E_{eff}}}{10.5}$$

Equation 32: KEAP Penetration Value

$$PV = PV_{base} + Mod_{pv} \leftrightarrow (E_{muzzle} - E_{base})$$

Table 72: KEAP Penetration Modifiers

E_{muzzle} At Least	But E_{muzzle} Less Than	PV_{base}	Mod_{pv}	E_{base}
0.03	0.5	16	7	0.03
0.5	1	19	12	0.5
1	1.5	25	10	1
1.5	5	30	8	1.5
5	7	58	6	5
7	9	70	4	7
9	12	78	2	9
12		84	1	12

Equation 33: HE and HEAP Effective Energy

$$E_{eff} = E_{muzzle} + (\frac{Cal}{2} + TL - 7)^3$$

Equation 34: Single-Shot Recoil

$$Mod_{rss} = \frac{-0.15 \leftrightarrow \sqrt{E_{muzzle}}}{Mass_{loaded}} + Mod_{energy}{}^{\surd}_{\lrcorner} \leftrightarrow \frac{Mod_{recoll}}{2}$$

Table 73: Recoil Energy Modifier

E_{muzzle}	Mod_{energy}
0 - 1000	0
1001 - 2500	1
2501 - 5000	2
5001 - 10000	3
10001 - 20000	4
20001 - 50000	5
50000+	6

Table 74: Warhead Availability

TL	Warhead
4	Most warheads
5	HEAP
5	WP
6	Flechette
6	Chaff
7	Submunition
7	RDM
8	SEFOP

Equation 35: Burst Recoil

$$Mod_{rburst} = Mod_{rss} \leftrightarrow \frac{N_{burst}}{2}$$

Equation 36: Explosive Damage Value

$$D = \frac{Cal^2 \leftrightarrow Mod_{ammotl}}{Mod_{whtype}}$$

Equation 37: Explosive Warhead Burst Radius

$$Rad_{bprim} = \frac{Mod_{mtype} \leftrightarrow \sqrt{D}}{Mod_{brwhtype}}$$

Table 75: TL Damage Modifier

TL	Mod_{ammotl}
4	0.11
5	0.14
6	0.18
7	0.21
8	0.25
9	0.29
10+	0.36

Table 76: Explosive Warhead Type

Type	Mod_{whtype}
HE	1
HEAP	1.5
SEFOP	2

Table 77: Munition Type Modifer

Type	Mod_{mtype}
Gun or Grenade	7
Mortar, Rocket or Bomb	10

Table 78: Burst Radius Modifier

Type	$Mod_{brwtype}$
HE	1.2
HEAP	2.4
SEFOP	1.2

Table 79: Explosive Penetration Modifier

TL	Mod_{expen}
HE	2.1
5	5.7
6	8.6
7	11.4
8	14.3
9+	17.1

Equation 38: KEAP Penetration Value

$$PV = PV_{base} + Mod_{pv} \leftarrow (E_{muzzle} - E_{base})$$

Table 80: KEAP Penetration Modifiers

E_{muzzle} At Least	But E_{muzzle} Less Than	PV_{base}	Mod_{pv}	E_{base}
0.03	0.5	16	7	0.03
0.5	1	19	12	0.5
1	1.5	25	10	1
1.5	5	30	8	1.5
5	7	58	6	5
7	9	70	4	7
9	12	78	2	9
12		84	1	12

Equation 39: Chemical Warhead Burst Radius

$$Rad_{bprim} = \frac{Cal^2}{8}$$

Equation 40: Illumination Round Burst Radius

$$Rad_{bprim} = (Mod_{illumtl} \leftarrow Cal)^2$$

Equation 41: Submunition Burst Radius

$$Rad_{bprim} = \frac{Cal^2}{4}$$

Equation 42: RDM Burst Radius

$$Rad_{bprim} = \frac{Cal^2}{2}$$

Table 81: KEAP Penetration TL Modifier

TL	Mod_{techpv}
4	1.0
5	1.3
6	1.7
7	2.4
8	3.0
10	4.5
12	5.0
14	6.0
17+	7.0

Table 82: Illumination TL Modifier

TL	$Mod_{illumtl}$
4 - 5	2.5
6 - 7	3
8 - 9	2.5
10+	4

Table 83: Chaff TL Modifier

TL	$Mod_{illumtl}$
4 - 5	2.5
6 - 7	3
8 - 9	2.5
10+	4

Equation 43: Chaff Burst Radius

$$Rad_{bprim} = (Mod_{illumtl} \leftarrow Cal)^2$$

Table 84: Warhead Mass

Caliber	Mass
2	0.2
3	0.4
4	0.5
5	1.5
6	3
7	6
8	12
9	17
10	21
11	25
12	30
13	35
14	43
15	50
16	60
17	72
18	85
19	100
20	115
21	140
22	160
23	185
24	215
25	250
30	500
35	1000
40	2500
45	5000
50	10000

Table 85: KEAP Mass Modifiers

TL	Type	Mass
4	Solid Shot	x 2.0
5	High-Velocity Armor Piercing	x 1.5
6+	All Other KEAP	x 1.0

Table 86: Special Ammunition Mass

Type	Mass	Includes Propellant?
Hand Grenade	x 0.3	Not Applicable
Low-Velocity Propelled Grenade	x 0.4	Yes
Medium-Velocity Propelled Grenade	x 0.4	Yes
Rockets and Missiles	x 0.4	No
Light Recoilless Rifle	x 0.4	Yes
Rifle Grenade	x 0.5	Not Applicable
High-Velocity Propelled Grenade	x 0.5	Yes
RAM Grenade	x 0.6	Yes
Heavy Recoilless Rifle	x 0.7	Yes
Mortar	x 0.8	No

Table 87: Warhead Price

TL	Type	Price
4+	HE	10
4	KEAP (AP)	5
5	KEAP (HVAP)	15
6	KEAP (APDS)	15
7	KEAP (APFSDS)	15
8	KEAP (APFSDSDU)	30
10	KEAP	35
12	KEAP	40
14	KEAP	45
17+	KEAP	50
5+	HEAP	15
8+	SEFOP	20
4+	Chemical	10
5+	WP/IS	20
4+	Illumination	10
7	Submunition	60
9+	Submunition (Homing)	100
7+	RDM	100
6+	Flechette	50
6+	Chaff	20

Equation 44: Rifle Grenade Range

$$R_{rg} = \frac{-\quad D}{Mass_{grenade}\leftarrow\!\rfloor}\surd\leftrightarrow Mod_{wtech}$$

Table 88: Rifle Grenade Range Modifier

TL	Mod_{gtech}
5 - 6	25
7 - 8	46
9+	67

Table 90: Mine Fuses

TL	Type	Price (Cr)
4	Contact	10
6	Radio	20
8	Proximity	100

Table 89: RAM Grenade Range

TL (m)	Direct Range (m)	Indirect Range
8	30	500
9	40	550
10	50	1500
11+	60	2000

Table 91: Nuclear Warheads

Size	Yield (kT)	Radius (m)		Ground Burst radius (m)			Air Burst Radius (m)		
		Crater	Induced	Destruction	Primary	Secondary	Destruction	Primary	Secondary
17	0.1	25	30	30	100	200	50	150	300
18	0.5	25	35	30	150	330	60	180	360
19	1.0	40	40	30	210	420	60	240	420
20	2.0	50	60	60	300	540	90	300	540
21	5.0	50	80	150	480	660	120	420	600
22	10.0	60	90	180	540	720	120	480	660
23	20.0	60	100	300	540	900	240	480	720
24	50.0	70	120	420	750	1200	300	600	900
25	100.0	100	140	480	750	1260	420	600	1080

Table 92: Collapsing Nuclear Warheads

Size	Yield (kT)	Radius (m)		Ground Burst radius (m)			Air Burst Radius (m)		
		Crater	Induced	Destruction	Primary	Secondary	Destruction	Primary	Secondary
2	0.001	10	5	20	25	50	30	60	120
3	0.002	10	10	20	30	60	35	70	140
3.5	0.005	15	10	20	40	80	35	75	150
4	0.010	15	15	25	50	100	40	95	190
6	0.050	20	20	25	75	150	45	120	240
7	0.100	25	30	30	100	200	50	150	300

Table 93: Short-Range Detonation Lasers

Yield	Price	DV	PV	Volume by TL (m^3)					
				8	9-10	11-12	13-14	15-16	17+
10	0.6	36	286	0.29	0.20	0.16	0.13	0.10	0.08
20	0.7	50	550	0.32	0.22	0.18	0.15	0.11	0.09
50	0.8	61	860	0.35	0.24	0.20	0.17	0.13	0.10
100	0.9	80	1,440	0.39	0.27	0.22	0.19	0.15	0.11
200	1.1	94	1,980	0.51	0.36	0.28	0.25	0.17	0.13
500	1.2	113	2,821	0.71	0.51	0.40	0.36	0.25	0.17

Table 94: Long-Range Detonation Lasers

Yield	Price	DV	PV	Volume by TL (m³) 13-14	15-16	17+
10	6	36	286	0.26	0.21	0.16
20	7	50	550	0.30	0.23	0.18
50	8	61	860	0.34	0.25	0.20
100	9	80	1,440	0.38	0.29	0.22
200	11	94	1,980	0.50	0.33	0.26
500	12	113	2,821	0.72	0.49	0.34

Table 95: Command Operating System

TL	Type	Mass (kg)	Cost (Cr)	Max Speed (km/hr)	Agility
5	Manual	1	40	300	-2
6	Semiautomatic	2	80	600	-1
7	Automatic	2	100	900	
8	Teleguided	2	100	1200	

Table 96: Command Link Type

TL	Type	Mass (kg)	Cost (Cr)	Range (km)
5	Wire	0	0	2
6	Wire	0	0	4
7	Wire	0	0	6
5	Radio	2	40	See Text
6	Radio	1	40	See Text
7	Laser	1	70	10
8+	Laser	1	50	See Text

Table 97: Target Designation Guidance

TL	Designator Type	Mass (kg)	Cost (Cr)
6	Radar	2	1000
7	Rader	2	1000
8+	Radar	1	1000
7	Laser	1	500
8	Laser	1	500
10+	Laser	1	500

Table 98: Homing Guidance

TL	Type	Mass (kg)	Cost (Cr)	Range (km)	Maneuver
6	Infra-Red	1	500	10	-2
7	Improved IR	1	1000	15	-1
8+	Advanced IR	1	1500	20	
7	Anti-Radiation	1	1000	12	-2
8+	Improved ARM	1	2000	24	-1

Table 99: Smart Guidance

TL	Type	Mass (kg)	Cost (Cr)	Maneuver
7	Target Memory	3	10,000	-1
8	Target Memory	2	5,000	
8-10	Target Seeker	1	1,000	-2
11-13	Target Seeker	1	1,000	
14+	Target Seeker	1	1,000	+2

Equation 45: CPR Gun Propellant Mass

$$Mass_{propel} = \frac{Mass_{warhead} \leftrightarrow Len_{barrek}}{145}$$

Table 100: CPR Gun Table

Caliber	Mass	E_{rated}
2	0.1	0.06
3	0.12	0.15
4	0.16	0.35
5	0.3	0.8
6	0.42	1.6
7	0.54	2.4
8	0.6	3.6
9	1	4.9
10	1.2	6
11	1.5	7.7
12	2.1	9.3
13	2.7	11.7
14	3.3	15
15	4	18.6
16	4.5	23
17	6	29
18	7.5	36
19	9	41
20	11	48
21	13	55
22	15	63
23	17	72
24	19	83
25	21	96
30	30	150
35	40	230
40	50	350
45	60	500

