GURPS®

VEHICLES EXPANSION 2

MORE NEW VEHICLES RULES FOR ANY CAMPAIGN

COMPILED BY DAVID PULVER

STEVE JACKSON GAMES

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VEHICLES 2 EXPANSION

COMPILED BY DAVID PULVER

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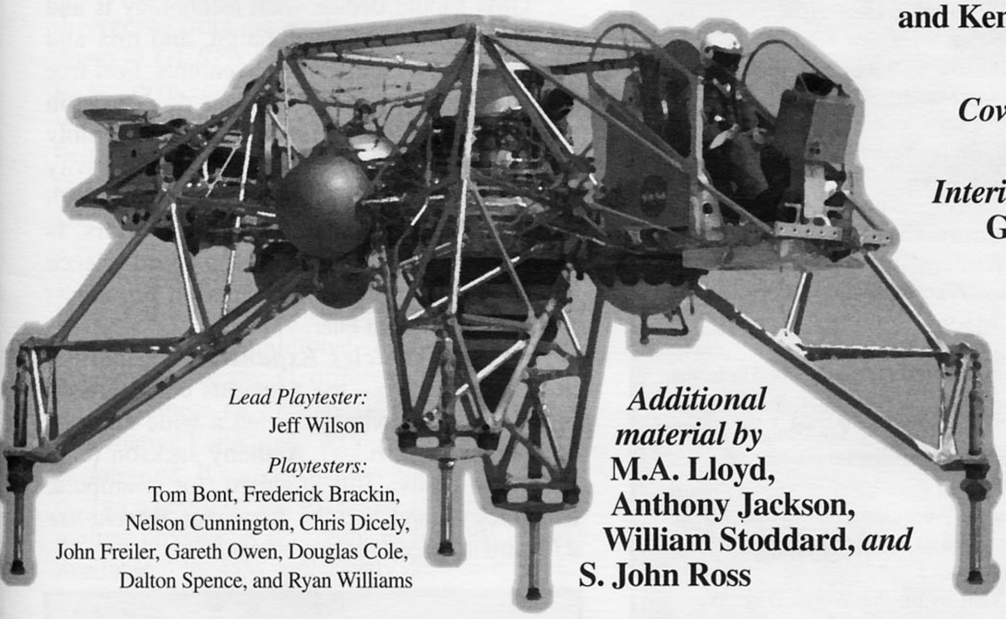

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ISBN 1-55634-602-6

1 2 3 4 5 6 7 8 9 10

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INTRODUCTION

About GURPS

Steve Jackson Games is committed to full support of the *GURPS* system. Our address is SJ Games, Box 18957, Austin, TX 78760. Please include a self-addressed, stamped envelope (SASE) any time you write us! Resources include:

Pyramid (**www.sjgames.com/pyramid/**). Our online magazine includes new ***GURPS*** rules and articles. It also covers ***Dungeons and Dragons, Traveller, World of Darkness, Call of Cthulhu,*** and many more top games – and other Steve Jackson Games releases like ***In Nomine, INWO, Car Wars, Toon, Ogre Miniatures,*** and more. *Pyramid* subscribers also have access to playtest files online!

New supplements and adventures. ***GURPS*** continues to grow, and we'll be happy to let you know what's new. A current catalog is available for an SASE. Or check out our website (below).

Errata. Everyone makes mistakes, including us – but we do our best to fix our errors. Up-to-date errata sheets for all ***GURPS*** releases, including this book, are available from SJ Games; be sure to include an SASE. Or download them from the Web – see below.

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Internet. Visit us on the World Wide Web at **www.sjgames.com** for an online catalog, errata, updates, Q&A, and much more. ***GURPS*** has its own Usenet group, too: rec.games.frp.gurps.

GURPSnet. This e-mail list hosts much of the online discussion of ***GURPS***. To join, e-mail majordomo@io.com with "subscribe GURPSnet-L" in the body, or point your web browser to **gurpsnet.sjgames.com**.

The ***GURPS Vehicles Expansion 2*** web page is at **www.sjgames.com/gurps/books/vehiclesx2/**.

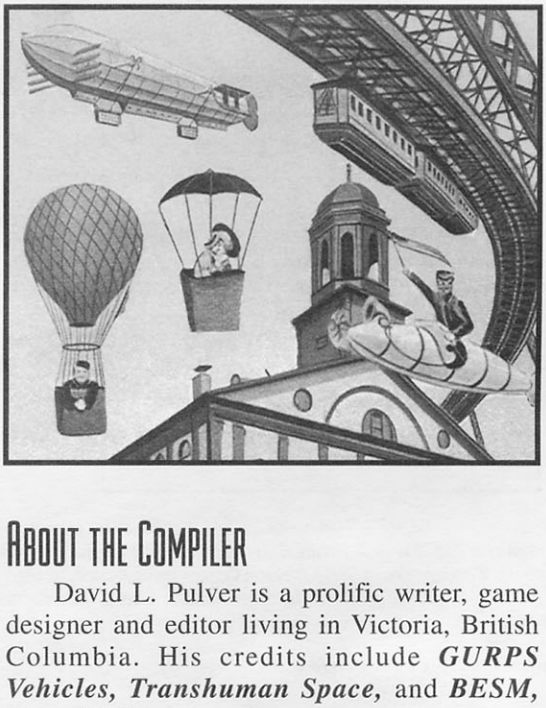
Page References

Rules and statistics in this book are specifically for the ***GURPS Basic Set,*** *Third Edition.* Any page reference that begins with a B refers to the ***GURPS Basic Set*** – e.g., p. B102 means p. 102 of the ***GURPS Basic Set,*** *Third Edition.* Page references that begin with CI indicate ***GURPS Compendium I.*** Other references are P for ***GURPS Psionics,*** S for ***GURPS Space,*** *Third Edition,* VE for ***GURPS Vehicles,*** *Second Edition,* and WT for ***GURPS Warehouse 23.*** For a full list of abbreviations, see p. CI181 or the updated web list at **www.sjgames.com/gurps/abbrevs.html**.

This book is the second supplement to ***GURPS Vehicles,*** *Second Edition.* Like the first volume, ***GURPS Vehicles Expansion 2*** adds a wide range of features for vehicles of all sorts, from powered turbosails for high-tech sailing ships to ley drives and disintegration screens for UFOs.

GMs should decide what technology is and isn't appropriate to a campaign, and mix and match to create memorable adventures. Feel free to decide that certain technologies don't exist in a particular setting, to make room for possibly more interesting inventions. Does contragravity make travel too easy? Replace grav vehicles with vacuum-filled airships or magnetic lifters. Is nuclear fusion too mundane for a weird-science future? Maybe everything runs on broadcast power or zero-point energy!

GURPS Vehicles Expansion 2 benefited immeasurably from the generous contributions of M.A. Lloyd (who provided a wide array of components and rules), Anthony Jackson (custom force fields), Bill Stoddard (for steampunk technology), and S. John Ross (for ***Warehouse 23*** weird science), among others.



About the Compiler

David L. Pulver is a prolific writer, game designer and editor living in Victoria, British Columbia. His credits include ***GURPS Vehicles, Transhuman Space,*** and ***BESM,*** *Second Edition.*

DESIGN OPTIONS 1

This chapter describes alternative options for creating vehicle subassemblies, body features, structures, and armor, expanding on Chapter 1 of ***GURPS Vehicles.***

Divergent Tech Levels

Technology that represents a significant divergence from the normal technology path laid down in ***GURPS*** for TL7 and below is referred to as "divergent technology." This is indicated with a notation such as TL(5+1), the first number being the TL at which it diverged and the second the number of TLs since the divergence point. Use the sum of both numbers for most purposes, e.g., TL(5+1) is effectively TL6. However, it would be a *different* TL6. Engineers and scientists used to a normal (or differently diverging) TL will suffer an additional -2 familiarity penalty over and above any TL differences.

Divergent technology most often occurs in "alternative Earth" type settings, such as ***GURPS Steampunk.*** It sometimes, but not always, develops as a result of the existence of different prevailing physics. A divergent technology is only available if the GM specifically decides it exists.

In some cases, divergent technologies only function in alternative Earths (or other worlds) where different physical laws hold sway, e.g., a working theory of the ether instead of quantum physics. These are referred to as "weird science" technologies.

Subassemblies

Subassemblies are major components that are added to a vehicle, such as wheels or turrets. Two additional subassembly options are below.

Pontoons

Some light aircraft, notably seaplanes, are designed to land on pontoons and float. Build these as waterproof or sealed pods attached to the body or wings containing nothing but empty space. Each cubic foot of pontoon volume adds 37 lbs. flotation. A vehicle should generally have two pontoons (each the same size) as under-body pods, although other symmetrical arrangements may be permitted by the GM.

The combined volume of the pods is typically 10%-30% of body volume. If the flotation of the pontoons alone is higher than total loaded weight, the vehicle is treated as having fine hydrodynamic lines for all water performance except calculating draft (pp. VE130-132). Use combined pontoon volume, not body volume, when referring to the *wMR and wSR Table* (p. VE132).

A vehicle may have both retractable wheels and pontoons; use the statistics for "retractable wheels that retract into the wings," except that instead of adding 0.025 times body volume to each wing, use (0.05/number of pontoons) as an absolute minimum volume for each pontoon pod. Pontoons cost $4 × surface area.

Extra Detail – Wing Pontoons on Flying Boats

A winged aircraft with a hydrodynamic hull (a flying boat) normally requires two small underwing pontoons (one pod per wing) for stability when floating, even though most of the flotation is provided by the body. If the pods do not provide flotation equal to at least 5% of the vehicle's loaded weight, it usually tips over, preventing it from safely landing or taking off.

Rigid Sail Subassemblies

These are high-tech alternatives to conventional masts and sails. Rigid sails are potentially less vulnerable to damage than ordinary sails, and can be controlled by a single crew member regardless of the sail area. There are three types:

Flettner Rotors (TL6): These are tall rotating cylinders which produce thrust from the wind via the Magnus effect (see ***Vehicles Expansion 1***). They have a small power requirement.

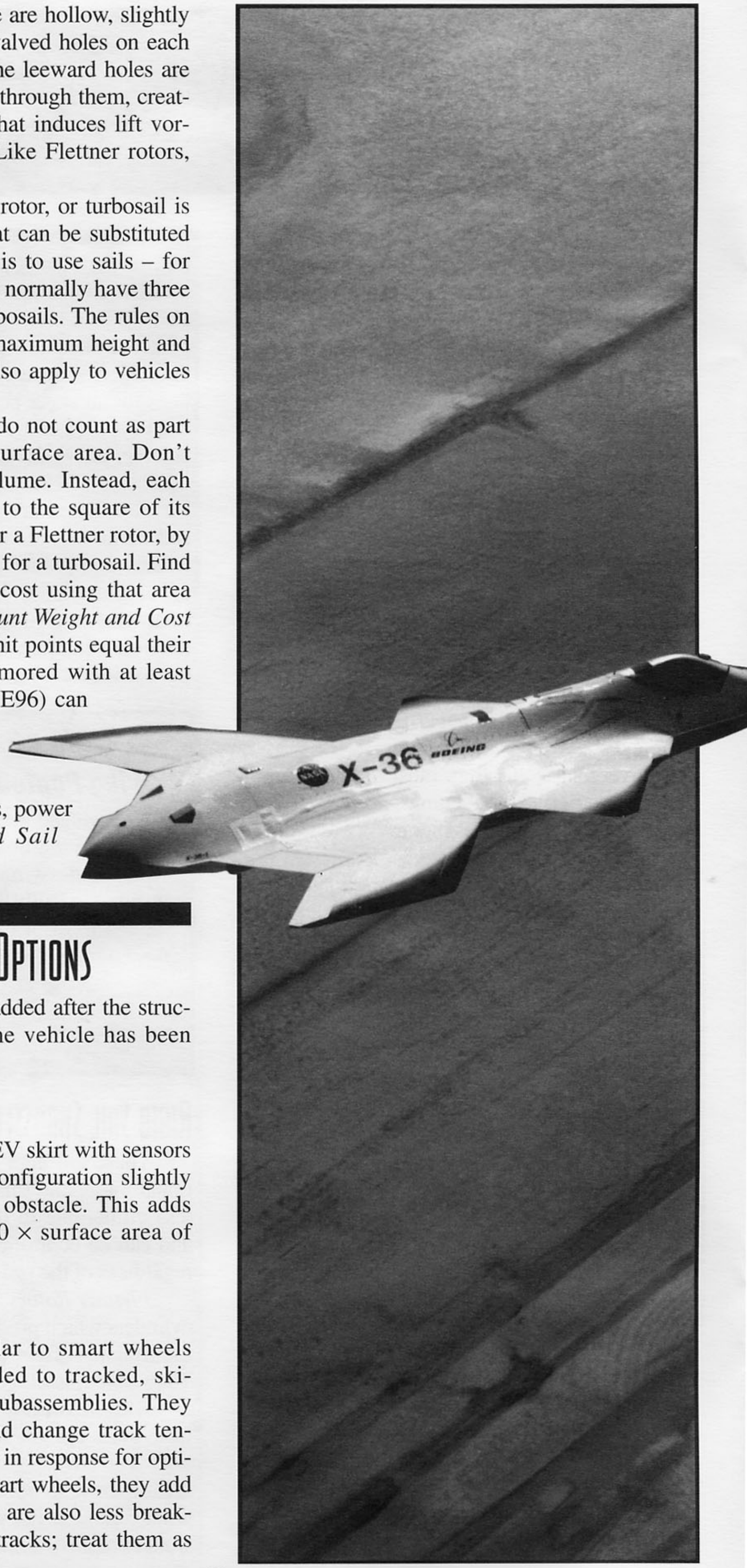
Wingsails (TL7): These rigid airfoils range from giant upright wings to forests of inch-wide slats. The advantages are simplified handling (no sailing crew is necessary), easier match to the wind direction (they travel at full speed in any wind except *Wind on the Bow*), and higher thrust.

Turbosails (TL7): These are hollow, slightly streamlined cylinders with valved holes on each side and a fan at the top. The leeward holes are opened and the fan pulls air through them, creating a low pressure region that induces lift vortices in the passing wind. Like Flettner rotors, they are also powered.

Each wingsail, Flettner rotor, or turbosail is a structural subassembly that can be substituted for a mast on a vessel that is to use sails – for example, a vessel that would normally have three masts could install three turbosails. The rules on masts (p. VE9) relating to maximum height and minimum vehicle volume also apply to vehicles with rigid sails.

Like masts, rigid sails do not count as part of a vehicle's structural surface area. Don't bother calculating their volume. Instead, each sail's surface area is equal to the square of its height multiplied by 0.63 for a Flettner rotor, by 0.5 for a wingsail, or by 0.2 for a turbosail. Find their structural weight and cost using that area and the *Mast and Open Mount Weight and Cost Table* (see p. VE20). Their hit points equal their area × 2. They must be armored with at least DR 1. Solar cells (see p. VE96) can be mounted on rigid sails at TL7+.

For thrust (and, for Flettner rotors and turbosails, power requirements), see *Rigid Sail Propulsion* on p. 7.



Special Structural Options

These options may be added after the structural weight and cost of the vehicle has been determined, as per p. VE20.

Smart Skirt (TL8)

This option equips a GEV skirt with sensors that allow it to change its configuration slightly – for instance, to avoid an obstacle. This adds 0.25 to MR and costs ($80 × surface area of GEV skirt).

Smart Tracks (TL8)

Smart tracks are similar to smart wheels (p. VE21), but can be added to tracked, ski-tracked, and half-tracked subassemblies. They sense ground conditions and change track tension and tread shape slightly in response for optimum performance. Like smart wheels, they add 0.25 to gMR. Smart Tracks are also less breakdown-prone than ordinary tracks; treat them as wheels when determining ground vehicle breakdowns (p. VE147). They are less prone to jam if damaged (see p. VE151, *Jamming Tracks*); a jam has a 1 in 6 rather than 2 in 6 chance of occurring. They cause no more damage to hard roads than a wheeled vehicle, unlike ordinary tracks which tend to chew up asphalt. Smart Tracks cost $80 × surface area of the tracks, minimum $4,000. The cost is halved at TL9 and again at TL10.

Tailless Aircraft (late TL7)

The wings subassembly is normally assumed to include a tail. However, a winged vehicle with this option lacks this separate vertical rudder and tail stabilizer. The vehicle must be given the controlled instability option (p. VE21). In addition, it is harder to detect with radar (-1 from Size Modifier) but not quite as maneuverable (-1 TL when computing aMR). This penalty to aMR is ignored if the aircraft has vectored thrust or 2D vectored thrust (pp. 12-13).

Armor

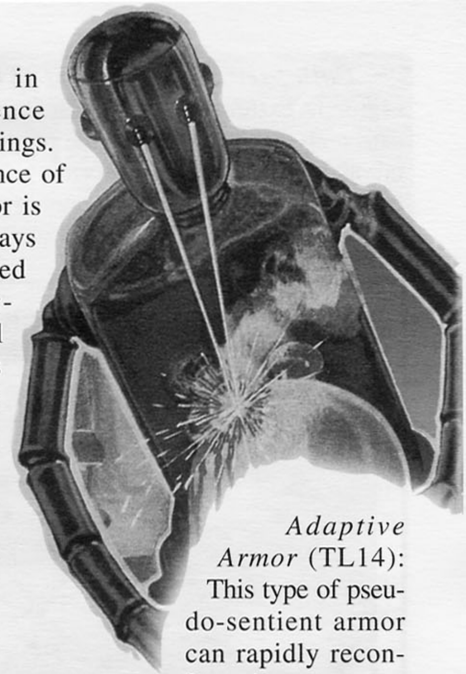
This section offers expanded types of armor. GMs should carefully consider the effect before adding them, since a stark imbalance between offense and defense can quickly derail any adventure based around vehicular combat. Historically, there have been military engagements where one or both sides either could do each other no harm or were extremely vulnerable to each other, but such situations tend to be rapidly corrected by advances in weapons or protective technology. Also, bear in mind that advances in vehicular armor are likely to be eventually reflected in personal armor as well.

Durable Ablative Armor

This is somewhat tougher ablative armor designed to resist minor chips. It appears at the same TL as ordinary ablative armor, but has 1.5 × the weight and double the cost of standard ablative armor. However, it subtracts 1/10 of its DR from each hit before determining how much armor is ablated. It is automatically fireproof.

Super Armor

Some campaign settings may have armor whose protective values go beyond the relatively straight-line projections of the standard TL developments. The listed TLs for these are speculative: super armor, like other superscience, could theoretically appear at much earlier TLs – and does, in many science fiction settings. The existence of super armor is almost always accompanied by super-powerful weapons as well, or at least widespread use of nukes!



Adaptive Armor (TL14): This type of pseudo-sentient armor can rapidly reconfigure its structure to best resist a particular single beam type (see p. VE123), giving 3 × DR against it. It will reconfigure *automatically* one second after a beam attack of a known type penetrates the armor or seriously threatens to do so (damage more than half what's needed to penetrate DR). If struck by diverse beam types in a single turn, it reconfigures against the most powerful attack. If struck by a previously unknown beam type, the armor may be able to adapt to it anyway. Roll vs. the armor's TL-4 to succeed each time it's struck; after it does so, the beam type is considered "known" to the armor in future.

Adaptive armor can instead be manually reprogrammed to resist a single known beam type. This takes one turn; turning the automatic adaptation back on also takes one turn. Higher-TL adaptive armor is capable of optimizing against two (TL15) or four (TL16) different beam types. Adaptive armor uses the statistics for any TL13+ armor but has double the normal cost.

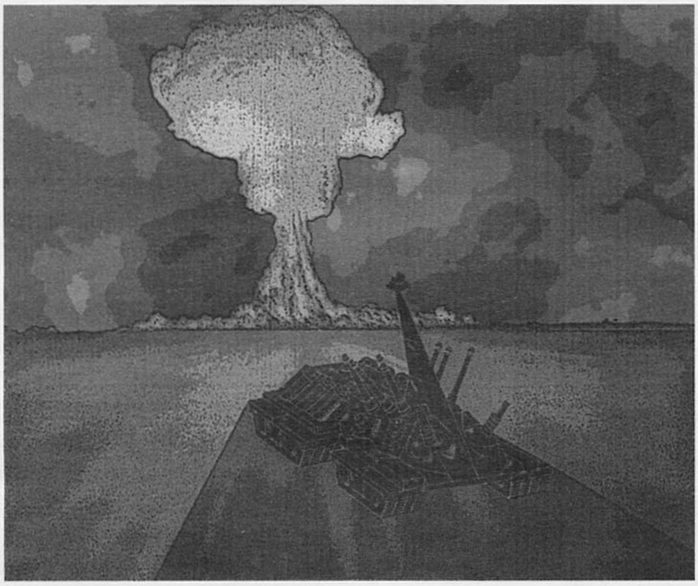
Extra Detail – Armor Volume

Realistically, armor should also take up volume, but in most cases that volume is small enough that it can be safely ignored. To find the volume of armor, divide the weight of the armor by the density of the armor material. Some typical densities are 50 lbs./cf for wood, ablative, non-rigid, and reflex armor, 200 lbs. per cf for composite armor, 300 lbs. per cf for laminate armor, and 400 lbs./cf for metal armor.

Collapsed Matter Armor (TL15): This armor is extremely strong for its weight and extremely dense; it may be the product of gravitational manipulation or a form of exotic matter. It has a weight of 0.001 lbs. per sf per point of DR, and a cost of $500 times weight. If using the rules for armor volume, treat it as having negligible volume.

Indestructible Armor (TL16): Not quite, but nearly so! Possibly an advanced form of the above, this is an impossibly light but extremely strong coating, perhaps only a few atoms or molecules thick. It weighs next to nothing (1 milligram per square foot), gives DR 500, and negates armor divisors of projectile weapons and monowire attacks.

Only one layer can be used directly, but extra layers built up as laminates over a foil-thin layer of gold or similar material weigh 0.00001 lbs./sf per point of DR at $100,000 times weight.