Equation 46: Mortar Barrel Mass

$$Mass_{barrel} = \frac{Cal^2 \leftrightarrow Len_{barrel}}{50}$$

Table 101: CPR Gun Technology

TL	$Mod_{cprtech}$
4	0.8
5-6	1.0
7	1.2
8	1.4
9+	1.6

Table 102: Reload Time per Mj

TL	Mod_{reload}
4	5.0
6	4.5
7	3.5
8	2.5
9+	1.5

Equation 47: CPR Gun Rate of Fire

$$ROF = \frac{60}{E_{muzzle} \leftrightarrow Mod_{reload}}$$

Equation 48: Indirect Fire Range

$$R_{indirect} = \frac{Len_{barrel} \leftrightarrow \sqrt{(Cal + TL - 4)}}{7.7}$$

Table 103: Indirect Fire Range Modifier

Type	Range
Base Bleed	x 1.2
Rocket-Assisted Projectile	x 1.5

Equation 49: CPR Direct Fire Range

$$R_{dshort} = 5 \leftrightarrow \left(Len_{barrel} + Cal + 20\right)$$

Table 104: Hypervelocity Smoothbore Ranges

TL	Modifier
7	1.15
8	1.30
9+	1.45

Table 105: MD Maximum Muzzle Velocity

TL	Velocity (m/s)
8	3000
9	4000
10	5000
11+	6000

Equation 50: Mass Driver Mass

$$Mass_{gun} = \frac{Cal^2}{50}$$

Equation 51: MD Muzzle Energy

$$E_{muzzle} = \frac{Mass_{warhead} \leftrightarrow V_{muzzle}}{2{,}000{,}000}$$

Table 106: Mass Driver Effeicency

TL	Efficiency
8	4.5
9	3.6
10	3.0
11	2.4
12	2.0
13	1.8
14	1.6
16+	1.4

Equation 52: Mass Driver Rate of Fire

$$ROF = \frac{60}{Mass_{warhead} \leftarrow 2.5}$$

Equation 53: Mass Driver Input Power

$$Power = \frac{E_{input} \leftrightarrow ROF}{60}$$

Equation 54: Indirect Fire Range

$$R_{indirect} = \frac{V_{muzzle} \leftrightarrow \sqrt{(Cal + TL - 4)}}{154}$$

Table 107: Indirect Fire Range Modifier

Type	Range
Base Bleed	x 1.2
Rocket-Assisted Projectile	x 1.5

Equation 55: MD Direct Fire Range

$$R_{dshort} = 5 \leftrightarrow \frac{V_{muzzle}}{20} + Cal + 20\surd \hookleftarrow$$

Table 108: High Energy Weapon Firing Unit

TL	Multiplier (kg/Mj)
10	8.0
11	6.0
12	4.0
15	2.0
16	1.0
18	0.5
20	0.3

Table 109: Firing Unit Cost

Weapon Type	Plasma (Cr/kg)	Fusion (Cr/kg)
Man-Portable	1200	2000
Cradle Gun	600	1000

Table 110: High Energy Weapon Support Hardware

TL	Multiplier (kg/Mj)
10	8.0
11	6.0
12	4.0
15	2.0
16	1.0
18	0.5
20	0.3

Table 111: Firing Unit Cost

Weapon Type	Plasma (Cr/kg)	Fusion (Cr/kg)
Man-Portable	1200	2000
Cradle Gun	600	1000

Table 112: Man-Portable Recoil Systems

TL	Type	Mass (kg/Mj)	Mod_{recoil}
10-11	Gyroscopic Compensator	6.0	0.8
12-13	Gyroscopic Compensator	5.0	0.8
14	Inertial Compensator	4.0	0.5
15	Inertial Compensator	3.0	0.4
16-17	Inertial Compensator	1.0	0.3
18-19	Inertial Compensator	0.5	0.2
20+	Inertial Compensator	0.3	0.2

Table 113: Cradle Recoil Systems

TL	Mass (kg/Mj)
10	75
11	50
12	35
13-14	20
15-16	15
17-18	10
19-20	6
21+	4

Table 114: Action Mass

TL	Mass (kg/Mj)
10	0.16
11	0.12
12	0.10
13	0.09
14	0.08
15	0.07
16	0.06
17	0.05
18	0.04
19	0.03
20	0.02
21+	0.01

Table 115: Rapid Pulse Receivers

ROF (per min)	Mod_{rmass}	ROF (per min)	Mod_{rmass}
12	1.00	132	1.50
24	1.05	144	1.55
36	1.10	156	1.60
48	1.15	168	1.65
60	1.20	180	1.70
72	1.25	192	1.75
84	1.30	204	1.80
96	1.35	216	1.85
108	1.40	228	1.90
120	1.45	240	1.95

Table 116: EPG Cartridges

TL	Mass (kg/Mj)	Price (Cr/Mj)
10	4.8	100
12	2.4	25
14	1.6	8
16+	0.8	4

Table 117: High Energy Efficiency

TL	Plasma	Fusion
10	1.6	—
11	1.5	—
12	1.4	—
13-14	1.3	1.00
15-16	1.2	0.95
17-18	1.2	0.90
19-20	1.1	0.85
21+	1.1	0.80

Equation 56: Magazine Mass

$$Mass_{mag} = \frac{Mass_{ammo} \leftrightarrow (N_{rounds} + 4)}{3}$$

Equation 57: Energy Weapon Fuel

$$Fuel = \frac{E_{pulse} \leftrightarrow N}{Mod_{fuel}}$$

Equation 59: Fusion Weapon Range

$$R_{fshort} = 150 \leftrightarrow \sqrt{E_{pulse}}$$

Equation 58: Plasma Weapon Range

$$R_{pshort} = 100 \leftrightarrow \sqrt{E_{pulse}}$$

Equation 60: Energy Weapon Damage

$$D = 40 \leftrightarrow \sqrt{E_{pulse}}$$

Table 118: High Energy Fuel Consumption

Type	Mod_{fuel}
Plasma	20,000
Rapid-Pulse Plasma	5,000
Fusion	15,000
Rapid-Pulse Fusion	3,000

Table 119: Velocity TL Modifier

TL	Mod_{tech}
4-6	66667
7-9	111111
10+	166667

Equation 61: Single-Shot Recoil

$$Mod_{rss} = \frac{-150 \leftrightarrow \sqrt{E_{muzzle}}}{Mass_{loaded}} \leftrightarrow Mod_{recoil}$$

Equation 62: Burst Recoil

$$Mod_{rburst} = Mod_{rss} \leftrightarrow \frac{N_{burst}}{2}$$

Equation 63: Missile Thrust

$$T_{req} = \frac{Mass_{avg} \leftrightarrow \sqrt{Vel_{design}}}{Mod_{tech}}$$

Equation 64: Missile Thrust

$$T_{req} = \frac{Acc_{design}}{Mass_{avg}}$$

Table 120: Focal Array Modifiers

TL	Heavy Array	Light Array
7	1	10
9	0.1	1
10	0.01	1
12	0.001	0.5
16	0.0005	0.1
20+	0.0001	0.05

Table 121: Non-Gravity Efficiency

TL	Efficiency
7	0.20
8	0.25
9	0.30
10	0.35
11	0.45
12	0.55
13	0.65
14	0.75
15	0.85
16+	0.95

Table 122: Laser Range and Focal Values

		Grav Focused			
TL	Non GF	Heavy	Light	Frequency Band	Range Factor
7	F=D	—	—	Infrared (IR)	3
8	F=D	—	—	Visible light (VL)	20
9	F=D	$F=10D^2$	F=D	Near ultraviolet (NUV)	33
10	F=D	$F=90D^2$	$F=10D^2$	Ultraviolet (UV)	50
11	F=D	$F=160D^2$	$F=90D^2$	Far ultraviolet (FUV)	100
12	F=D	$F=250D^2$	$F=160D^2$	FUV	100
13	F=D	$F=360D^2$	$F=250D^2$	FUV	100
14	F=D	$F=360D^2$	$F=360D^2$	FUV	100
15	F=D	$F=360D^2$	$F=360D^2$	Soft X-Ray/Extreme UV (EUV)	1,000
16	F=D	$F=360D^2$	$F=360D^2$	X-Ray (XR)	2,000
17	F=D	$F=360D^2$	$F=360D^2$	XR	5,000
18	F=D	$F=360D^2$	$F=360D^2$	XR	10,000
19	F=D	$F=360D^2$	$F=360D^2$	Far X-Ray (FXR)	50,000
20	F=D	$F=360D^2$	$F=360D^2$	Extreme X-Ray (EXR)	100,000
21	F=D	$F=360D^2$	$F=360D^2$	Near Gamma Ray (NGR)	200,000
22	F=D	$F=360D^2$	$F=360D^2$	Gamma Ray (GR)	500,000
23	F=D	$F=360D^2$	$F=360D^2$	Gamma Ray (GR)	1,000,000

Table 123: X-Ray Laser Range and Focal Value

TL	Heavy Focal Modifier	Frequency Band	Range Factor
13	F=160D2	Extreme X-Ray (EXR)	100,000
14	F=250D2	EXR	100,000
15	F=360D2	EXR	100,000
20+	Same as Table 122: Laser Range and Focal Values		

Table 124: Laser Atmospheric Range

Atm Code	Visible and IR	UV and beyond
0 (Vacuum)	1.0	1.0
1 (Trace)	1.0	0.9
2-3 (Very Thin)	0.5	0.1
4-5 (Thin)	0.2	0.02
6-7 (Standard)	0.1	0.01
8-9 (Dense)	0.05	0.005
A+ (Exotic)	0.01	0.001

Table 125: Small Arms Configurations

Configuration	CM
One-Handed	0.4
Two-Handed	1.3
TL7 Optical Sights	1.05
TL8 Optical Sights	1.1
TL9+ Optical Sights	1.15

Table 126: *Traveller* Range Bands

DM	Name	Distance (m)
0	Contact	0 - 3
1	Very Short	4 - 15
2	Short	16 - 45
3	Medium	46 - 150
4	Long	151 - 450
5	Very Long	451 - 1500

DM	Name	Distance (km)
6	Distant	5
7	Very Distant	50
8	Regional	500
9	Continental	5,000
10	Planetary	50,000
11	Far Orbit	500,000

DM	Name	Distance (au)
12	Interplanetary	1
13	Outsystem	10
14	Oort	100

Table 127: Laser ROF Modifier

Rate of Fire (Shots per Minute)	FA Multiplier
3 and below	x1
6	x2
12	x4
24	x8

Table 128: CLC Output

TL	Equivalent Energy (Mj/kg)
11-12	1
13-15	2
16-19	3
20+	4

Table 129: Accelerator Tunnel Characteristics

TL	Length Multiplier LM	Focal Area Multiplier FM C-PAW	N-PAW	Mass Multiplier MM
8	0.12	1	—	1.20
9	0.14	1	1	1.00
10	0.16	2	1	1.00
11	0.20	3	2	0.75
12	0.25	3	3	0.75
13	0.30	4	3	0.75
14	0.5	4	4	0.75
15	1.0	5	4	0.75
16	1.25	5	5	0.60
17	1.3	5	5	0.50
18	1.4	6	5	0.40
19	1.5	6	6	0.40
20	1.6	6	6	0.30
21	1.7	6	6	0.30
22	1.8	7	6	0.20
23	1.9	7	7	0.20
24	2.0	7	7	0.10