Extra Detail – Rad Shielding and Cosmic Rays

Realistically, radiation shielding is a primarily a function of mass, and is not affected by TL. Radiation protection is measured in Protection Factor (PF). Divide radiation intensity by the PF of any shielding between the radiation source and the victim.

Radiation shielding on spacecraft, however, is rated in terms of cPF, its protection against highly penetrating cosmic rays that are found in space. These ignore ordinary PF.

cPF depends on the weight of armor per sf of area. Find the weight of armor in lbs. per sf (the weight number on the armor table); this may vary by vehicle location. Then look up the cPF that provides on the table below:

cPF Table

lbs./sf	*cPF*	*lbs./sf*	*cPF*	*lbs./sf*	*cPF*
1-99	1	1,000-1,199	100	2,200-2,399	10,000
100-199	2	1,200-1,399	200	2,400-2,599	20,000
200-399	5	1,400-1,599	500	2,600-2,799	50,000
400-599	10	1,600-1,799	1,000	2,800-2,999	100,000
600-799	20	1,800-1,999	2,000	3,000-3,199	200,000
800-999	50	2,000-2,099	5,000	3,200-3,399	500,000

Multiply cPF by 100 to get ordinary PF against solar radiation or planetary radiation belts.

Permanent habitats or spacecraft built for long, slow manned voyages should have armor massing at least 200 lbs. per sf (cPF 5+); 1,000 lbs. per sf (cPF 100) or more is usually preferred for minimal risk.

Component Options

These options can be applied to components built into a vehicle.

Reconfigurable Component (TL11)

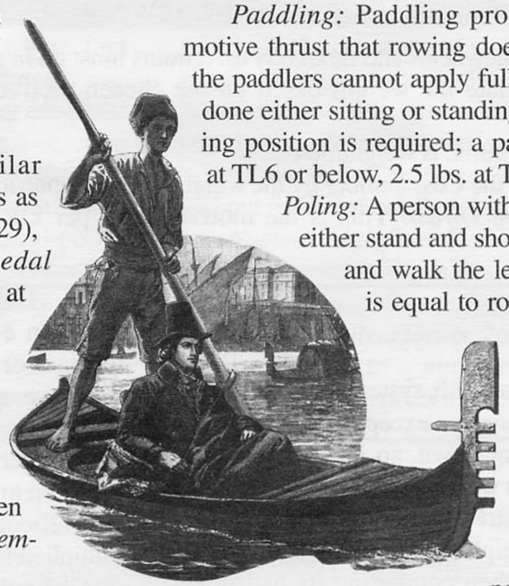
The component can alter its shape and function, transforming into two or more pieces of equipment. Transformation requires (16-TL) seconds. Weight and volume are the weight and volume of the largest included system(s), cost is the combined cost of all the configurations times the number of configurations, and power consumption is that of the current configuration.

Extradimensional Reconfiguration (TL15)

This superscience option enables a component to reconfigure itself by storing unused parts in another dimension. This doubles the cost, but the weight and power consumption are that of the current configuration. Reserve enough volume for the largest configuration. If the component is reconfigured to take up a smaller volume, the difference is treated as empty space.

Propulsion and Lift Systems 2

This chapter offers new components and means of propelling or lifting a vehicle, expanding on the rules found in Chapter 2 of ***GURPS Vehicles***.



Harnessed Human Propulsion

Harnessed humans (or similar humanoid bipeds) use the same rules as any other harnessed animals (p. VE29), but a proper load-distributing *bipedal harness* (efficiency 0.02) is available at TL1. $20, 3 lbs.

Rigid Sail Propulsion

These replace conventional mast-and-canvas sails with rigid structures, which may be wind-driven or powered – see *Rigid Sail Subassemblies*, pp. 3-4.

Flettner rotors and turbosails both require power. The idea of a powered sail may seem absurd, but in a good wind powered sails generate more thrust than conventional aquatic propulsion. Turbosails also require additional weight and cost for the fans they use.

Rigid Sails Table

TL	Type	Weight	Cost	Thrust	Bow	Abeam	Quarter	Astern	Power
6	Flettner Rotor	0.5	$5	2.7	0.5	1	1	1	0.25
7	Wingsails	0	0	0.9	0.5	1	1	1	0
7	Turbosails	0.04	$1	1.8	0.5	1	1	1	0.1

Weight, Cost, Power, and *Thrust* are per sf of sail area. Multiply thrust by the wind Beaufort number (p. VE30).

Bow, Abeam, Quarter, and *Astern* are multipliers to top speed for those relative wind conditions; see *Sails and Wind* (p.VE158). These modifiers replace the normal modifiers on p. VE158.

Aquatic Propulsion

These are alternatives to the systems described on p. VE29 and p. VE32.

Paddling and Poling (TL0)

Two alternatives to rowing are paddling, using a single- or double-ended paddle, and poling with a long pole. An exposed crew station is required, but no rowing position (see p. VE30) is necessary.

Paddling: Paddling produces 50% of the motive thrust that rowing does (p. VE30), since the paddlers cannot apply full strength. It can be done either sitting or standing on deck. No rowing position is required; a paddle weighs 5 lbs. at TL6 or below, 2.5 lbs. at TL7 or above.

Poling: A person with a pole or staff may either stand and shove, or hold the pole and walk the length of the boat; it is equal to rowing in output, but is only effective if the bottom is shallow enough for the pole to reach. This usually will limit maximum operating depth to 3 yards or less. A pole typically weighs 10 lbs. at TL6 or below, 5 lbs. at TL7 and above.

Feathered Paddlewheels (Late TL5)

These are more advanced paddlewheels, in which the individual paddles rotate in addition to the rotation of the entire wheel. This angles the paddles so their drag always contributes to thrust rather than uselessly forcing water up or down as the paddle enters or leaves the water. This adds some mechanical complexity, but substantially increases thrust. See the table on p. 8.

Aquatic Flexibodies (TL8)

A conventional flexibody system moves like a snake, and can swim like one if necessary. Aquatic flexibodies add movable fins and a tail to swim like a fish. Although they are optimized for water performance, they are useless on land.

Powered Aquatic Propulsion Table

TL	Type	Weight in lbs. when Motive Power is under 5 kW	5 or more kW	Cost	Aquatic Motive Thrust
5	Feathered Paddlewheel	125 × kW	(25 × kW) + 500	$15	10
8	Aquatic Flexibody	40 × kW	(4 × kW) + 180	$200	25
9	Aquatic Flexibody	30 × kW	(3 × kW) + 135	$200	35
10	Aquatic Flexibody	20 × kW	(2 × kW) + 90	$200	35
11	Aquatic Flexibody	15 × kW	(1.5 × kW) + 60	$200	35
12	Aquatic Flexibody	10 × kW	(1 × kW) + 45	$200	35

Location: Paddlewheels and flexibody drivetrains must go in the body.

Weight: Calculate the weight based on the chosen motive power as shown on the table.

Volume: The volume is weight/50 cf.

Cost: Multiply the Cost number by the weight of the propulsion system.

Aquatic Motive Thrust: This is the motive thrust per kW of motive power in water.

Active Flotation

This is an aquatic lift system. Any powered aquatic propulsion system except a flexibody can be installed to point down, so its thrust offsets part of the vehicle's weight.

Subtract the active flotation thrust from the vehicle's loaded weight to determine if the vehicle can float, or when computing its hydrodynamic drag. Of course, a vehicle that floats only on active flotation is in trouble if the power fails! An active flotation system can additionally be used to add to loaded weight to enable a light vehicle to submerge.

An active propulsion system may be built with vectored thrust (1.5 × weight, volume, and cost, as per p. VE41). This enables it to increase or decrease loaded weight for flotation purposes and to propel the vehicle in or under water.

X-Wing Stopped Rotors (TL8)

Conventional helicopters are limited in top speed because the faster the helicopter goes, the more lift the forward edge of the rotor disk creates in comparison to the rear edge. At high speeds, this renders the aircraft completely unstable.

The X-wing design is designed to counter this. It uses an ordinary helicopter design with a special wide-bladed rotor, plus jet engines. In addition to being wider and stiffer than usual, X-wing rotors are perforated along each edge. This allows air to be sucked into the trailing edge and blown out the front, further increasing lift.

An X-wing's rotors function in normal helicopter mode to take off vertically, with the jet engines used to augment forward motion. Once the X-wing is moving fast enough for the rotors to be redundant, they are locked in place ("stopped") forming two pairs of wings, one raked forward and one backwards. These provide enough lift for the X-wing aircraft to fly at high subsonic speed like a conventional jet airplane.

An X-wing is designed with top-and-tail rotors (p. VE8) or coaxial rotors (p. VE8), a helicopter drivetrain (pp. VE33-34), and reaction engines (two turbofan engines mounted in pods in most designs) or reactionless thrusters. The vehicle may have up to Very Good streamlining. The X-wing can take off and fly like a helicopter but can accelerate past normal rotary wing speed limits, up to 400 mph.

Helicopter drivetrain weight (and cost) is multiplied by 1.25. When calculating the surface area of rotors with the X-wing option (see p. VE18), multiply by 3.5 instead of 3.

When the rotor is locked, it behaves exactly as a standard wing of the same surface area as the rotor. Recalculate its performance as an airplane. The rotors provide no thrust, so the aircraft will need another propulsion system (typically a jet engine). Rotors can only be unlocked while the vehicle is travelling below 300 mph. The aircraft must accelerate to a speed greater than its airplane-mode stall speed in order to safely lock its rotors. The transition takes one second, during which it cannot maneuver, accelerate, or decelerate.

Rocket Engines

Rocket engines produce thrust by expanding a gas, usually the product of a chemical reaction or a heated reaction mass, out the back of the engine. Additional types include:

Cryogenic Liquid Fuel Rockets (TL6): These chemical rockets burn fuels and oxidizers, at least one of which is a gas at ordinary temperatures and must be kept cold. This complicates fuel handling and storage in exchange for slightly better fuel economy.

Cold Gas Thrusters (late TL5): These are little more than a valve and nozzle on a tank of compressed gas. Performance is unimpressive, but they are very reliable (one moving part) and very safe (cool, nonflammable, chemically inert, nontoxic, nonradioactive exhaust). They are often used where safety is critical, such as for space suit thrusters.

Electric Rockets (late TL7): These electrically heat reaction mass. There are many kinds – arcjets, resistojets, magnetoplasmadynamic thrusters, and so on. They are fuel-efficient, but heavy and power-intensive, and so are usually found as small engines for use in vehicle designs where fuel economy is more important than high thrust.

Laser Rockets (TL8): These use an off-board laser, typically ground-based, to heat a reaction mass (typically an ablative plastic lining the interior of the drive) which provides thrust. They require a large ground-based laser beamed-power installation (p. VE87), but no receiver is needed. Laser-driven spacecraft are usually fairly small, due to the high power requirement.