Table 130: Atmospheric Range Modifiers

Atmosphere (UWP Code)	N-PAW firing Neutral Beam	C-PAW or N-PAW Charged Beam
Vacuum (0)	1.000	0.001
Trace (1)	1.000	0.005
Very Thin (2,3)	0.100	0.010
Thin (4,5)	0.020	0.050
Standard (6,7)	0.010	0.100
Dense (8,9)	0.005	0.100
Exotic (A+)	0.001	0.050

Table 131: Particle Accelerator ROF Modifiers

ROF (Shots per minute)	FA Multiplier
3 and below	x1
6	x1.3
12	x1.7
24	x2.2

Table 132: Meson Tunnel Multipliers

TL	Length Mult	Vol Mult	Mass Mult
11	0.8	0.020	1.00
12	1.0	0.010	0.75
14	1.2	0.010	0.60
16	1.4	0.005	0.50
18	1.5	0.005	0.40
20	1.6	0.002	0.30
22	1.8	0.002	0.20
24	2.0	0.001	0.10

Table 133: ESA Field Generator

TL	Volume (m^3/Mj)	Mass (t/Mj)	Cost (MCr/Mj)	Armor (AV/Mj)
9	0.4	0.8	1	5.7
10	0.3	0.6	0.8	7.1
11	0.2	0.4	0.6	7.9
12	0.15	0.3	0.5	8.6
14	0.1	0.2	0.4	10
16	0.075	0.15	0.3	11.4
18	0.05	0.1	0.25	12.9
20	0.025	0.05	0.2	14.3

Table 134: ESA Size Multiplier

Protected Volume (m^3)	Displacement (TD)	AV Multiplier
less than 14,000	less than 1,000	x1
14,000-139,999	1,000-9,999	x1/2
140,000-1,399,999	10,000-99,999	x1/4
1,400,000-13,999,999	100,000-999,999	x1/8
14,000,000+	1,000,000 and up	x1/16

Table 135: Predesigned ESA Generators

TL	AV	Vol (m^3)	Mass (t)	Energy (MJ)	Price (MCr)
9	5	0.35	0.70	0.88	0.88
9	10	0.70	1.40	1.75	1.75
9	25	1.75	3.51	4.39	4.39
10	5	0.21	0.42	0.70	0.56
10	10	0.42	0.85	1.41	1.13
10	25	1.06	2.11	3.52	2.82
11	5	0.13	0.25	0.63	0.38
11	10	0.25	0.51	1.27	0.76
11	25	0.63	1.27	3.16	1.90
12	5	0.09	0.17	0.58	0.29
12	10	0.17	0.35	1.16	0.58
12	25	0.44	0.87	2.91	1.45
13	5	0.09	0.17	0.58	0.29
13	10	0.17	0.35	1.16	0.58
13	25	0.44	0.87	2.91	1.45

Table 136: Force Field Generators

TL	Type	Volume (m^3)	Mass (t)	Power (MW)	Price (MCr)	Flicker Rate
15	Black	135	135	15	400	10%
15	Black	200	200	20	600	20%
15	Black	270	270	25	800	30%
15	Black	350	350	30	1,000	40%
16	Black	300	300	35	500	50%
16	Black	400	400	40	700	60%
17	Black	450	450	45	900	70%
18	Black	250	250	45	500	80%
19	Black	250	250	45	500	90%
20	White	300	300	50	900	—
21	White	400	400	50	910	—

Table 137: Force Field Size Multipliers

Protected Volume (m^3)	Displacement (TD)	Power Multiplier
14-1,399	10-99	x1
1,400-13,999	100-999	x2
14,000-139,999	1,000-9,999	x3
140,000-1,399,999	10,000-99,999	x4
1,400,000-13,999,999	100,000-999,999	x5
14,000,000+	1,000,000 and up	x6

Table 138: Minimum Volume

Antenna Diameter	Minimum Volume
10	1.4
20	14
40	140
90	1,400
200	14,000
400	140,000
800	1,400,000
1,200+	14,000,000

Table 139: Accumulators

TL	Capacity (m^3/MJ)
15	0.035
16	0.030
17	0.025
18	0.020
19	0.015
20	0.010
21	0.005

Equation 65: Meson Screen Protection Value

$$PV = \text{TLMod} \leftrightarrow \sqrt{\text{Power}/\text{SizeMod}}$$

Table 140: Meson Screen TL Modifiers

TL	Mod
12	50
13	60
14	70
15	80
16	90
17	100
18	105
19	110
20	115
21	120

Table 141: Meson Screen Size Modifiers

Protected Volume (m^3)	Displacement (TD)	Size Modifier	$\sqrt{\text{Mod}}$
less than 14,000	less than 1,000	x1	1
14,000-139,999	1,000-9,999	x2	1.414
140,000-1,399,999	10,000-99,999	x4	2
1,400,000-13,999,999	100,000-999,999	x8	2.828
14,000,000+	1,000,000 and up	x16	4

Table 142: Predesigned Meson Screens

TL	PV	Vol (m^3)	Mass (t)	Area (m^2)	Power (MW)	Cost (MCr)
12	158	200	150	1.0	10	20
12	250	500	375	0.4	25	50
12	354	1000	750	0.2	50	100
12	433	1500	1125	0.1	75	150
12	500	2000	1500	0.1	100	200
13	190	200	150	1.0	10	20
13	300	500	375	0.4	25	50
13	424	1000	750	0.2	50	100
13	520	1500	1125	0.1	75	150
13	600	2000	1500	0.1	100	200
14	221	200	150	1.0	10	20
14	350	500	375	0.4	25	50
14	495	1000	750	0.2	50	100
14	606	1500	1125	0.1	75	150
14	700	2000	1500	0.1	100	200
15	253	200	150	1.0	10	20
15	400	500	375	0.4	25	50
15	566	1000	750	0.2	50	100
15	693	1500	1125	0.1	75	150
15	800	2000	1500	0.1	100	200
16	285	200	150	1.0	10	20
16	450	500	375	0.4	25	50
16	636	1000	750	0.2	50	100
16	779	1500	1125	0.1	75	150
16	900	2000	1500	0.1	100	200

Table 143: Nuclear Damper Design

TL	Volume (m^3/MW)	Power (MW/km)	Price (MCr/MW)	Min Power (MW)
12	5	0.0005	0.13	1.5
13	8	0.0003	0.3	0.9
14	10	0.0002	0.67	0.6
15	11	0.0001	1.5	0.3
16	13	0.00008	2	0.24
18	18	0.00006	4	0.18
20	18	0.00003	6	0.09

Table 144: Predesigned Nuclear Dampers

TL	Range (km)	Vol (m^3)	Mass (t)	Area (m^2)	Power (MW)	Price (MCr)
12	5,000	12.50	12.50	1.25	2.50	0.33
12	50,000	125.00	125.00	12.50	25.00	3.25
12	5,000	12.50	12.50	1.25	2.50	0.33
12	50,000	125.00	125.00	12.50	25.00	3.25
12	5,000	12.50	12.50	1.25	2.50	0.33
14	50,000	100.00	100.00	10.00	10.00	6.70
15	5,000	5.50	5.50	0.55	0.50	0.75
15	50,000	55.00	55.00	5.50	5.00	7.50

Equation 66: Damper Screen SV

$$SV = TLMod \leftrightarrow \sqrt{Power / SizeMod}$$

Table 145: Damper Screen TL Mod

TL	TLMod
12	50
13	80
14	100
15	110
16	130
18	180
20	180

Table 146: Damper Screen Size Mod

Protected Volume (m^3)	Displacement (TD)	Size Modifier	$\sqrt{\text{Mod}}$
less than 14,000	less than 1,000	x1	1
14,000-139,999	1,000-9,999	x2	1.414
140,000-1,399,999	10,000-99,999	x4	2
1,400,000-13,999,999	100,000-999,999	x8	2.828
14,000,000+	1,000,000 and up	x16	4

Table 147: Explosive Reactive Armor

TL	Description	Det	AV
7	Basic ERA	5	17
8	Improved ERA	4	23
9	Advanced ERA	3	29

Table 148: Sand Armor Values

TL	AV/m^3	Cost (Cr/m^3)
8	50.00	800
9	50.00	800
10	78.57	1,200
11	78.57	1,200
12	78.57	1,200
13	100.00	1,600
14	100.00	1,600
15	157.14	2,000
17	157.14	3,000
19	157.14	3,000
21	235.71	4,000

Table 149: Sand Launcher

TL	Volume (m^3/m^3)	Density (t/m^3)	Cost (MCr/m^3)
8	4.25	1.24	0.018
9	3.67	1.24	0.020
10	3.20	1.25	0.022
11	2.50	1.27	0.025
12	1.80	1.30	0.030
13	1.40	1.33	0.035
14	1.10	1.36	0.041
15	0.68	1.47	0.059
17	0.56	1.53	0.080
19	0.45	1.62	0.108
21	0.35	1.73	0.145

Volume: Launcher volume per m^3 of ready canisters desired.
Density: Mass of launcher per cubic meter of launcher
Cost: Cost the launcher per cubic meter of launcher

Table 150: Standard Sandcaster Turrets

TL	Canisters Carried	AV per Canister	Volume (m^3)	Mass (t)	Price (MCr)	Area (m^2)
8	16	25	42	50	0.6	10
9	18	25	42	50	0.65	10
10	20	39	42	50	0.7	10
11	24	39	42	50	0.75	10
12	30	39	42	50	0.8	10
13	35	50	42	50	0.85	10
14	40	50	42	50	0.9	10
15	50	79	42	50	1	10
17	54	79	42	50	1.2	10
19	58	79	42	50	1.4	10
21	62	118	42	50	1.6	10

Table 151: Tractors and Repulsors

Type	kN per m³, by TL 12	14	16	18	20	Power (MW/kN)	Price (MCr/m³)
Tractor	30	300	3,000	6,000	15,000	0.001	0.1
Repulsor	—	—	200	400	800	0.002	0.2
Manipulator	—	—	200	400	800	0.002	0.3
Range Mod	0.1	0.01	0.001	0.0001	0.00001		

Table 152: Stocks

TL	Type	Length (cm)	Mass (kg)	Price (Cr)
2	Pistol Grip	0	0.4	10
2	Wooden Stock	35	2.5	30
2	Carbine Stock	25	1.5	25
3	Pistol Grip	0	0.3	10
3	Wooden Stock	25	1.5	25
3	Carbine Stock	25	1.0	20
4	Pistol Grip	0	0.2	5
4	Wooden Stock	25	1.0	25
4	Carbine Stock	25	0.7	20
5	Hollow Pistol Grip	0	0.1	25
6	Folding Stock (5cm folded)	25	0.5	50
7	Plastic Stock	25	0.5	30
7	Bullpup Configuration	5	0.1	10

Table 153: Shock Absorbers

TL	Type	Mass (kg)	Price (Cr)	Mod_{recoil}
5	Shock-Absorbing Stock	0.1	50	0.95
7	Shock-Absorbing Stock	0.2	75	0.9
9	Folding Shock-Absorbing Stock	0.2	150	0.9
9	Shock-Absorbing Stock	0.2	75	0.85
10	Gyroscopic Compensator	0.5	300	0.5
14	Inertial Compensator	1.0	1000	0.3

Table 154: Optic Sights

TL	Range	Mass (kg)	Price (Cr)
7	x 1.05	0.1	150
8	x 1.10	0.1	150
9+	x 1.15	0.1	150