Gas-Core Fission Rockets (TL8): These operate at much higher temperatures than conventional solid-core fission rockets. This improves performance, but the reactor core is no longer solid, and as a result fission fuel mixes with the exhaust. This means the exhaust is lethally radioactive. It also loses 0.005 (TL8) or 0.00125 (TL9+) lbs. of fissionables per hour per lb. of thrust, so the reactor must be refueled frequently. Fissionable fuel is typically $250 per pound, and takes up weight/200 cf if stored in a fuel bunker.

Nuclear Light-Bulb Fission Rockets (TL8): These gas core rockets hold the hot plasma in a transparent crystal capsule. Thermal radiation passes through, heating hydrogen propellant. Thrust to mass ratio is inferior to an ordinary gas-core fission rocket, but the exhaust is completely nonradioactive. The core operates for 2 years without needing fresh fission fuel.

Nuclear Lightfield Fission Rockets (TL12): These superscience engines use a force screen filled with enough fission fuel to go incandescent (see *Lightfield Reactor*, p. 26), functioning in a similar fashion to a nuclear light bulb. Light leaving the screen heats a reaction mass.

Rocket Engine Table

TL	*Rocket Engine*	*Weight*	*Fuel*	*Power*	*Cost*	*Isp*
	Chemical Rocket:					
6	with hydrogen/oxygen	0.02 × thrust	4.5HO	0	$25	380
6	with kerosene/oxygen	0.02 × thrust	1.5KO	0	$25	290
7	with hydrogen/oxygen	0.015 × thrust	3.75HO	0	$25	460
7	with kerosene/oxygen	0.015 × thrust	1.25KO	0	$25	350
8+	with hydrogen/oxygen	0.012 × thrust	3.3HO	0	$25	520
8+	with kerosene/oxygen	0.012 × thrust	1.1KO	0	$25	400
5+	Cold Gas Thruster					
	with hydrogen	0.03 × thrust	34H	0	$15	180
	with argon	0.007 × thrust	7.6A	0	$15	42
7	Electric Rocket	(60 × thrust) + 20	6H	40	$25	1,030
8	Electric Rocket	(20 × thrust) + 20	4H	80	$25	1,550
9+	Electric Rocket	(10 × thrust) + 20	2H	80	$25	3,100
8	Laser Rocket	0.025 × thrust	2.4AP	40	$50	1,550
9+	Laser Rocket	0.02 × thrust	2.4AP	40	$25	1,550
8+	Gas Core Fission Rocket	(0.05 × thrust) + 1,000	0.8H	0	$100	7,760
8	Nuclear Light Bulb	(2.5 × thrust) + 4,000	4H	0	$100	1,550
9+	Nuclear Light Bulb	(1 × thrust) + 1,000	2.5H	0	$50	2,480
12	Nuclear Lightfield	0.05 × thrust	2H	0	$50	3,100
13	Nuclear Lightfield	3.5 × thrust	0.033H	0	$50	188,000
9+	Antimatter Plasma	(30 × thrust) + 1,000	0.5H	6AM	$100	12,200

Weight depends on the desired thrust (in pounds) of the rocket.

Volume is weight divided by 50.

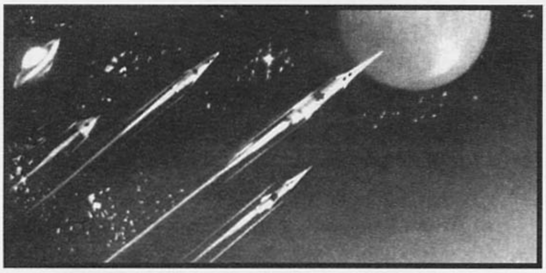
Cost is weight multiplied by the value in this column.

Power is thrust multiplied by this column. Power usage marked AM is in micrograms of antimatter per hour rather than kilowatts. A microgram of antimatter per hour is approximately equivalent to 50 kW.

Fuel is in gallons per hour per pound of thrust. Fuel types are abbreviated as follows: A is argon, H is liquid hydrogen, W is water, KO is kerosene/liquid oxygen rocket fuel, HO is liquid hydrogen-oxygen rocket fuel. Exception: AP is fuel consumption in lbs. of ablative plastic.

Isp is specific impulse, in seconds – see pp. 31-32.

Antimatter Plasma Rockets (TL9): These antimatter rockets heat reaction mass by mixing it with somewhat more antimatter than an antimatter thermal rocket (p. VE36). They trade increased antimatter usage for a reduced fuel consumption.



Magical and Superscience Space Sails

These cinematic alternatives to the lightsail (p. VE31) may exist in universes whose physical laws differ from our own.

Aether Sails (TL(2+2))

What if the universe were full of air and the circular motions of the planets and the stars were driven by aethereal winds? If a vessel can somehow leave the surface of the planet, sails could catch these currents. Since circulation is the natural state of the aether, these cosmic winds are fairly constant, but the GM may occasionally rule the vehicle has encountered an eddy or area of turbulence which alters thrust for a time.

Aether sails are divergent technology sails that naturally function only beyond the lunar sphere, since the aether circulation exists only there, but in the air filling the universe below the moon they may function as ordinary aerial sails. Aether sails must be mounted on masts and have the same area and mast restrictions as aerial sails. Aether sails must usually be made of some rare material (e.g., the silk of the venomous giant moonspiders that dwell in the crystal forests of Luna). The cost reflects this rarity.

Interstellar voyages may be possible with aether sails. The GM may assume that the stars are a lot closer, or allow a vessel with aether to sail into natural wormholes ("aether vortices") or through the eye of an aether storm to emerge in another star system! The latter would be rated as a gale (p. VE159) and require Seamanship rolls to avoid damage.

Ether Sails (TL(5+1))

In the 19th century, light was shown to be a wave, like sound, but what did it travel through, especially in the airless void of space? Physicists speculated the universe was filled by a tenuous form of matter, so thin that solid planets could pass through it unhindered. They named this substance the luminiferous ("light carrying") ether.

Ether Sails are divergent technology sails that interact with the ether, stealing momentum and energy from light. In game terms, the sails are functionally similar to light sails. Sail thrust is for 1 AU from Sol. Distance and luminosity may have the same effects as for conventional light sails (p. VE31), or the device may have a fixed momentum or energy throughput in which thrust is constant; the sail expands or contracts, or becomes more or less opaque, to compensate for variations in light level.

Interstellar travel may be possible through natural wormholes, as per aether sails.

Tachyon Sails (TL(7+3))

What if a wind of faster-than-light particles blew out from the galactic core? Perhaps there are strange-matter hyperstars there, and these sails can catch the tachyon wind they emit! In conjunction with gravitational orbits around the galactic center and a system for charging the sails to use the galactic magnetic field to make grand turns, a tachyon sailship can travel between the stars at high sublight speeds!

Tachyon intensities may vary with distance from the core, but the nearby stars are at essentially the same distance, so the effect is negligible. Like lightsails, the performance is direction dependent, which is negligible on the scale of interstellar trips but limits the usefulness of the sail as an in-system drive.

As a result, a tachyon sailship may be forced to travel in a direction other than that of its intended destination to build up speed before altering heading for its destination. Tachyon sails have the same size limits, furl times, and approach restrictions as lightsails. They represent superscience technology.

Tachyon Hypersails (TL(7+3))

What if hyperspace were like an ocean, and the tachyon winds blew through it, rather than normal space? A hyperdrive (p. VE39) is needed to enter hyperspace, but once there, hypersails are unfurled and used for propulsion! As long as hypersails are in use, there is no energy cost to remain in hyperspace. FTL speed is based on tachyon sail thrust: each g of sAccel gives a constant FTL speed of *x* parsecs per day FTL (default of 1 pc/day). Hyperspatial storms or currents may also exist, and further influence FTL speed.

Alternative Space Sails Table

TL	Type	Weight	Cost	Power	Sail Area
2+2	Aether Sails	0.4	$200	–	0.4 square feet
5+1	Ether Sail Generator	100	$2,000	0.5	0.188 square miles
7+3	Tachyon Sails	12.5	$100,000	0	0.03 square miles

All statistics are per pound of thrust at full power. For tachyon hypersails, treat as tachyon sails but add half the weight, volume, and cost of a hyperdrive (p. VE39). It requires the normal energy requirement to enter hyperspace, but none to remain in it.

Reactionless and Other Incredible Drives

These drives represent superscience alternatives to reactionless thrusters (p. VE38) for STL propulsion. In addition, the TL9 Super Thrusters (from ***GURPS Space***) are also included on the table below.

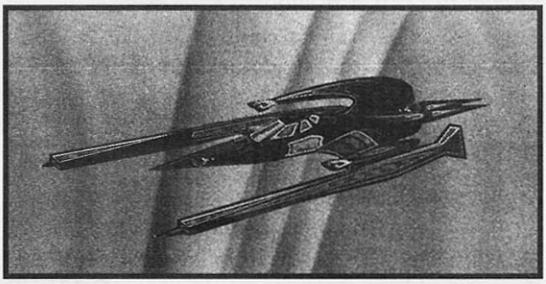
Ley Drive (TL(6+3)): Treat this weird science drive as an MPD (see below), but it only functions along ley lines (see ***GURPS Places of Mystery***) – assuming they exist! The drive must be no more than 100 miles above or 100 yards horizontally from a ley line. If it strays from a ley line, it will fall! It draws power from the ley line and so has no power requirement.

Magnetic Planetary Drive (TL(7+5)): A weird-science version of magnetic levitation (p. VE38), this drive simulates the way some UFOs are said to maneuver. An MPD produces apparently reactionless thrust by surfing on the planetary magnetic field (or in some variations, gravitational field). It can be seen as a cinematic version of a magsail (see ***Vehicles Expansion 1***). An operating MPD may cause odd electrical or magnetic effects beneath it: headlights blink out, instruments (particularly magnetic compasses) react wildly, and so on. The effect is unpredictable; it happens whenever the GM wants it to and does whatever he likes. An MPD is +4 to be detected by a MAD sensor. It performs as a vectored thrust drive (p. VE41) at no extra weight, volume, or cost. It can fly as long as it is within a planetary magnetosphere, but cannot operate in deep space. Some planets (e.g., Venus and Mars) and many moons lack magnetospheres or have very weak ones, and hence MPDs (unless gravity-based) would not function there.

Grav Drives (TL12): These advanced reactionless drives generate a self-propagating bubble of space-time with arbitrary local gravity. Since the bubble occupants don't feel acceleration, grav drive ships can safely pull hundreds of gravities. Grav drives are logical precursors to, or spin-offs from, contragravity or warp drive, and may represent a merger of contragravity and reactionless-drive technology. The standard ***GURPS*** version is still limited to the speed of light, but some fictional equivalents are not. Grav drives can also represent a slower-than-light version of warp drives that fold space in front of the vehicle.

Real-world and science-fiction grav drives that create a warp bubble often have additional unusual characteristics – see *Pseudovelocity Drives*, p. 12, for one possibility. Some variations of grav drives can only operate at some distance from a large gravity well.

Boost Drives (TL13): These drives instantly boost a ship to a substantial velocity without acceleration effects. Boosts often allow a vessel to reach a high fraction of the speed of light, or the drive can be cycled to build up such a speed. Boost drives are rated for pounds of boost capacity and speed change per drive cycle. If boost velocity or speed is fixed, another drive may be required for close maneuvering. Like a hyperdrive, a boost drive will only function if the spacecraft being boosted has a mass equal to or less than its boost capacity. Boost drives may suffer from other campaign-specific restrictions at the GM's option, e.g., not functioning close to a planet or star's gravity well.