Table 155: Laser Sights

TL	Range (m)	Mass (kg)	Price (Cr)
8	40	1.0	400
9	240	1.0	1000
10+	240	0.5	300

Table 156: Advanced Sights

TL	Type	Range (m)	Mass (kg)	Price (Cr)
6	Telescopic	+15	0.1	200
9	Electronic	+20	0.2	2000

Table 157: Aircraft Weapon Mounts

TL	Type	Drag	Mass (t)	Capacity (RE or t)	Cap%	Price (kCr)
4	Fixed Gun Mount	0	0.000	0.20	20.0	0.0
4	Flexible Gun Mount	1	0.005	0.05		0.1
5	Fixed Gun Mount	0	0.000	0.50	50.0	0.0
5	Gun Turret	1	0.400	0.10		5.0
5	Heavy Gun Turret	2	0.500	0.20		50.0
6	Remote Gun Turret	1	0.500	0.30		50.0
6	Heavy Gun Turret	2	0.500	0.50		500.0
4	Fuselage Hardpoint (dry)	(1)	0.020	2.00	10.0	2.0
4	Inboard Wing Hardpoint (dry)	(1)	0.002	1.50	7.5	2.0
4	Outboard Wing Hardpoint (dry)	(1)	0.002	0.50	2.5	2.0
5	Wingtip Launch Rail	(1)	0.010	0.10		0.1
5	Fuselage Hardpoint	(1)	0.030	2.00	10.0	2.5
5	Inboard Wing Hardpoint	(1)	0.030	1.50	7.5	2.5
5	Internal Bomb Bay	0	1.000	1.00		15.0
6	Triple Bomb Rack	(2)	0.050			4.0
6	Multiple Bomb Rack	(4)	0.100			8.0
7	Retractable Missile Bay	0	1.000	1.00		30.0

Table 158: Hull Materials

TL	Description	Toughness	Density (t/m³)	Price (MCr/m³)	Power (kW/m³)
0	Cured Hides*	0.06	1.2	0.0010†	—
0	Bone/light wood*	0.14	0.4	0.0003†	—
1	Wood**	0.29	0.8	0.0004†	—
3	Iron	2.14	8	0.0016	—
4	Soft Steel	2.43	8	0.0016	—
5	Hard Steel	2.86	8	0.002	—
6	Light Alloy	2.43	6	0.004	—
6	Fiberglass	0.36	1	0.001	—
6	Titanium Alloy	4.29	8	0.010	—
7	Light Composite	5.71	7	0.007	—
7	Aluminum	1.43	3.2	0.0024	—
7	Fiberglass	0.36	0.4	0.0024	—
8	Composite Laminate	8.57	8	0.008	—
9	Light Ceramic Composite	7.14	6	0.009	—
10	Crystallron	11.4	10	0.009	—
12	Superdense (SD)	20.0	15	0.014	—
12	Advanced Composites	12.9	11	0.008	—
14	Bonded Superdense	40.0	15	0.028	1
15	Enhanced Bonded SD	47.1	15	0.031	1
16	Collapsed Crystalline	28.6	13	0.022	—
17	Coherent Superdense	57.1	15	0.035	1
18	Enhanced Coherent SD	68.6	15	0.052	1

* Hulls of this material can't retain pressure integrity undersea or in a vacuum

** Hulls of this material can't retain pressure integrity in a vacuum

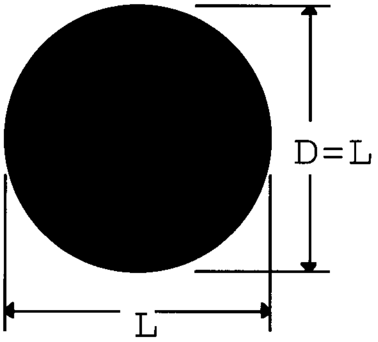
† If purchased commercially; may be obtained free from local resources, but construction time is doubled.

Table 159: Basic Hull Size

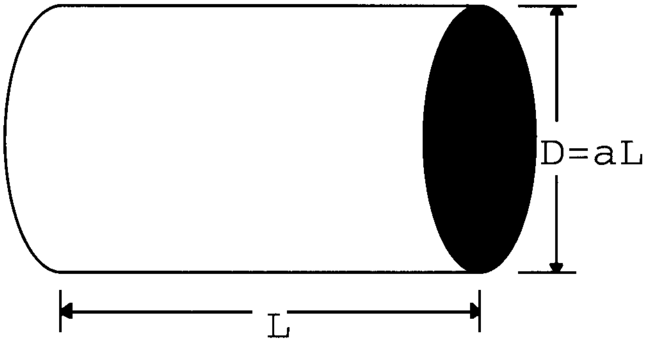
Volume (m^3)	Surface Area (m^2)	Diameter (m)	Displacement (Td)	Structural Factor
1.4	6.05	1.39	0.1	0.001
2.8	9.61	1.75	0.2	0.001
4.2	12.6	2.00	0.3	0.001
5.6	15.3	2.20	0.4	0.001
7.0	17.7	2.37	0.5	0.001
8.4	20.0	2.52	0.6	0.001
9.8	22.1	2.66	0.7	0.001
11.2	24.2	2.78	0.8	0.001
12.6	26.2	2.89	0.9	0.001
14	28.1	2.99	1	0.001
28	44.6	3.77	2	0.001
42	58.4	4.31	3	0.001
56	70.8	4.75	4	0.002
70	82.1	5.11	5	0.003
84	92.8	5.43	6	0.003
98	103	5.72	7	0.004
112	112	5.98	8	0.005
126	122	6.22	9	0.006
140	130	6.44	10	0.007
210	171	7.37	15	0.014
280	207	8.12	20	0.021
350	240	8.74	25	0.029
420	271	9.29	30	0.038
490	301	9.78	35	0.048
560	329	10.2	40	0.059
630	355	10.6	45	0.070
700	381	11.0	50	0.082
770	406	11.4	55	0.095
840	431	11.7	60	0.108
910	454	12.0	65	0.122
980	477	12.3	70	0.136
1,050	500	12.6	75	0.151
1,120	522	12.9	80	0.167
1,190	543	13.1	85	0.182
1,260	564	13.4	90	0.199
1,330	585	13.6	95	0.216
1,400	605	13.9	100	0.233
1,680	683	14.7	120	0.306
2,100	793	15.9	150	0.428
2,800	961	17.5	200	0.658
3,500	1,115	18.8	250	0.920
4,200	1,259	20.0	300	1.21
5,600	1,525	22.0	400	1.86
7,000	1,770	23.7	500	2.60
8,400	1,998	25.2	600	3.42
9,800	2,215	26.6	700	4.31
10,500	2,319	27.2	750	4.75
11,200	2,421	27.8	800	5.27
12,600	2,619	28.9	900	6.29
14,000	2,809	29.9	1,000	7.36
15,400	2,993	30.9	1,100	8.49
16,800	3,172	31.8	1,200	9.68
17,500	3,260	32.2	1,250	10.3
18,200	3,346	32.6	1,300	10.9
19,600	3,516	33.5	1,400	12.2
21,000	3,681	34.2	1,500	13.5
22,400	3,843	35.0	1,600	14.9
23,800	4,001	35.7	1,700	16.3
24,500	4,079	36.0	1,750	17.0
25,200	4,157	36.4	1,800	17.8
26,600	4,309	37.0	1,900	19.3
28,000	4,459	37.7	2,000	20.8
42,000	5,843	43.1	3,000	38.3
56,000	7,079	47.5	4,000	58.9
70,000	8,214	51.1	5,000	82.3
84,000	9,275	54.3	6,000	108
98,000	10,279	57.2	7,000	136
112,000	11,236	59.8	8,000	167
126,000	12,154	62.2	9,000	199
140,000	13,039	64.4	10,000	233
154,000	13,894	66.5	11,000	269
168,000	14,724	68.5	12,000	306
182,000	15,531	70.3	13,000	345
196,000	16,318	72.1	14,000	386
210,000	17,086	73.7	15,000	428
224,000	17,837	75.3	16,000	471
238,000	18,572	76.9	17,000	516
252,000	19,294	78.4	18,000	562
266,000	20,002	79.8	19,000	610
280,000	20,698	81.2	20,000	658
350,000	24,018	87.4	25,000	920
420,000	27,122	92.9	30,000	1,210
560,000	32,856	102	40,000	1,860
700,000	38,126	110	50,000	2,600
840,000	43,053	117	60,000	3,420
980,000	47,713	123	70,000	4,310
1,050,000	49,959	126	75,000	4,780
1,120,000	52,155	129	80,000	5,270
1,260,000	56,415	134	90,000	6,290
1,400,000	60,521	139	100,000	7,360
2,800,000	96,070	175	200,000	20,800
3,500,000	111,480	188	250,000	29,100
4,200,000	125,888	200	300,000	38,300
5,600,000	152,502	220	400,000	58,900
7,000,000	176,963	237	500,000	82,300
8,400,000	199,834	252	600,000	108,000
9,800,000	221,463	266	700,000	136,000
10,500,000	231,887	272	750,000	151,000
11,200,000	242,082	278	800,000	167,000
12,600,000	261,857	289	900,000	199,000
14,000,000	280,911	299	1,000,000	233,000