Hyper Boost Drive (TL13): Some versions of boost drive may be capable of functioning as hyperdrives (p. VE39) if they accelerate to light speed. Build these as boost drives but with a hypershunt capacity (p. VE39) equal to boost capacity/2,000. There is no special power requirement to enter or remain in hyperspace. Transition occurs automatically as the drive reaches light speed; likewise, it will leave hyperspace at light speed and must decelerate down to normal space. If hyperspace boost drives are the only form of stardrive, the GM may wish to reduce their tech level to TL10.

Reactionless and Other Incredible Drives Table

TL	Type	Weight	Power	Cost
(6+3)	Ley Drive	(0.04 × thrust)	none	$500
9	Super Reactionless Thruster	(0.4 × thrust)	0.5	$125
(7+5)	Magnetic Planetary Drive	(0.04 × thrust)	0.1	$500
12	Grav Drive	(0.001 × thrust) + 20	0.001	$100
13+	Grav Drive	(0.0005 × thrust) + 10	0.001	$20
13	Boost Drive	(0.01 × boost capacity)	180	$500
14	Boost Drive	(0.005 × boost capacity)	180	$500
15	Boost Drive	(0.005 × boost capacity)	180	$50

Weight is per lb. of thrust, with the exception of boost drives, where it is per pound of boost capacity.

Volume is weight/50 cf.

Power is per lb. of thrust, with the exception of boost drives. For boost drives, the entry is an energy requirement, in kWs per pound of boost capacity; multiply by the percentage of light speed that the drive can add or subtract from its current velocity in a single drive cycle. As with hyperdrives (p. VE39), the energy requirement is normally provided by an energy bank.

Cost is per pound of drive weight.

Pseudovelocity Drives

A grav drive, boost drive, or reactionless drive may be described as using a pseudovelocity drive, which produces motion without accumulating momentum or kinetic energy. A pseudovelocity drive does not produce acceleration effects on the ship or anything inside it, and may be unaffected by relativity (GM's option). If so, it may be capable of accelerating beyond the speed of light; reaching light speed takes 8,300 hours divided by sAccel in G. If a pseudovelocity drive is turned off, fails, or is disabled, a ship using it instantly loses all speed gained as a result of acceleration while under pseudovelocity. The drive may also be damaged as a result – see below.

If a vessel propelled by a pseudovelocity drive contacts another object, the effects depend on how large the object is relative to the ship. If the ship has a Size Modifier at least 6 greater than the object encountered, its drive field will sweep the object up and carry it along with it. (The GM may calculate changes in the vessel's sAccel and other statistics due to the increased mass or volume carried.) Otherwise, the object was large enough to disrupt the ship's drive field: the field fails (see below), and the ship drops out of pseudovelocity and collides with the object (or is snared in its drive field, if the object was itself a much larger pseudovelocity ship).

In a collision, do not count speed reached while under pseudovelocity drive. For example, if a ship had reached a velocity of 360 mph using an ion drive before accelerating to 100,000 mph with a pseudovelocity grav drive, its collision speed would be based on its 360-mph "real" velocity rather than its 100,000-mph "pseudovelocity."

A vessel should decelerate to zero pseudovelocity before turning off the drive. If this isn't done, or if the drive was disabled, or the field failed due to an encounter with a sizable object, roll vs. the ship's HT-3. Critical failure destroys the drive; failure disables it (or destroys it if it was already disabled); success means it is damaged (halve sAccel or, if boost drive, speed change, until repaired); critical success means it is unharmed. In any event, pseudovelocity drops to zero. Objects can only leave a vessel using pseudovelocity drive if they are also using pseudovelocity drive and deliberately synchronize their drive fields (which requires both to cooperate).

Why Pseudovelocity Drives?

In game terms, the advantage of having boost, grav, or reactionless drives use pseudovelocity mechanics is to permit vessels to travel at considerable sublight (or even translight) velocities without worrying about collisions with interstellar particles or the campaign-unbalancing threat of launching missiles or ramming at near-light speeds.

Aerostatic Lift Systems

These systems expand on the lift systems described on pp. VE40-41.

2D Thrust Vectoring (TL7)

2D vectored thrust (as used on aircraft like the F-22 Raptor and F-35 JSF) enables the engine nozzles to swivel up or down, improving maneuverability and lowering stall speed and take off run length for airplanes, but without

Extra Detail – Vectored Thrust with Coupled Lift Fan

A turbofan, hyperfan, or super turbofan jet engine may be designed with an engine-coupled lift fan. The fan augments vectored thrust for takeoff and landings, but not for maneuvers while in flight. An example of an aircraft using this mechanism is the F-35 Joint Strike Fighter.

To design an engine-coupled lift fan, give the aircraft a jet engine with 2D vectored thrust, and then install a lift fan (p. VE40) and MMR rotor drivetrain (p. VE34), both rated for (jet engine thrust)/7.5 kW each. The combination increases the thrust of the engine by 40% for vertical takeoff and landing only. The advantage is that the exhaust temperature is significantly cooler than a single turbofan with full thrust directed downwards, and will not melt asphalt or require specially prepared flight decks. While an afterburner can be mounted in the jet engine, this does not boost the power of the lift fan, and will cause an immediate loss of control and a crash if both are used simultaneously.

actually permitting true vertical takeoff, landing, or hovering. It is a cheaper and lighter alternative to full vectored thrust.

An aircraft may use 2D vectored thrust to perform some of the abilities described under *Vehicles with Vectored Thrust or No Stall Speed* (see p. VE156). It may increase or decrease altitude and can trade acceleration to reduce stall speed. Each 2 mph/s of acceleration not used in a turn allows the vehicle to reduce stall speed by 5%, to a maximum of -50% to stall speed. Giving a reaction engine 2D vectored thrust multiplies its cost and weight by 1.2. This is not compatible with vectored thrust.

Gravity Screen

A gravity screen is a chemical substance or a mechanical or electromagnetic process that insulates against gravity. Placed between two masses, it lessens their gravitational effect on each other, by analogy to the way an electrical insulator lessens electrical force between two charged surfaces. The effectiveness of a chemical substance depends on its purity, but purer material is also much more expensive; similarly, the power consumption of a mechanical screen (supplied by clockwork or steam) or an electromagnetic field (supplied by batteries) increases sharply with effectiveness.

The standard version is a weird science product of divergent technology, and becomes available at TL(5+1). Superscience versions may also exist at TL12 and higher. The latter devices may use rapidly circulating hyperdense masses or electrons circulating in a superconducting loop.

Divergent Technology – Lifting Gas

The puny lift of hydrogen will never do for the aerial fortress of the fiendish Dr. Abdul Khan! These divergent technology options can replace ordinary lighter-than-air gas in a gas bag (p. VE40).

Vacuum Balloons (TL(4+4)): A balloon filled with vacuum would lift slightly better than hydrogen (13.6 cf per lb. of lift). This is treated as lifting gas (p. VE40) except that it must go in a sealed body or pod, not in a gasbag subassembly. A container full of vacuum has to be fairly strong or it will be crushed by the air pressure. Under 1 bar pressure this requires DR12 (×4 if extra light frame, ×2 if light, ×0.5 if heavy, ×0.25 if extra heavy). A serious drawback to a vacuum balloon is the risk of implosion. If any hit penetrates the DR of the body or subassembly containing the balloon, it implodes and is destroyed.

Antigravity Gases (TL(5+1)): These weird-science gases provide lift beyond that possible for buoyancy alone. The least farfetched provide the same lift as vacuum, but most are better than that; 10 times the lift of hydrogen (1.48 cf/lb.) is typical. Cost and origin are up to the GM, but most are either cheap (so our heroes can afford them) or easily made (so they can be whipped up from the materials available in Darkest Africa). Destructive distillation of some natural antigravity material is a logical source, but exposure to radioactivity and the action of acid on "unobtainium" metal are also popular. And if the fiendish doctor's flying fortress is lifted by gases exhaled by small children who have had a lethal dose of radium blown into their lungs, it's unlikely that particular bit of world-altering technology will be widely distributed.

Gravity Screen Table

Weight Reduction	Cost per sf	Power per sf
10%	$11.20	0.11 kW
20%	$25	0.20 kW
30%	$42.80	0.43 kW
40%	$66.60	0.67 kW
50%	$100	1 kW
60%	$150	1.5 kW
70%	$233.40	2.3 kW
80%	$400	4 kW
90%	$900	9 kW
95%	$1,900	19 kW
99%	$9,900	99 kW
99.9%	$99,900	999 kW

An object with reduced weight also has lower escape velocity, equal (on Earth) to 25,200 mph multiplied by the square root of (1-weight reduction fraction). For example, 99% weight reduction (weight reduction fraction of 0.99) lowers escape velocity to 2,520 mph.

Gravitic Balloons

One of the most effective uses of this gravity screen technology applies it to a relatively small mass. If the outer wall of a gasbag is coated with a gravity screen – such as a paint made from some exotic chemical or a metal foil to carry some electromagnetic influence – the weight of the air it contains is decreased, making it lighter than air!

The resulting aerostatic lift can be calculated as follows:

Volume = 13.6/(Weight Reduction Fraction)

Volume in this calculation is the cubic feet of air needed to lift 1 lb. at sea level. For example, a 99% gravity screen gives a weight reduction fraction of 0.99; a volume of 13.7 cf of air (13.6/0.99) lifts 1 lb., producing greater lift than hydrogen. Cost for such a balloon is the cost of the gravity screen based on the surface area of the gasbag plus 50% of the per-flight cost of hot air. Since the "lifting gas" is ordinary air, gravitic balloons have smaller crew requirements: 1 crewman per 1,000,000 cf of air volume.

Any solid structures within the gravity screen have reduced weight, and thus are easier to lift! However, use the unmodified weight to calculate acceleration, which is based on inertia rather than gravity.

Negative Mass (TL(5+1))

This is an exotic "weird science" natural or synthetic material that has negative mass – where objects with positive mass attract each other, a negative mass repels and is repelled by any normal object. (Presumably, such objects attract each other, or they would break apart into microscopic fragments over time.) Objects with negative mass are unlikely to occur naturally on any planet, or even in the solar system; their natural tendency is to drift into interstellar space, although they might also exist in other dimensions.

Assume that 1 cubic foot of solid matter with negative mass, whether a rare natural deposit or newly synthesized by advanced technology, weighs -100 lbs. It provides 100 lbs. of lift force for any vehicle that contains it, and costs $40,000. GMs can assume any density they like for negative-mass matter, but the cost per pound should remain roughly the same. A negative mass can be surrounded by a gravity screen, if both sorts of material are possible in a particular universe. The gravity screen reduces the lift from the negative mass. For example, a -1,000-lb. mass surrounded by a 50% screen weighs -500 lbs.

Superscience Alternatives to Contragravity Lift

Psionic Levitation (TL9): A vehicle with the Robotic structure option and a psionic computer (p. P62) may be able to psionically levitate. The standard rules require a fairly light vehicle, since the maximum power allowed (25) lifts only 5,250 lbs. A kinetic bubble (TL10, p. P68) increases that by a factor of 10, but at 0.01 lb. and $750 per cf is very expensive.

Magnetic Planetary Lifter (TL(7+4)): This is identical to a Magnetic Planetary Drive (p. 11) but only provides static lift, not thrust. A different drive is needed for propulsion.

Repulsion Lift (TL12): This is a hover system extrapolated from tractor/presser beam technology. Standard repulsion lift craft float 1 yard off the ground; for other heights multiply weight and power consumption by the ceiling in yards. While they have no effect on performance, repulsion lift units may, optionally, exert a ground pressure of [lift/(vehicle surface area/10)]. This displaces water to a depth of 1 inch per 5 lb./sf, leaving a wake, and can damage things the repulsion lift craft overruns.

Alternate Contragravity Table

TL	Type	Weight	Cost	Power
(7+4)	MPL	(0.026 × thrust)	0.1	$500
12	RL	(lift/2,000)+20	(lift/1,000)+40	0.025 kW

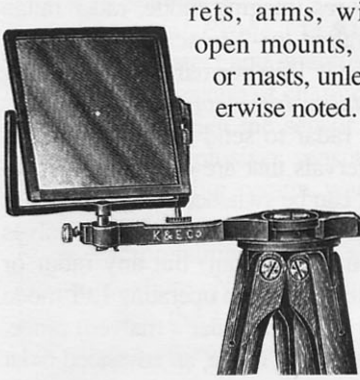
Weight, cost, and power are per pound of lift.

Other Components 3

This chapter describes other equipment that can be installed in a vehicle. It expands upon the components detailed in Chapters 4 through 8 of ***GURPS Vehicles,*** particularly sensors, power plants, and force fields.

Instruments and Electronics

A wide variety of gadgets can be installed in a vehicle for communication, navigation, and other purposes. Equipment in this section can be installed in the body, superstructures, pods, turrets, arms, wings, open mounts, legs, or masts, unless otherwise noted.



Pre-Radio Communications

These options are also available for pre-radio communications (p. VE47):

Mechanical Semaphore (late TL4): A pair of movable pointers mounted on a mast can be used to send any hand semaphore alphabet. Naked eye visibility is a mile. Transmission rate is operator's (Telegraphy skill -4) symbols/minute. Systems using single pointers, rotating colored disks, shutter arrangements, or more than two arms perform similarly, but don't use hand semaphore codes.

Heliograph (TL5): A heliograph consists of a mirror and a sighting device. Slight movements of the mirror send a pulse code by moving a reflected beam on or off the target. Only the target can read the signal properly, and messages can only be sent from a stable platform, not a ship or a moving vehicle, unless the heliograph is equipped with TL7+ Full Stabilization (p. VE45). Signal rate is (4 × Telegraphy skill) characters per minute. Range is limited by line of sight, and also depends on the light source; sunlight gives a maximum range of 30 miles and moonlight is 5 miles. If artificial sources are attached to the heliograph, range will vary depending on the light's intensity. Larger mirrors have better ranges, but may be slower – at one extreme, a square-mile lightsail in Earth orbit should be visible at 10 AU, and might send a few characters per hour.

Shape Telegraph (TL5): The standard Redl's Cone Telegraph consists of a mast with four fabric cones which can be opened like umbrellas. The 16 open and closed combinations are used to send coded signals. Variants may use different shapes or combinations, although symmetrical shapes are preferred, to ensure legibility when viewed from any direction. Signal rate is slow: 6 code groups per minute. Naked-eye visibility is 3 miles.

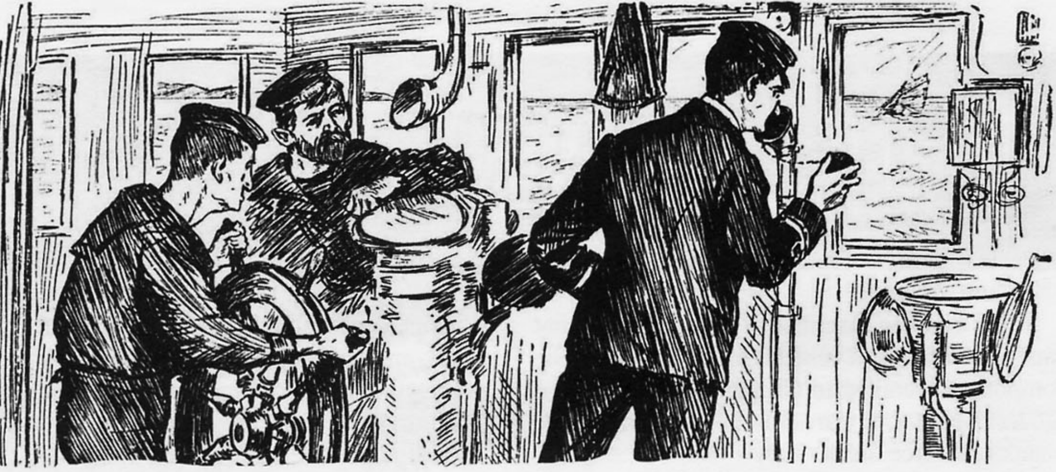
Light Telegraph (TL5): This is a shape telegraph with colored lamps replacing the shapes. Early systems changed signals by running up new lamps (0.5 characters per minute), but shutters (1.5 characters per minute) or electrical switches (60 characters per minute) are much faster. Naked eye range is 3 miles for typical systems – beyond that the lamps are too close to reliably make out signals.

Signal Lamp (TL5): This lamp (limelight or electrical) is fitted with a shutter allowing it to be used for Morse code. Effective range is 15 miles (or line of sight), and (4 × Telegraphy skill) characters can be sent per minute. Searchlights can be fitted with shutters for $50, and used as signal lamps at 20 × their range.

Early Communications Table

TL	*Type*	*Weight*	*Cost*	*Power*
4	Mechanical Semaphore	200	$500	0
5	Heliograph	15	$250	0
5	Shape Telegraph	200	$500	0
5	Light Telegraph	140	$800	neg.
5	Signal Lamp, limelight	175	$300	0
5	Signal Lamp, electric	30	$100	neg.

Location: Mechanical semaphores, light or shape telegraphs require a mast, which cannot be used for sailing at the same time as when signaling.



Sound Communications

Megaphone (TL2): These focus sound in a particular direction, doubling its range along that line. They are sometimes fixed to ship's rails or used in security vehicles.

Whistle or Foghorn (TL5): Any vehicle with a steam or combustion power plant may install a powered whistle or horn. It can be audible at 10 miles over normal backgrounds and can send a pulse code at (Telegraphy skill) characters per minute. At TL7+ any vehicle with a power plant can be equipped with an electrical version with equal performance.

Voicetubes (TL5): This system of speaking tubes is used to carry sound between key areas of a large vehicle. Any vehicle with mechanical controls may have them for free; otherwise they cost $20 per station so equipped.

Intercom (TL6): The electrical equivalent of voice tubes, using telephone gear at TL6, and later anything from coaxial cable to microwave guides to fiber optics. Intercoms are free to vehicles with electronic or computer controls; otherwise, they cost $50 per station. For an extra $1,000, the necessary switches can be installed to allow several point-to-point conversations at once, and to selectively route general announcements.

Speaker (TL7): An electronic sound generator usable as a public address system, to play music, or just function as a whistle or horn, though it isn't as loud as a dedicated device. Double cost if the speaker can also generate infrasonic or ultrasonic sounds.

Sound Communications Table

TL	Type	Weight	Volume	Cost	Power
2	Megaphone	5	0.1	$50	0
5	Whistle or Foghorn	30	0.6	$100	neg.
7	Electric Horn	2	0.4	$50	neg.
7	Speaker	2	0.4	$450	neg.

Halve speaker weight, volume, and cost at TL8, and again at TL9+.

Radar and Ladar

Two additional options are available for radar and ladar systems (pp. VE51-52):

Multimode Radar (late TL7): This option allows the radar to switch between search radar mode, low-res imaging, and high-res imaging. Switching modes can be performed at the start of any turn. In low-res imaging mode, radar range is halved (equivalent to -2 to scan). In high-res mode, radar range is 1/50 normal (-10 to scan).

Low Probability Intercept (LPI, late TL7): This allows the radar to send out pulses at frequencies and intervals that are especially hard to detect. The radar can be switched to LPI mode (or back) at the start of any turn. LPI mode halves range (equivalent to -2 Scan) but any radar or radar/laser detectors detect an operating LPI-mode radar at only 1.5 times the radar's (halved) range. In addition, when in LPI mode, an advanced radar or radar/laser detectors cannot determine the radar's bearing or perform transmission profiling unless they are of *higher* TL than the LPI radar.

Radar Table

Options	Weight	Volume	Cost	Power
Multimode Radar	×1.5	×1.5	×5	×1
Low Prob. Intercept	×1	×1	×2*	×1

* ×1 with TL8+ multimode radar and AESA.

Scientific Sensors

These sensors are primarily used by probes and survey craft. Operation is typically automated, although complex surveys may require Electronics Operation (Sensors) rolls. Rolls against a science skill (or occasionally another skill such as Prospecting or NBC Warfare) may also be necessary to interpret the data. Unless otherwise noted, a sample must be in contact with the sensor (robot arms are useful for transferring solid samples to a sensor) and at least 10 minutes will be required for a sensor reading.

Meteorology Station (TL5): A weather station able to measure temperature, air pressure, wind speed and direction, water vapor levels, and other conditions. Use Meteorology skill to analyze data.

Basic Radiation Sensor (TL6): This detects radiation intensity in millirads at the location of the sensor. No skill is required to use the sensor or to interpret its data, and it provides immediate results.

Advanced Radiation Sensor (TL7): A more sophisticated radiation sensor, it measures radiation and electrical and magnetic fields. It can determine the bearing and approximate range of a source and, with a successful Physics skill roll, can give some idea of the source's nature; e.g., the identity of the radioactive elements that are decaying, the size and strength of a field source, or the energy content of a solar flare or plasma. Treat it as a radscanner with Scan 15 for purpose of detecting plasma discharges from fusion rockets, plasma guns, etc.

Chemical Probe (TL6): An instrument designed to detect and quantify a specific chemical or related group of chemicals; the type must be specified when the sensor is designed. This could be an explosives sensor, smoke detector, nerve gas warning system, water vapor detector, engine pollution emissions monitor, etc. At TL6, interpretation requires a Chemistry or (in some situations) NBC Warfare skill roll. At TL7 and higher, the systems are digital and basic warnings ("nerve gas present!") will not require skill rolls.

Chemical Sensor Array (TL7): This is able to distinguish a wide range of volatile chemicals. Various uses include atmosphere testing, water testing, detection of drugs or explosives, sorting of plants (by smell), or providing a robot with taste and smell, giving it the equivalent of the Discriminatory Taste and Discriminatory Smell advantages. At TL8 and up, sensor-on-a-chip devices reduce the system's weight dramatically.