Figure 1: Hull Configurations

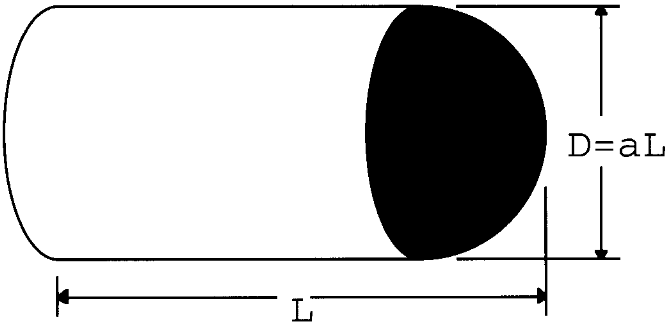
Sphere



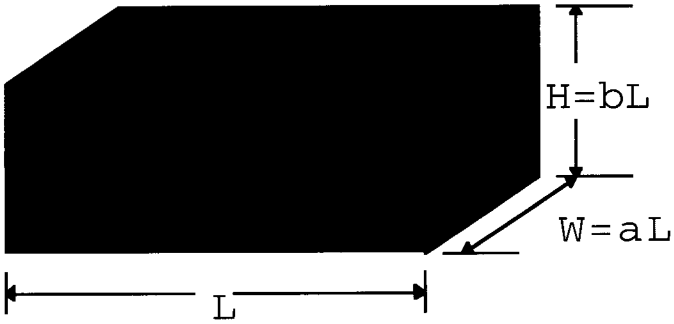
Cylinder



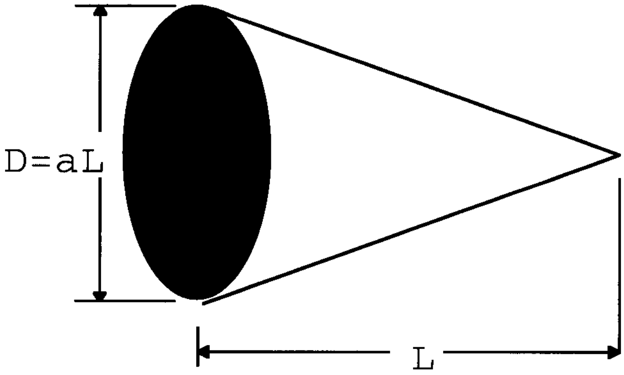
Rounded Cylinder



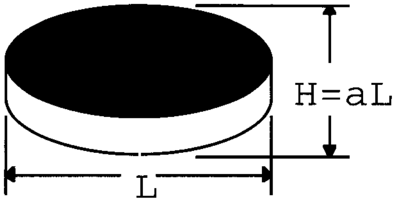
Box



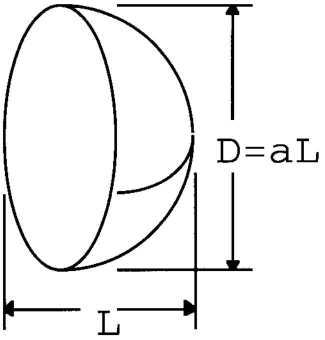
Cone



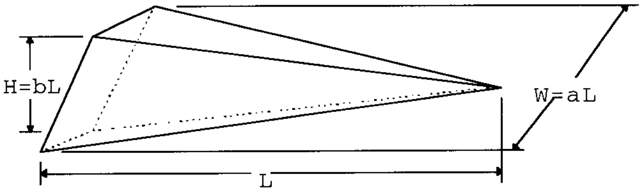
Disk



Dome



Wedge



Equation 67: Basic Hull Factors

(a) Diameter $= \sqrt[3]{\frac{6 \leftrightarrow \text{Volume}}{\pi}}$

(b) Area $= \pi \leftrightarrow \text{Diameter}^2$

(c) $\text{SF} = \frac{\sqrt{\text{Vol}^3}}{225{,}000}$

Table 160: Hull Shape Modifiers

Configuration	Surface Modifier	Streamlining Cost Modifiers			Dimension Modifiers		
		USL	SL	AF	Length	Width	Height
Cylinder							
Short (1:1)	1.15	0.6	0.8	N/A	0.87	0.87	0.87
Medium (2:1)	1.20	0.6	0.8	N/A	1.39	0.69	0.69
Long (3.5:1)	1.32	0.6	0.8	N/A	2.00	0.57	0.57
Rounded Cylinder							
Short (2:1)	1.15	0.7	0.8	1.2	1.43	0.71	0.71
Medium (3.5:1)	1.28	0.7	0.8	1.2	2.05	0.59	0.59
Long (5:1)	1.40	0.7	0.8	1.2	2.58	0.52	0.52
Box							
Cube (1:1:1)	1.24	0.4	0.6	N/A	0.81	0.81	0.81
Medium (2:1:1)	1.3	0.4	0.6	N/A	1.28	0.64	0.64
Long (4:2:1)	1.45	0.4	0.6	N/A	1.61	0.81	0.40
Slab (20:5:2)	1.81	0.4	0.6	N/A	2.76	0.69	0.28
Monolith (9:4:1)	1.86	0.4	0.6	N/A	2.20	0.98	0.24
Cone							
Short (1:1)	1.28	0.8	0.9	1.1	1.26	1.26	1.26
Medium (2:1)	1.28	0.8	0.9	1.1	2.00	1.00	1.00
Long (4:1)	1.43	0.8	0.9	1.1	3.18	0.79	0.79
Needle (10:1)	1.80	0.8	0.9	1.1	5.85	0.59	0.59
Disc							
Thin (10:1)	2.13	1.4	1.6	1.2	1.88	1.88	0.19
Medium (5:1)	1.56	1.4	1.6	1.2	1.49	1.49	0.30
Thick (2:1)	1.21	1.4	1.6	1.2	1.10	1.10	0.55
Dome							
	1.1	1.4	1.6	1.2	0.61	1.21	1.21
Wedge							
	0.5	0.7	1.5				
Open Frame							
	2	0.3	N/A	N/A	4.00	0.50	0.50
Close Structure							
	1.4	0.3	N/A	N/A	1.75	1.30	0.30

Table 161: Streamlined Hull Speed Regime

TL	Type	Waste Volume	Waste Area	Price Mult	Max Spd (km/hr)	Thrust Efficiency
4	Simple	0.01	0.2	0.7	320	1.2
5	Fast Subsonic	0.02	0.2	0.75	800	1.3
6	Transonic	0.05	0.25	0.9	1100	1.4
6	Supersonic	0.01	0.3	1.0	2800	1.5
7	Hypersonic	0.15	0.35	1.2	5000	4.1
8	Hypersonic	0.15	0.35	1.2	unlimited	4.5

Table 162: Airframe Hull Speed Regime

TL	Type	Waste Volume	Waste Area	Price Mult	Min Spd (km/hr)	Max Spd (km/hr)	Thrust Efficiency
4	Simple	0.01	0.3	0.7	150	320	0.85
5	Fast Subsonic	0.05	0.3	0.75	160	800	0.90
6	Transonic	0.1	0.35	0.9	180	1100	0.95
6	Supersonic	0.2	0.4	1.0	280	2800	1.00
7	Hypersonic	0.3	0.45	1.2	350	5000	2.75
8	Hypersonic	0.3	0.45	1.2	325	unlimited	3.00

Table 163: Advanced Thrusters

TL	Type	Thrust (kN/m^3)	Mass (t/m^3)	Price (MCr/m^3)	Min Thrust (kN)	Fuel Rate (m^3/hr/kN)	Fuel Type	PowerIn (MW/kN)
10	HEPlaR	2000	1	0.01	200	0.00125	LHyd	0.0050
11	Thruster Plates	400	2	0.25	4000	—	—	0.0025

HEPlaR requires 0.0005m^2 of surface area per kN of thrust. Thruster plates require 0.0001m^2/kN.

Table 164: Contragravity Drives

TL	Type	Vol (m^3/kN)	Mass (t/kN)	Power (MW/kN)	Price (MCr/kN)	Area (m^2/kN)	Thrust Factor
9	Standard AG	0.003	0.0038	0.0018	0.000012	0.0018	0.08
10	Improved AG	0.002	0.0020	0.0014	0.000016	0.002	0.12
12	High Efficiency AG	0.002	0.0013	0.0007	0.000020	0.002	0.16

Table 168: Exotic Drives

TL	Type	Thrust (kN/m^3)	Mass (t/m^3)	Price (MCr/m^3)	Fuel Rate (m^3/hr/kN)	Fuel Type	PowerIn (MW/kN)
7	Ion Drive	0.033	1.0	0.04	0.00020	Ion	1.0
9	Daedalus	15	1.0	0.50	0.00005	TNP	
9	Bussard Ram	45	1.0	0.85	0.00035*	LH*	

*When operating as a fusion rocket

Ion drives require 0.0005m2 per kN of thrust

Bussard Ram requires 0.0005 m2/kN for the exhaust; the scoop requires 25% of the total surface area (front quarter of ship)

Table 165: Solid Rockets

TL	Type	Impulse (kN·s/m^3)	Price (MCr/m^3)
2	Solid	900	0.25
3	Solid	1,020	0.25
4	Solid	1,320	0.15
5	Solid	1,920	0.13
6	Hybrid	2,880	0.10
6	Solid	2,820	0.10
7	Hybrid	3,000	0.05
7	Solid	2,880	0.05
8	Hybrid	3,240	0.05
8	Solid	2,940	0.04

Mass: All solid propellants mass 1t/m^3

Area: All solid rockets require 0.0005m^2/kN

Table 166: Liquid Rockets

TL	Type	Thrust (kN/m^3)	Price (MCr/m^3)	Fuel Rate (m^3/hr/kN)	Fuel Type
5	Liquid	300	2.00	1.28	LRF
6	High Density	650	1.50	0.62	Perox
6	Hypergolic	850	1.83	1.22	Hyp
6	Liquid	500	1.50	1.16	LRF
7	High Density	1,080	0.53	0.61	Perox
7	Hypergolic	930	1.20	1.22	Hyp
7	LH Liquid	650	2.00	7.69	HRF
7	Liquid	850	0.67	1.19	LRF
8	High Density	1,250	1.00	0.57	Perox
8	Hypergolic	1,320	1.00	1.14	Hyp
8	LH Liquid	730	2.67	7.26	HRF
8	Liquid	770	0.83	1.06	LRF

Mass: All liquid rocket engines mass 1t/m^3

Area: All liquid rockets require 0.0005m^2 of surface area per kN of thrust

Table 167: Nuclear Rockets

TL	Type	Thrust (kN/m^3)	Price (MCr/m^3)	Min Thrust (kN)	Rate Fuel (m^3/hr/kN)	Fuel Type
7	NTR	80	8.00	—	84.82	LHyd
8	NTR	100	10.00	—	84.29	LHyd
8	Advanced NTR	120	12.00	—	59.52	LHyd
9	GCNTR	50	16.67	—	1.43	LHyd
9	Exp Fusion	30	3.5	15,000	0.0072	LHyd
10	Fusion	90	0.35	1,000	0.00035	LHyd

Mass: All nuclear rockets mass 1t/m^3

Area: All nuclear rockets require 0.0005m^2/kN

Table 169: Solar Sails

TL	Density (t/km^2)	Price (MCr/km^2)
8	0.5	0.001
9	0.4	0.0005
10	0.3	0.0004
12	0.2	0.0003
14	0.1	0.0002
16	0.05	0.0001

Table 171: Thrust Options

TL	Type	Volume	Mass	Cost	Thrust	Fuel	Notes
6	Afterburner	x1.1	x1.1	x1.1	x1.5	x2	Any turbojet or turbofan
8	AZH (Turbojet mode)	x1	x1	x1	x1	x1	
8	AZH (Ramjet mode)	x1	x1	x1	x1.66	x4	
8	AZH (Rocket mode)	x1	x1	x1	x2.5	x9	Special fuel (see text)

Table 173: Fuels

Type	Density (t/m³)	Cost (Cr/m³)	Comments
Hyp (Hypergolic Liquid)	1	400	Hydrazine & Nitrogen Tetroxide
LRF (Liquid Rocket Fuel)	1	167	Kerosene & Liquid Oxygen
HCD (Hydrocarbon Distillates)	0.9	250	Aviation Gasoline or Jet fuel
HRF (Hydrogen Rocket Fuel)	0.3	267	Liquid Hydrogen & LOX
Perox	1.4	800	Hydrogen Peroxide/Kerosene
TNP (Thermonuclear Pulse Pellets)	0.1	3,500	Frozen deuterium/helium-3
Ion (Ionizates)	1.5	100	Liquid Xenon, etc.
LHyd (Liquid Hydrogen)	0.07	300	Price depends on local refueling rates

Table 170: Aircraft Thrust Agencies

TL	Type	MinVol (m³)	Thrust (kN/m³)	Price (MCr/m³)	Fuel (m³/kN/hr)	Airframe
4	Propeller	0.025	2.5	0.012	0.060	Simple
5	Propeller	0.005	4.2	0.032	0.036	Fast Subsonic
5	Propeller	0.005	5.6	0.032	0.036	Fast Subsonic
5	Turbojet	0.167	30.0	0.150	0.050	Supersonic
5	Ramjet	0.042	60.0	0.250	0.250	Hypersonic
6	Propeller	0.005	6.4	0.040	0.031	Fast Subsonic
6	Turbojet	0.069	36.0	0.150	0.025	Supersonic
6	Ramjet	0.013	75.0	0.300	0.200	Hypersonic
7	Propeller	0.005	7.2	0.040	0.028	Fast Subsonic
7	Turboprop	0.250	9.0	0.100	0.033	Fast Subsonic
7	Turbofan	0.103	39.0	0.175	0.012	Supersonic
7	SCRAMjet	0.013	80.0	0.400	0.200	Hypersonic
8	Propeller	0.005	8.0	0.040	0.025	Fast Subsonic
8	Turboprop	0.250	12.0	0.100	0.030	Fast Subsonic
8	MHD Turboprop	0.500	16.0	0.200	0.020	Fast Subsonic
8	High-Bypass Turbofan	0.133	30.0	0.063	0.010	Supersonic
8	AZH (Turbojet mode)	0.278	36.0	0.500	0.050	Hypersonic

Table 172: Rotor Assemblies

TL	Type	Mass (kg/kN)	Cost (Cr/kN)	Power (kW/kN)	MaxL (kN)
5	Light Main+Tail Rotor	2.0	40	25	20
5	Light Tandem Rotors	2.4	72	20	50
5	Light Coaxial Rotors	1.6	64	20	30
6	Main+Tail Rotor	3.1	31	25	600
6	Tandem Rotors	3.5	53	20	none
6	Coaxial Rotors	2.5	50	20	600
9	Lift Activator Disk	13.3	133	11	none
9	X-Wing	3.0	150	20	400
9	Ornithopter	3.6	180	40	10
12	Ornithopter	2.0	60	33	20

Table 174: Maximum Speed in Atmosphere

Acceleration	Speed (km/hr)
Acceleration x 0.5	Speed = Acceleration x 700
0.5 < Acceleration x 10	Speed = 350 + (Acceleration - 0.5) x 350
10 < Acceleration (20	Speed = 3,485 + (Acceleration - 10) x 120
20 < Acceleration	Speed = 4,685 + (Acceleration - 20) x 60

Table 175: Maneuver Points

Vehicle Max Speed		Streamlined Hull Mmvr Pts	Airframe Hull Mnvr Pts
At least	but Less Than		
0	43	0	0
43	86	0	1
86	172	1	2
172	344	2	3
344	688	3	4
688	1376	4	5
1376	2752	5	6
2752	5504	6	7
5504	11008	7	8
11008	22016	8	9
22016		9	9

Equation 68: Take-off Roll

$$R_{to} = 0.19 \leftrightarrow S_{\min} \leftrightarrow \sqrt{W_{to}}$$

Equation 69: Landing Roll

$$R_{la} = 0.19 \leftrightarrow S_{\min} \leftrightarrow \sqrt{W_{la}}$$

Table 176: Sights and Rangefinders

TL	Type	Range (m)	Mass (kg)	Cost (kCr)
4	Iron Sight	200	5	0.25
5	Telescopic Sight	400	10	0.50
6	Optic Rangefinder	600	20	1.00
7	Laser Rangefinder	800	40	5.00
8	Imaging Radar	1600	60	10.00
10+	Advanced Rangefinder	3000	80	20.00

Table 177: Ballistic Computers

TL	Mass (kg)	Price (kCr)	Modifier
6	10	2	1
8	20	5	2
10	40	20	3
12	40	100	4
14	30	500	5
16	20	1000	6
18	20	2000	7

Mass is in kg; cost is in thousands of credits. Modifier is the number of difficulty level increases (due to range, target motion, and so on) that may be negated by the ballistic computer.

Table 178: Indirect Fire Sights

TL	Mass (kg)	Price (kCr)
4	50	4
5	50	6
6	75	8
7	100	10
8	200	20
9	200	100
10	200	150
11-13	200	200
14-15	100	250
16-17	100	300
18-20	50	350
21+	50	400

Mass is in kg; price in kCr.

Fire direction centers may be added; the fire direction center must not be from a TL greater than the weapon's indirect fire sights.

Table 179: Fire Direction Centers

TL	Delay (s)	Range (km)	Price (MCr)
4	50	10	0.10
5	30	20	0.20
6	25	25	0.30
7	20	30	0.40
8	15	35	0.50
9	10	40	0.75
10	5	50	1.00
11-13	0	60	1.50
14-15	0	80	3.00
16-17	0	100	5.00
18-20	0	150	8.00
21+	0	300	10.00

Delay is correction delay, in seconds; range is in kilometers; price is in millions of credits (MCr).

Table 180: Weapon Stabilization

TL	Mass (kg)	Price (MCr)	Fire if move:
6	50	20	1 x Safe Speed
7	75	40	2 x Safe Speed
8+	100	50	Any Speed

Mass is in kg; price is in kCr.

Table 181: Beam Pointers

	Volume by TL (m^3)							
(km)	8	9	10	12	14	15	17	19
0.5	0.193	0.096	0.077	0.058	0.039	0.019	0.010	0.006
5	0.385	0.193	0.145	0.116	0.077	0.039	0.019	0.010
50	0.770	0.385	0.289	0.231	0.145	0.077	0.039	0.019
500	1.448	0.770	0.393	0.296	0.233	0.145	0.077	0.039
5,000	2.889	1.448	1.141	0.948	0.573	0.289	0.145	0.077
50,000	4.0	2.0	1.60	1.333	0.800	0.400	0.200	0.103
500,000	50	25.	17.67	16.67	10.0	5.0	2.833	1.417

Mass: all beam pointers mass 1t/m^3

Price: all beam pointers cost MCr0.1/m^3

Table 182: Master Fire Directors

	Volume by TL (m^3)							
(km)	8	9	10	12	14	15	17	19
0.5	0.385	0.193	0.154	0.143	0.077	0.039	0.019	0.010
5	0.770	0.385	0.290	0.233	0.154	0.077	0.039	0.019
50	1.541	0.770	0.578	0.462	0.290	0.154	0.077	0.039
500	2.896	1.541	1.156	0.961	0.578	0.290	0.145	0.072
5,000	5.778	2.896	2.311	1.926	1.156	0.578	0.289	0.144
50,000	8.000	4.000	3.200	2.667	1.600	0.800	0.400	0.200
500,000	100.0	50.0	35.33	33.33	20.0	10.00	5.0	2.833

Mass: all MFDs mass 1t/m^3

Price: all MFDs cost MCr0.1/m^3

Power: all MFDs require 0.01MW/m^3

Table 183: Computers

CM	CP	Computer Volume (m³) by TL 5	6	7	8	9	10	11	12	13	14	15
1.00	1.00	50.000	1.973	0.374	0.122	0.032	0.018	0.009	0.005	0.005	0.005	0.005
0.80	1.25	—	10.000	1.893	0.617	0.164	0.091	0.045	0.020	0.007	0.005	0.005
0.70	1.43	—	—	5.000	1.630	0.433	0.241	0.120	0.052	0.019	0.005	0.005
0.60	1.67	—	—	—	5.000	1.328	0.741	0.367	0.159	0.058	0.014	0.005
0.50	2.00	—	—	—	—	5.000	2.789	1.381	0.598	0.219	0.052	0.009
0.45	2.22	—	—	—	—	—	6.000	2.972	1.286	0.472	0.111	0.019
0.40	2.50	—	—	—	—	—	—	7.000	3.029	1.111	0.262	0.045
0.35	2.86	—	—	—	—	—	—	—	8.000	2.933	0.692	0.120
0.30	3.33	—	—	—	—	—	—	—	—	9.000	2.124	0.367
0.25	4.00	—	—	—	—	—	—	—	—	—	8.000	1.381
0.20	5.00	—	—	—	—	—	—	—	—	—	—	7.000

Mass: all computers mass 0.2t/m³

Power, price: Computer price and power both depend on TL. Multiply the volume given here by the appropriate entry in the next table

Table 184: Computer Power and Price

TL	Power (MW/m³)	Price (MCr/m³)	TL	Power (MW/m³)	Price (MCr/m³)
5	0.03	0.01	14	0.63	0.06
6	0.10	0.01	15	0.86	0.08
7	0.10	0.03	16	1.67	0.10
8	0.08	0.04	17	2.20	0.12
9	0.12	0.05	18	3.00	0.15
10	0.17	0.05	19	4.33	0.18
11	0.29	0.29	20	7.00	0.25
12	0.38	0.05	21	15.00	0.45
13	0.44	0.05			

Table 186: Crewstations and Workstations

TL	Type	Mass (t)	Price (MCr)
4	Primitive Mechanical Crewstation	0.1	0.00010
5	Basic Mechanical Crewstation	0.1	0.00020
6	Enhanced Mechanical Crewstation	0.2	0.00030
7	Electronic Workstation or Crewstation	0.2	0.00050
8	Enhanced Electronics W/S or C/S	0.2	0.00075
9	Computer Linked W/S or C/S	0.2	0.00100
10	Dynamic Linked W/S or C/S	0.2	0.00150
13	Holographic Linked W/S or C/S	0.2	0.00200
17	Synaptic Linked W/S or C/S	0.2	0.00250
21	Synaptic Fluidic W/S or C/S	0.2	0.00300

Table 187: Navigation Aids

TL	Volume (m³)	Mass (t)	Power (MW)	Price (MCr)	Description
2	0.0001	0.0001	—	0.001	Magnetic Compass
5	0.0001	0.0001	—	0.001	Gyrocompass
6	0.0001	0.0001	0.0002	0.001	Transponder
7	0.0010	0.0010	0.0005	0.005	Inertial positioning
8	0.0010	0.0010	0.0005	0.005	Satellite positioning
10	0.0010	0.0010	0.0005	0.005	Integrated IGS positioning

Each level includes all the functions of the previous level.

Table 188: Flight Avionics

TL	Volume (m³)	Mass (t)	Power (MW)	Price (MCr)	Description
5	0.0001	0.0001	—	0.001	Gyrocompass, barometric altimeter
6	0.0001	0.0001	0.0005	0.005	Radar altimeter, transponder
7	0.001	0.001	0.001	0.01	Weather radar, FLIR, inertial positioning
8	0.001	0.001	0.001	0.02	Imaging radar
10	0.001	0.001	0.001	0.025	Imaging EMS, inertial/gravitational positioning

Each level includes all the functions of the previous level

Table 189: Terrain-Following Avionics

TL	Volume (m³)	Mass (t)	Power (MW)	Price (MCr)	Area (m²)	TF (km/hr)	NOE (km/hr)
any vehicles without NOE avoionics use this row						120	40
8	0.2	0.05	0.005	0.010	0.5	360	120
9	0.02	0.04	0.004	0.011	0.4	390	130
10	0.15	0.04	0.004	0.012	0.4	420	140
11	0.15	0.03	0.003	0.013	0.3	450	150
12	0.1	0.03	0.003	0.014	0.3	480	160
13	0.1	0.02	0.002	0.015	0.2	510	170
14	0.05	0.02	0.002	0.016	0.2	540	180
15	0.05	0.02	0.002	0.017	0.2	570	190
16	0.03	0.03	0.003	0.018	0.3	600	200
17	0.03	0.03	0.003	0.019	0.3	750	250
18	0.02	0.04	0.004	0.02	0.4	900	300
19	0.02	0.04	0.004	0.022	0.4	1050	350
20	0.01	0.05	0.005	0.024	0.5	1200	400
21	0.01	0.05	0.005	0.028	0.5	1350	450

Table 190: Radio Communicators

Rating	Volume by TL (m^3)									Power (kW)	Price (kCr)
	5	6	7	8	10	12	15	18	20		
5	0.096	0.047	0.009	0.001	0.000	0.000	0.000	0.000	0.000	0.009	0.237
50	0.146	0.096	0.047	0.009	0.001	0.000	0.000	0.000	0.000	0.093	0.481
500	0.289	0.146	0.096	0.047	0.009	0.001	0.000	0.000	0.000	0.933	4.667
5,000	0.670	0.289	0.146	0.096	0.047	0.009	0.001	0.000	0.000	9.333	28.148
50,000	—	0.670	0.289	0.146	0.096	0.047	0.009	0.001	0.000	93.333	85.556
500,000	—	—	0.309	0.153	0.103	0.052	0.011	0.001	0.000	105.333	93.556
1,000AU	—	—	0.7	0.3	0.15	0.1	0.05	0.01	0.001	200	0.15

Mass: 2 t/m^3

Antenna Area: 1 m^2/kW

Price: x3 if TL5. x2 if TL6.