Laser Chemscanner (TL8): Chemicals absorb laser energy at specific known wavelengths. This device can detect chemical compounds in the air as well as surface contaminants, such as a slick of chemicals coating an object or the ground. It is most often used to identify chemical weapons or pollution levels in the atmosphere. Unlike most scientific sensors, it functions at range and can provide immediate results. A standard model has a base range of 1,000 yards.

Geology Survey Array (TL7): A set of instruments for determining the composition and nature of soil, dust, or ore samples. Detailed analysis, e.g., the commercial potential of an ore deposit or the likely fertility of a soil, requires contact with the sample. The array can also determine a sample's age (by isotope dating) and weathering.

Magnetometer (TL7): This precisely measures local magnetic fields. It can be used to map a world's magnetosphere, to measure the paleomagnetic field locked in rocks, and to serve as a short-range (1 yard) metal detector. Use as anything other than a compass or metal detector requires a Geology roll to interpret the results.

Seismology Package (TL7): An instrument that detects and measures ground vibrations from earthquakes, nuclear detonations, nearby conventional explosions, etc. By measuring how vibrations travel through the ground after an explosion or earth tremor, a seismology package can probe the local geology within a few miles of the epicenter. This allows the sensor operator to discover data such as the location of subterranean fault lines, caves, and mine shafts on a successful Geology skill roll.

Major earthquakes or nuclear explosions can be studied to obtain data on the interior structure of an entire planet. A seismology package's seismometer must be stationary and in good contact with the ground in order to perform its functions.

Scientific Sensors Table

TL	*Type*	*Weight*	*Volume*	*Cost*	*Power*
5	Meteorology Instruments	40	2	$500	0.02
7+	Meteorology Instruments	5	0.1	$20,000	neg.
6	Basic Radiation Sensor	2	0.04	$100	neg.
7	Advanced Radiation Sensor	100	2	$50,000	0.05
6	Chemical Probe	1	0.02	$100	neg.
7	Chemical Sensor Array	10	0.2	$20,000	0.02
8	Chemical Sensor Array	1	0.02	$8,000	neg.
8	Laser Chemscanner	4	0.08	$2,000	neg.
7	Geology Array	250	5	$750,000	1
7	Magnetometer	5	0.1	$5,000	neg.
7	Seismology Package	50	1	$20,000	neg.
7	Life Detection Package	35	1	$50,000	0.05

Weight, volume, and cost halve one TL after the device last appears on the table, and halve again a TL later. Laser chemscanner is per 1,000 yards range.

Life Detection Package (TL7): A set of experiments designed to detect microbial life, usually used by planetary probes. It usually does not work if the life forms or the planetary soil, atmosphere, or hydrology are very different than the package designers expected; at best, such unexpected conditions require a Xenobiology roll to interpret.

T-Ray Imaging (TL8)

A *T-ray Imager* is a terahertz (0.3 mm) spectroscopic radar. T-rays can image objects (living or unliving) behind a few millimeters of metal or several inches of nonconductive material, and on a successful "identification" result can determine chemical compositions, identifying the main compounds in objects as small as a cubic inch. They can scan life forms like any other object, and identify large ones by shape and anatomy. Treat a T-ray imager as a chemscanner (p. VE54) but available one TL earlier, with 100 times the weight and cost, and with the limitations described above.

Exotic Sensors

Orgone Scope (TL(6+2)): This is a weird-science device. It operates in a manner similar to radar, but sends out waves of "orgone radiation," a form of fictional radiation that is reflected by the life force of living things. Nonliving items (and some alien races) do not register, while something as large as a whale produces a blip like the radar return of a small ship. An orgone scope can see through solid rock, though it may be blocked by the horizon on a life-bearing world (by the plants on the surface and bio-organisms in the soil, rather than by the ground itself). An orgone scope has the same range, Scan, weight, cost, volume, and power consumption as a radar of the same TL – see *Radar*, pp. VE51-52. Orgone scopes may also have any radar options other than Ladar and AESA.

Ultrascanner (TL10): A superscience sensor that is able to scan the interior of an object and produce a 3D model of it. It is sometimes known as a xadar, deep radar, or imaging gravscanner. The target must be visible or be detected first by another sensor. Producing a blueprint-quality model requires the complete attention of the operator for 1 second per 30 cf of volume scanned and an additional Sensor Operation roll; otherwise resolution is equivalent to multiscanners, but ignoring any penalties for sealed containers or cover. Use the rules for multiscanners in chemscanner mode, except each foot of solid material scanned through counts as a mile of range, and force screens block the beam entirely.

FTL Effect Sensors: A variety of sensors related to FTL drives may exist; their functionality depends on the exact nature of stardrive used in the campaign. In general, design them as a PESA but read the range in light-seconds or AUs rather than miles. Some suggested types are described on p. S30 (point detectors, FTL scan detectors, hyperspace emergence detectors and hyperdrive wake detectors) and others are possible.

Other Sensors Table

TL	*Type*	*Weight*	*Volume*	*Cost*	*Power*
10	Ultrascanner	20	0.4	$25,000	100
11	Ultrascanner	5	0.1	$10,000	25
12+	Ultrascanner	1	0.02	$2,000	5

Miscellaneous Equipment

These are various items that can be installed in a vehicle. They all count as "miscellaneous equipment" for purposes of hit location rolls.

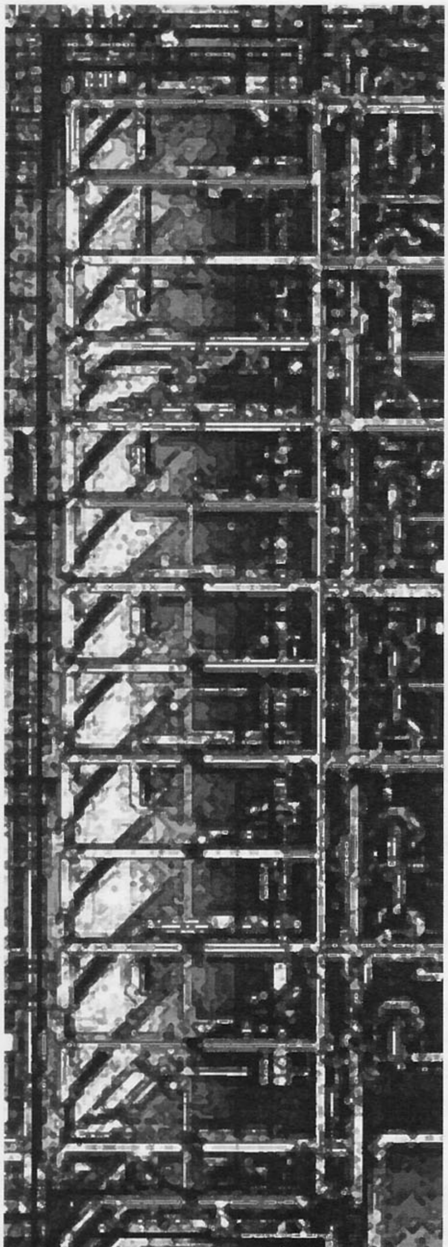
Towed Signs

Aircraft sometimes tow large fabric or plastic advertising signs. A typical sign (legible at a couple of miles) is 20 lbs., costs $20, and adds 20 to Aerodynamic Drag per letter. An aircraft needs a hardpoint that can support the weight, should recalculate performance with the added drag, and suffers a -2 to aSR while towing the sign.

External Impact Absorbers (TL7)

These externally mounted shock absorbers, airbags, or crushable frame sections reduce the severity of impacts to the vehicle (rather than just to its occupants). They must be installed on a specific face of the vehicle, and lower the effective velocity of collisions against that side. Among their uses is cushioning the impact of hard-landing space probes or drop capsules on worlds that lack much in the way of atmosphere.

Select a weight; volume is negligible (often part of the frame) and cost is $50 per pound if the system is single-use, $100 per pound if reusable. Performance is calculated after the vehicle's loaded weight (Lwt.) is determined. The speed of any collision is reduced by 100 mph × square root of (absorber mass/Lwt.) for reusable impact absorbers, 400 mph × the square root of (absorber mass/Lwt.) if the absorber is a single-use system.



Fuel Transfer and Processing

Alcohol Still (TL3): A fermentation vat and distillation column that is able to produce fuel alcohol (p. VE90). Fermentation takes a week and consumes 25 lbs. of grain or 100 lbs. of fruit per gallon of fuel produced. Statistics are per gallon produced per week. Power consumption is in gallons of alcohol for the distillation process, but solid fuels are often used instead. 1 cf of coal is equivalent to 8 gallons of alcohol for this purpose.

Metal Oxide Reduction Plant (TL7): This device converts sand, lunar dust, crushed asteroid, or other rocky material into Metal/LOX fuel (p. VE90). The process varies from complicated chemical cycles to simple brute-force electrolysis of molten rock. Decide on the weight of raw material processed per hour; each pound produces 0.075 gallons of Metal/LOX fuel.

Fissionables Processor (TL8): This device concentrates fissionable ores, usually by chemical reaction and electrolysis. Decide on the weight of ore processed per hour; a high-grade ore might produce 1-2% weight of fissionables. At double weight, volume, and cost, the processor can produce fuel pellets suitable for reloading fuel rods, nuclear pulse drives, or gas core fission rockets, although actually loading either under field conditions presents a major radiation hazard. Assume each kW-year requires about 0.05 lbs. of refined fissionables.

Antimatter Converter (TL14): This uses exotic total conversion technology (the same process as antimatter generation under time reversal) to convert matter into an equal mass of antimatter. It is rated for micrograms produced per hour.

Fuel Telegate (TL16): A teleport system linking the vehicle to a fuel source elsewhere – such as a huge fixed fuel tank, the atmosphere of a gas giant, or another dimension filled with hydrogen. This is particularly valuable for spacecraft, allowing reaction drives to avoid issues like mass ratio and tank weight and obtain a degree of performance normally restricted to reactionless propulsion systems. Range depends on teleport technology: it could be local, interstellar, or even extra-dimensional.

Fuel Accessory Table

TL	*Type*	*Weight*	*Volume*	*Cost*	*Power/Fuel*
5-	Still	50	2	$10	0.5 Al
6	Still	30	2	$20	0.3 Al
7+	Still	20	2	$50	0.2 Al
7	Metal Oxide Reduction Plant	1,500*	30*	$5,000*	25*
8	Fissionables Processor	1,500*	30*	$8,000*	25*
14	Antimatter Converter	0.25!	0.005!	$7.5!	0
16	Fuel Telegate	0.00002#	0.0000004#	$0.1#	0.0001#

* per pound of raw material processed per hour.
# per gallon/hour it can supply
! per microgram per hour.

Weight, cost, and volume of metal-oxide reduction plant, fissionables processor, and antimatter converter are halved one TL after they first appear, and halved again a TL later.

Force Screens

These alternate rules provide flexibility for the creation of superscience force screens of all types and sizes. Some ultra-tech cultures may even replace "material" technology with fields of force.