Table 192: Laser Communicators

Rating	Volume by TL (m^3)							Power (kW)	Price (MCr)
	8	9	10	12	15	18	20		
5	0.004	0.002	0.001	0.001	—	—	—	0.05	0.0012
50	0.016	0.008	0.006	0.004	0.001	—	—	0.1	0.005
500	0.02	0.01	0.008	0.005	0.002	—	—	0.2	0.011
5,000	0.04	0.02	0.015	0.01	0.003	0.001	—	0.4	0.021
50,000	0.07	0.035	0.025	0.018	0.005	0.002	0.001	0.8	0.036
500,000	0.11	0.055	0.04	0.028	0.007	0.003	0.002	1.5	0.056
1,000AU	—	0.120	0.07	0.05	0.015	0.007	0.005	3	0.18

Mass: 2 t/m^3

Antenna Area: 1m^2 for all versions

Table 191: Radio Communicator Options

TL	Option	Price	Range	Power
6+	Directional	x1.5	x10	x1
7+	Tight beam	x3	x100	x1
5+	Receive only	x1/3	—	x0.1

Table 193: Meson Communicators

Rating	Volume by TL (m^3)				Power (MW)	Price (MCr)
	15	16	18	20		
500	0.5	0.3	0.01	—	0.05	0.25
5,000	2	1.5	0.5	0.1	0.2	1
50,000	30	16	5	0.2	1	2.5
500,000	150	80	25	15	3	5
1,000AU	500	220	85	50	5	20

Mass: 2 t/m^3

Antenna Area: 10 m^2/MW, minimum 1m^2

Table 194: Range Factors

Range (km)	Range Factor	Name
5,000	9	Continental
50,000	10	Planetary
500,000	11	Far Orbit
5,000,000	12	
50,000,000	13	
500,000,000	14	
5,000,000,000	15	Solar
50,000,000,000	16	Kuiper Belt
500,000,000,000	17	Oort Cloud

Table 195: Detection Probability

Signal	Chance of Detection
<0	undetectable
0.0	small (5%) chance for skilled operator
0.5	medium chance
1.0	high chance for skilled operator
2.0	guaranteed for any operator

Table 196: TL8-9 Scanners

Sensitivity	Area by TL (m^2)		Typical Range (km)	Resolution at 50,000km
	8	9		
12.5	1	0.5	1,600,000	100m
13	4	2	5,000,000	50m
13.5	40	20	16,000,000	13m
14	400	200	50,000,000	5m
14.5	—	2,000	160,000,000	0.2m

Volume: 4m^3 per m^2 of area.

Mass: 1 ton/m^3.

Power: 0.01 MW/m^2.

Price: MCr4/m^2.

Table 197: TL8-9 Trackers

Sensitivity	Max Range	Diameter	Area by TL (m^2)		Resolution at 50,000km
			8	9	
13	50,000	1.5	2.0	1.0	20m
13.5	150,000	5.0	22.0	10.0	5m
14	500,000	—	15.0	100.0	1.5m
14.5	1,500,000	—	50.0	2000.0	0.5m

Volume: 4m^3 per m^2 of area.

Mass: 1 ton/m^3.

Power: 0.01 MW/m^2.

Price: MCr5/m^2.

Table 198: PEMS Arrays

Sensitivity	Diameter (m)	Area by TL (m^2) 10-11	12-13	14-15	Detection Range (km)	Firing Range (km)	Resolution at 50,000km
12.5	1.0	0.2	0.1	0.1	1,600,000	60,000	20
13.0	3.0	2	1.0	0.5	5,000,000	200,000	7
13.5	10.0	20	10	5	16,000,000	600,000	2
14.0	30.0	200	100	50	50,000,000	2,000,000	0.7
14.5	100.0	2,000	1,000	500	160,000,000	6,000,000	0.2
15.0	300.0	20,000	10,000	5,000	500,000,000	20,000,000	0.07
15.5	300.0	200,000	100,000	50,000	1.6 billion	20,000,000*	0.07*
16.0	300.0	—	1,000,000	500,000	5 billion	20,000,000*	0.07*

Volume: PEMS volume depends on TL, according to **Table 199 PEMS Voume**; Mass: 1 ton/m^3; **Power:** 0.001 kW/m^2; **Price:** MCr5/m^2

Table 199: PEMS Volume

TL	Volume (m^3/m^2)
10-11	2
12-13	1
14-15	1

Table 200: Passive Tracker Targets

TL	# of targets
8	1
9	3
10-11	10
12-13	20
14-15	30

Table 201: Active Sensors

Sensitivity	Area by TL (m^2) 8	9	10-11	12-13	14-15	Typical Range (km)
11.0	5	1	0.5	0.25	0.1	160,000
11.5	50	10	5.0	2.5	1	500,000
12.0	500	100	50	25	10	1,600,000
12.5	5,000	1,000	500	250	100	5,000,000
13.0	50,000	10,000	5,000	2,500	1,000	16,000,000
13.5	—	100,000	50,000	25,000	10,000	50,000,000
14.0	—	1,000,000	500,000	250,000	100,000	160,000,000
14.5	—	—	—	2,500,000	1,000,000	500,000,000

Volume: Sensor volume is $5m^3$ per m^2 of area at all TL;
Mass: 2t/m^3; **Power:** 0.5MW/m^2 at TL8, 1MW/m^2 at TL9+; **Price:** MCr2/m^2

Table 202: Active Tracker Targets

TL	Targets
8-9	10
10-11	20
12-13	40
14-15	60

Table 204: LIDAR Volume

TL	Vol (m^3/m^2)
8	10
9	5
10-11	4
12-13	3
14-15	2

Table 203: LIDAR

Sensitivity	Maximum Firing Range (km)	Area by TL (m^2) 8	9	10-11	12-13	14-15
13.5	50,000	0.5	0.2	0.1	0.1	0.05
14.0	200,000	1.6	0.6	0.3	0.2	0.1
14.5	500,000	5.0	2.0	1.0	0.6	0.5
15.0	2,000,000	—	6.6	3.3	2.0	2.5
15.5	5,000,000	—	20.0	10.0	6.0	12.5

Volume: depends on TL; see **Table 204: LIDAR Volume**;
Mass: 2t/m^3; **Power:** 1 MW/m^2; **Price:** MCr 5 per m^2.

Table 204: LIDAR Volume

FF&S Range Hexes	km	Sensitivity
0.01	300	5.0
1-7	30,000-210,000	5.5
8-16	240,000-480,000	6.0

Table 205: Vehicle Passive Sensors

Range	Volume by TL (m^3) 8	9	10-11	12-13	14-15	Space Sensitivity	Resolution at 5km (m)
5km	0.01	0.005	0.002	0.002	0.002	10	0.3
50km	0.04	0.02	0.01	0.005	0.005	11	0.1
500km	0.50	0.20	0.10	0.05	0.02	11.5	0.03

TL	Description	Range (km)	Vol (m^3)	Mass (t)	Power (MW)	Price (kCr)
4	Headlight	0.03	0.002	0.001	0.0001	0.05
4	Searchlight	0.25	0.01	0.01	0.001	0.1
5	Active IR Searchlight	0.12	0.01	0.01	0.001	2.0
6	Active IR Scope	0.06	0.001	0.001	0.0001	1.0
6	Passive IR Viewer	0.03	0.001	0.001	0.0001	1.0
7	Active IR Goggles	0.06	neg	0.0001	0.0001	0.3
7	Light Amplification Scope	0.06	0.001	0.005	0.0001	5
8	Passive IR Goggles	0.06	neg	0.0001	0.0001	0.5
8	Light Amplification Scope	0.12	0.001	0.001	0.0005	1
8	Image Enhancement Viewer	0.25	0.001	0.005	0.001	3
9	Image Enhancement Scope	0.25	0.001	0.001	0.0005	1
9	Imaging Radar	0.3	0.01	0.02	0.003	20
10	Wide Spectrum Visual Viewer	0.5	0.01	0.02	0.003	20
11	Wide Spectrum Visual Scope	0.5	0.001	0.005	0.001	10
12	Wide Spectrum Visual Goggles	0.3	neg	0.0001	0.0001	5

Mass: 1t/m^3; **Area:** 0.1m^2 for all; **Power:** 0.001MW/m^3;
Price: MCr2/m^3.

Table 206: Maneuvering Crew

CM x Size	C_{Mn}
1,400	3
2,055	4
4,427	5
9,538	6
20,549	7
44,272	8
95,381	9
205,492	10
442,719	11
953,809	12
2,054,919	13
4,427,189	14
9,538,089	15

Table 207: Accommodations

TL	Description	Volume (m^3)	Mass (t)	Power (MW)	Price (MCr)
—	Seat, Restricted	1.5	0.02	—	0.0001
—	Seat, Cramped	2.5	0.02	—	0.0001
—	Seat, Adequate	3.5	0.02	—	0.0001
—	Seat, Roomy	7	0.02	—	0.0002
—	Bunk	14	0.5	—	0.005
9	Low Berth	14	1.0	0.001	0.05
9	Emergency Low Berth	28	2.0	0.002	0.1
—	Small Stateroom	28	2.0	0.0005	0.04
—	Large Stateroom	56	4.0	0.001	0.1
—	Sanitary Facilities	3.5	0.05	—	0.0001

Table 208: Life Support A

TL	Type	Volume (m^3/m^3)	Mass (t/m^3)	Power (MW/m^3)	Price (MCr/m^3)
5	Overpressure	0.001	0.001	—	0.0001
5	I (Minimal)	??	??	??	??
5	II (Basic)	0.005	0.005	0.0001	0.0003
6	III (Standard)	0.008	0.008	0.0002	0.0005
7	IVx Extended)	0.016	0.015	0.001	0.001

Volume is required volume of life support per m^3 of enclosed hull volume.

Table 209: Life Support B

TL	Type	Volume (m^3/p)	Mass (t/p)	Power (MW/p)	Price (MCr/p)	Min Cap (persons)
5	Oxygen tanks & Masks	0.01	10	—	??	—
8	V-a (Endurance)	100	50	0.01	??	25
9	V-b (Endurance)	200	75	0.02	??	30
10	V-c (Endurance)	500	125	0.05	??	40
10	V-d (Endurance)	1,500	200	0.05	??	75

All values are per person supported.

Volume is required volume of life support per person

Min Cap: Due to their nature, endurance systems have to be built to support a *minimum* number of people.

Table 210: Airlocks

TL	Type	Volume (m^3)	Mass (t)	Area (m^2)	Power (MW)	Price (MCr)
5	Minimal	1.0	0.06	1	—	0.001
5	Standard	3.0	0.2	2	0.001	0.005
5	Decontam addition	1.0	1.0	—	0.001	0.001

Table 211: Standard Food Supply

Meal Quality	Volume (m^3/p)	Mass (t/p)	Price (Cr/p)
Meager	0.074	0.056	441
Normal	0.116	0.095	525
Good	0.137	0.095	819
Excellent	0.137	0.096	1,365

All values are per person, and include 2 weeks' meals at the listed quality, plus one week of emergency rations "just in case."

Table 212: Food Storage

TL	Volume (m^3/m^3)	Mass (t/m^3)	Power (MW/m^3)	Price (MCr/m^3)
6	1.25	0.125	0.0025	0.000625
8	1.2	0.100	0.0023	0.000500
10	1.1	0.075	0.002	0.000450
12+	1.05	0.065	0.0015	0.000400

All values are per cubic meter of storage capacity needed.

Table 213: G-Tanks

TL	Description	Volume (m^3)	Mass (t)	Power (MW)	Price (MCr)
8	G Tank (Passenger)	5.5	2	—	0.01
8	G Tank (Crew)	6.5	2	—	1

Table 214: Artificial Gravity/Inertial Compensation

TL	Max Comp	Volume (m^3/m^3/G)	Mass (t/m^3)	Power (MW/m^3)	Price (MCr/m^3)
10	1G	0.01	0.02	0.7	0.05
11	2G	0.005	0.02	0.7	0.05
12	3G	0.003	0.02	0.7	0.05
13	4G	0.0025	0.02	0.7	0.05
14	5G	0.002	0.02	0.7	0.05
15	6G	0.0015	0.02	0.7	0.05

Volume is per m^3 of enclosed hull volume, per G compensated. All other values are per m^3 of AG machinery

Table 215: Power Plant Scale Efficiencies

Min Volume	Additional Power/Volume
x10	x1.1
x100	x1.21
x1,000	x1.33
x1,000	x1.46
x100,000	x1.61

Table 216: Chemical Power Plants

TL	Type	Min Output (MW)	Volume (m^3/MW)	Mass (t/MW)	Price (MCr/MW)	Fuel (m^3/hr/MW)
3	Primitive External Combustion	0.025	10.0	40.0	0.005	0.20
4	External Combustion	0.030	5.0	10.0	0.003	0.15
4	Primitive Internal Combustion	0.013	4.0	4.0	0.004	0.30
5	Advanced External Combustion	0.300	3.3	6.7	0.007	0.15
5	External Combustion Turbine	0.350	2.9	5.7	0.009	0.15
5	Internal Combustion	0.003	3.3	3.3	0.007	0.25
5	Improved Internal Combustion	0.004	2.5	2.5	0.005	0.25
6	Advanced Internal Combustion	0.250	2.0	4.0	0.006	0.20
7	Internal Combustion Turbine	0.300	1.7	1.7	0.008	0.30
8	Advanced IC Turbine	0.800	1.3	1.3	0.013	0.20

Table 217: Fission Power Plants

TL	Power (MW/m^3)	Density (t/m^3)	Price (MCr/m^3)	Min Size (m^3)	Area (m^2/MW)	Fuel Rate (m^3/MW/hr)	Fuel Type
6	0.30	10	0.1	30	10	0.75	Radio
7	0.60	8	0.1	20	10	0.25	Radio
8	1.00	6	0.1	10	10	0.10	Radio

Table 218: Fusion Power Plants

TL	Power (MW/m³)	Density (t/m³)	Price (MCr/m³)	Min Size (m³)	Area (m²/MW)	Fuel Rate (m³/MW/yr)	Fuel Type
9	2.0	4	0.2	1,000	1	0.15	deuter
10	2.0	4	0.2	500	0.1	0.15	deuter
11	2.0	4	0.2	200	0.1	0.15	deuter
12	2.0	4	0.2	10	0.01	0.15	LHyd
13	3.0	3	0.2	1	0.01	0.10	LHyd
14	3.0	3	0.2	0.25	0.001	0.10	LHyd
15	6.0	2	0.2	0.1	0.001	0.10	LHyd
16	7.0	1	0.2	0.075	0.001	0.10	LHyd

Table 219: Fusion+ Power Plants

TL	Power (MW/m³)	Density (t/m³)	Price (MCr/m³)	Min Size (m³)	Area (m²/MW)	Fuel Rate (m³/m³/hr)	Fuel Type
10	3.0	2.0	0.01	0.020	10	0.0015	hvy water
11	3.8	2.0	0.01	0.015	10	0.0015	hvy water
12	4.8	2.0	0.01	0.010	1	0.0015	hvy water
13	6.0	1.5	0.01	0.007	1	0.0015	hvy water
14	7.7	1.5	0.01	0.006	0.1	0.0015	hvy water
15	9.8	1.0	0.01	0.004	0.1	0.0015	hvy water

Table 220: Fuel Cells

TL	Power (MW/m³)	Density (t/m³)	Price (MCr/m³)	Min Size (m³)	Area (m²/MW)	Fuel Rate (m³/MW/hr)	Fuel Type
7	0.50	1	0.02	0.01	10	0.30	HGHCD
12	0.75	1	0.02	0.01	1	0.25	HGHCD
14	1.50	1	0.02	0.01	0.1	0.20	HGHCD
16	1.75	1	0.02	0.01	0.01	0.2	HGHCD

Table 221: Antimatter Power Plants

TL	Power (MW/m³)	Density (t/m³)	Price (MCr/m³)	Min Size (m³)	Area (m²/MW)	Fuel Rate (m³/MW/yr)	Fuel Type
17	50	6	0.5	8.00	0.01	0.0050	AM
18	100	5	0.5	1.00	0.01	0.0020	AM
19	250	4	0.5	0.25	0.001	0.0010	AM
20	500	3	0.5	0.10	0.001	0.0005	AM
21	1,000	2	0.5	0.02	0.001	0.0002	AM

TL	Power (MW/m³)	Density (t/m³)	Price (MCr/m³)	Area (m²/MW)
6	0.001	2	0.005	12
7	0.0015	2	0.006	12
8	0.002	2	0.006	12
9	0.0025	2	0.006	12
10	0.003	2	0.006	12
11	0.004	2	0.006	12

Table 222: Fuels

Type	Density (t/m³)	Cost (Cr/m³)	Comments
Wood	0.9	50	
Alcohol	0.8	200	
Coal	1.4	100	
Hydrocarbon Distillates (HCD)	0.9	250	
High-Grade HCD (HGHCD)	0.9	1,000	Required for fuel cells
Liquid Hydrogen (LHyd)	0.07	35	
Deuterium	0.14	350	"Heavy" Hydrogen
Heavy Water	1.07	300	
Radioactives	19.0	75,000	
Antimatter (AM)	0.07	200,000	

Table 223: Accumulators

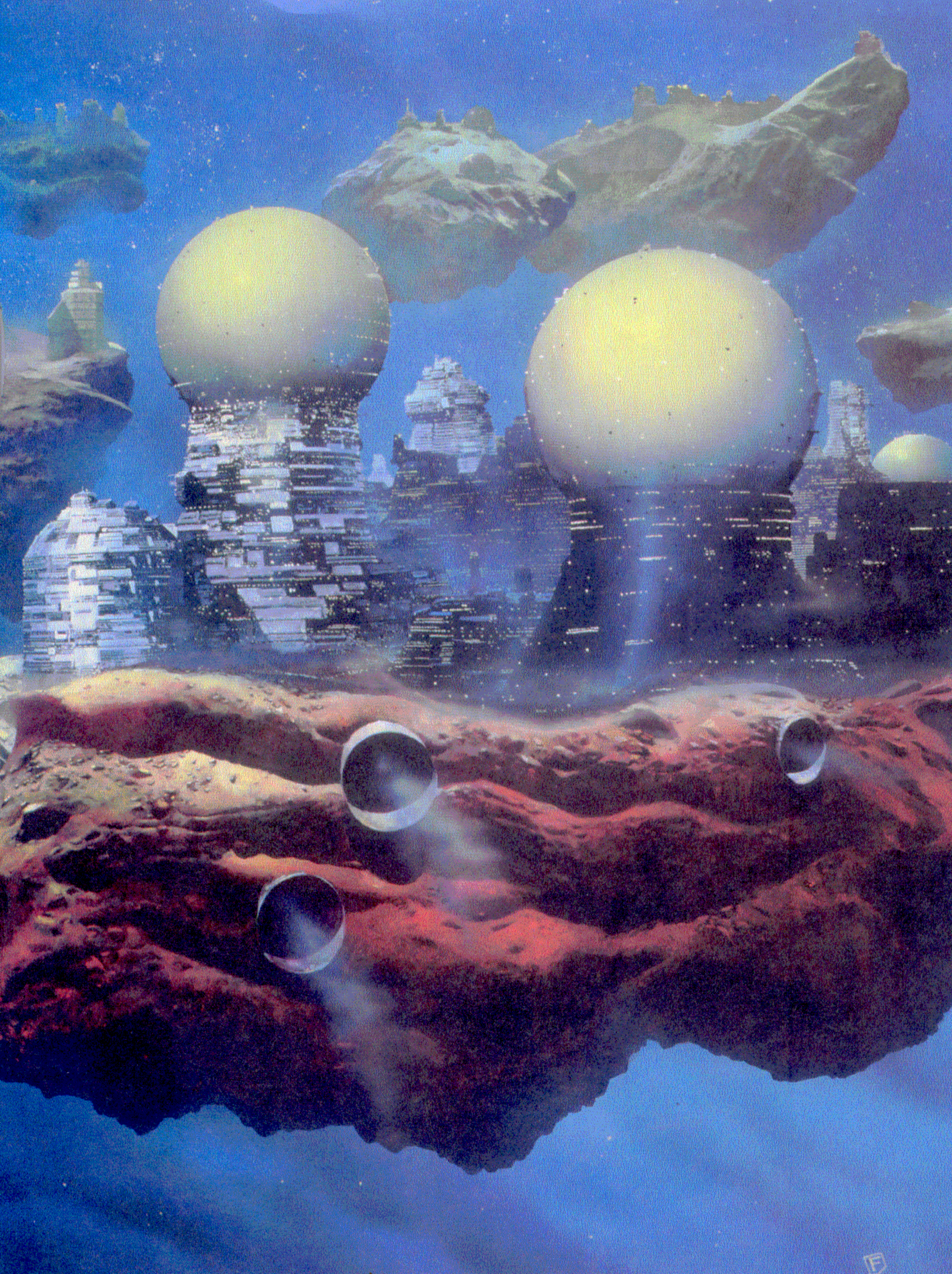
TL	Capacity (m³/MJ)	TL	Capacity (m³/MJ)
7	0.250	15	0.035
8	0.125	16	0.030
9	0.100	17	0.025
10	0.080	18	0.020
11	0.060	19	0.015
12	0.050	20	0.010
13	0.045	21	0.005
14	0.040		

Table 224: Batteries

TL	1 Hour Output (MW/m³)	Mass (t/m³)	Price (MCr/m³)
4	0.04	2.0	0.0010
5	0.06	2.0	0.0010
6	0.08	2.0	0.0008
7	0.10	2.0	0.0008
8	0.20	2.0	0.0010
9	0.40	2.0	0.0020
10	0.80	2.0	0.0030
11	1.00	2.0	0.0040
12	1.50	2.0	0.0050
13	2.00	2.5	0.0080
14	2.50	2.5	0.0100
15	3.00	2.5	0.0150
16	3.50	2.5	0.0200
17	4.00	2.5	0.0250
18	6.00	3.0	0.0300
19	8.00	4.0	0.0400
20	10.00	5.0	0.0500
21	12.00	6.0	0.1000

Table 225: Battery Discharge Rates

Time	Output	Price	TL
0.0036 s	x15,625	x25	9
0.036 s	x3,125	x16	8
0.36 s	x625	x9	7
3.6 s	x125	x4	6
36 s	x25	x2	5
6 min	x5	—	4
1 hr	x1	—	4
10 hrs	x0.1	—	4
100 hrs	x0.02	—	5
1,000 hrs	x0.004	—	6



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