Decide if the vehicle will mount a force field grid or a force field generator. A force field grid is designed as a surface feature, after the vehicle's surface area is known. A field generator is an item of miscellaneous equipment installed in the vehicle's body or any structural subassembly. At the GM's option, a particular campaign setting might have only force field grids or only force field generators, rather than allowing both to exist.

Grid

The screen is a grid built into the vehicle's surface. Use the weight, cost, and power values on p. VE93. The screen will normally be a form-fitting design that follows the vehicle's shape.

Generator

The screen is a generator internal to the vehicle. The default screen it produces is normally a bubble that surrounds the vehicle, but other types of screen are possible. This type is much more versatile, although it has the disadvantage that it occupies volume inside the vehicle, rather than being built into a surface grid. The screen uses the rules for force field grids (p. VE93 and above), with these exceptions:

To design a screen generator, select a Force Screen Rating (FSR) which directly determines the longest dimension of the screen (in yards) and, by formula, sets its DR (which varies by TL). At TL11, force screens have a minimum FSR of 100; at TL12, minimum FSR is 10; at TL and above, minimum FSR is 1. The minimum does not apply to screens given the Deflector option. The longest dimension of the screen cannot exceed FSR yards. Screens may protect less area, if desired, but do not gain any benefit from doing so. Larger areas may be protected by multiple screens. A force screen cannot be projected *through* another force screen, but it may be projected *around* another screen.

Weight, Volume, and Cost: The base weight of a screen generator is (FSR squared) if FSR is less than 10; otherwise it is (FSR cubed)/10. Volume is weight/20 cf, cost is $500 per pound of screen weight. Power is 5 kW per pound of screen weight.

Screen DR: A screen's DR is FSR × T, where *T* is 50 at TL11, 75 at TL12, 100 at TL13, 150 at TL14, 200 at TL15, or 250 at TL16.

Screen Options

A screen with no options functions exactly as described on p. VE93. However, any of the Geometry Options (generator only, below), Defense Options (below), Overload Options (p. 21), or Other Options (pp. 22-23) may be added to the screen, modifying its final weight, cost, and power, as well as the way it functions.

In many settings, some or all of these options will not exist; in others, some of them might be required by the nature of force field physics in a particular setting. For example, the GM could decide that the *only* possible force field systems in the campaign world are force field generators with the energy-absorbing and explosive options.

Geometry Options

These options alter the shape of the force screen. They are mutually incompatible.

Flat (Generator Only): Projects a flat wall, up to FSR yards across. The wall can be projected up to FSR yards from the generator. Halve weight, cost, and power requirement.

Internal (Generator Only): The screen forms in a space between separated generator nodes; the generators are outside of the field. This is often used for doorways. Halve the weight, cost, and power requirement.

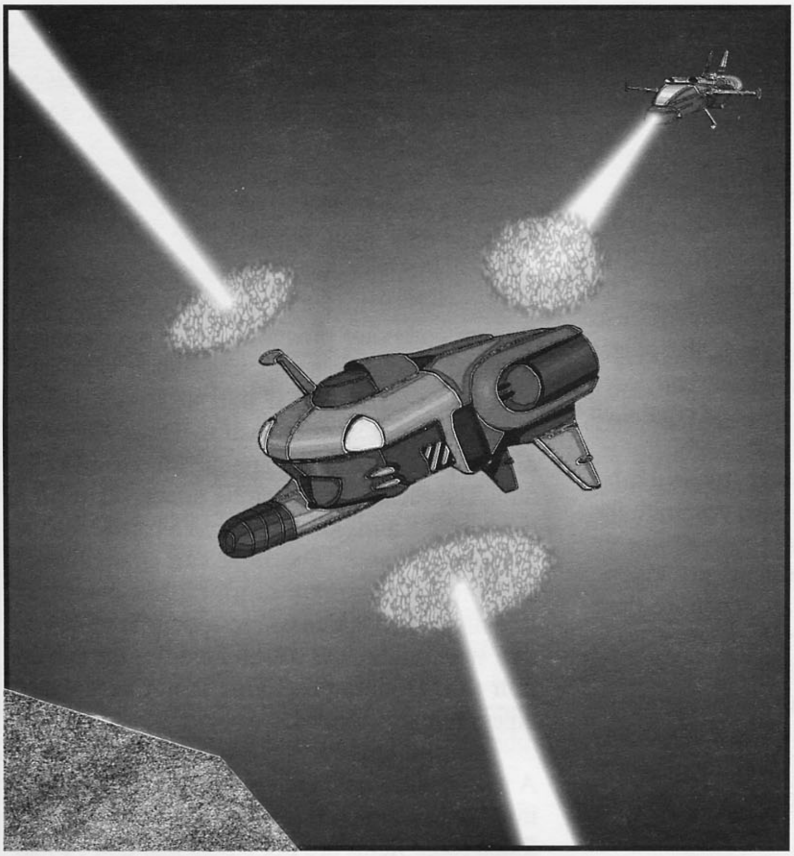
Defense Options

Standard force screens protect against attacks from outside the screen, but have no effect on anything exiting the screen. They can be penetrated at low velocities, allowing someone to walk through a screen, or the osmotic passage of gases. However, many other variations are possible. Defense options are mutually incompatible.

Barrier: This stops people from attacking into or out of a screen. Multiply DR by 1.5 if the screen also has the energy screen or kinetic screen option, otherwise multiply by 2.

Deflector Screen, PD 6 (Generator only; for grids, see p. VE93): Has no DR, but PD 6. Not compatible with any option that modifies DR, including reduced DR.

Deflector Screen, PD 8 (Generator only; for grids, see p. VE93): as above, but PD 8.



weight, cost, and power by 1.25 in addition to modifiers for deflector. Not compatible with any option that modifies DR, including reduced DR.

Overload Options

Science fiction force screens vary considerably in how, or if, they overload. It's rare to have more than a few types of variants in any given setting. Common overload options are:

Explosive: The screen explodes catastrophically on overload. Blast damage is 1d per kilowatt of power the screen required. Halve weight and cost.

Fast Recovery: Sheds one lost energy level per turn (or if a hit point-based screen, recovers 10% per turn). The screen has 2/3 normal DR.

Fragile: If penetrated, screen is overloaded immediately, destroying the generator. Multiply DR by 1.25.

Heavy-Duty: If overloaded, screen goes down until it has time to recover an energy level, then comes back up, rather than being destroyed. Not compatible with Explosive. Double weight and cost.

Hit Point-Based: The screen does not lose energy levels; instead it loses hit points. It has hit points equal to 5 × its (modified) DR. The vehicle protected does not take damage until the screen's hit points are reduced to 0; excess damage affects the vehicle. Regenerates hit points at 1% per turn; screen is considered to "overload" if all hit points are lost. Multiply DR by 0.4.

No Overload (Grid Only): The screen never overloads. Not compatible with other overload options. Multiply DR by 0.5.

Segmented: The screen has six sides, which overload *separately*. Double weight, cost, and power consumption. For an additional doubling of cost, you may increase the DR of one face by up to 50% by reducing the DR of all other faces by the same amount.

Slow Recovery: Regains lost energy levels (or hit points) at 1/6 normal rate (1 level per minute). Halve weight and cost; divide power consumption by 5.

4 × weight, cost, power consumption. Not compatible with any option that modifies DR, including reduced DR.

Portal: A portal screen is like a barrier screen, but the user can open holes in the screen to fire through (or attack out of with a thrusting hand weapon). Holes in the screen last for one turn. An attacker can shoot (or thrust) through a hole, thus bypassing the screen, but takes a -10 penalty to hit. Multiply DR by 1.25.

Tunable: A tunable screen is like a barrier screen, but the user can tune it to permit specific frequencies of energy to pass through. This allows the screen to be transparent to a particular beam type (e.g., X-ray laser, ultraviolet laser, particle beam, etc.). This can be changed each turn. Increase DR by 100% if the screen frequency cannot be changed in combat, 50% if it can change quickly. If the firer can determine the current setting of a screen and has a weapon capable of changing frequency (such as a rainbow laser), he can fire right through it from outside; this requires an Electronics Operation (Sensors) roll at -5 (required each turn if the screen can change quickly).

Shield, PD 6 or PD 8 (Generator only): As PD 6 or PD 8 deflector, but also allows a block defense equal to 1/2 of the operator's Gunner (Force Screen) skill vs. one attack/turn. Multiply

Other Options

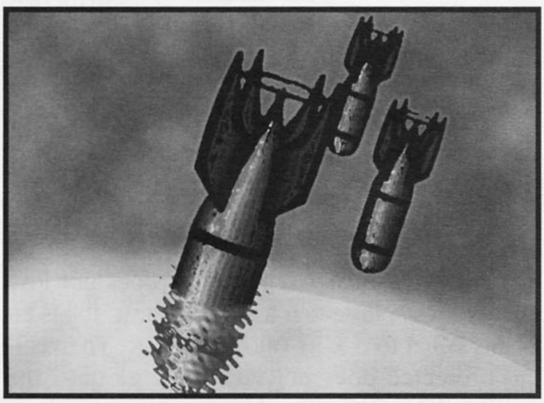
Atmosphere-Limited: The screen only works in an atmosphere, or only in vacuum. Multiply DR by 1.2 (or, if Deflector, add +1 to PD).

Cheap: Double weight, halve cost.

Compact: Halve weight, double cost.

Cutting (Generator Only): Normally, when a screen forms in a way that intersects a solid object, there is a hole in the screen until the object is removed. A cutting screen will instead attempt to chop through that object; the object takes 1d(5) per DR 50 of the barrier, and loses DR 1 per die of damage. This damage continues until the object is removed or cut through.

Disintegration: These screens work by destroying objects before they can penetrate the screen. They are thus ineffective against energy weapons; assume they will destroy any kinetic weapon whose damage fails to penetrate their DR. Any object touching the screen takes 1d(5) per DR 25 of screen; for large objects, damage is applied per hex. A disintegrator screen gains an energy level if more than 10% of its surface is in contact with another object. Power requirement is doubled. Disintegrator screens must also be barrier screens.



Energy Screen: This screen has full effect against lasers, disrupters, paralysis beams, neural weapons, X-ray lasers, grasers, disintegrators, and any other weapons which use electromagnetic energy. Halve DR vs. particle beams and antiparticle or pulsar weapons, but ignore the armor divisor for an antiparticle or pulsar weapon. There is no effect vs. other weapons. DR is doubled (or if a deflector, add +1 to PD).

Energy-Absorbing Screen: This screen also absorbs power when hit by attacks, which can be used to recharge a vehicle's energy banks or fed directly to systems that require electrical power. If used as a solar collector, it constantly absorbs (FSR squared) kilowatts. On any turn it discharges an energy level, it produces 0.001 × (DR squared) kilowatts power. It cannot discharge unless the absorbed power is drained into an energy bank or used to power another energy-using system. This option is often combined with the explosive overload option (p. 21). 2 × weight and cost, 1/10 power requirement;

Flicker: A flicker screen turns on and off rapidly, and thus might not stop any given attack. It is normally assumed that weapons fired from within the field if directed by a Targeting or Gunner computer program can be synchronized with the field's flickering, and thus it is possible to fire out normally; if not, treat as a barrier screen. It has a chance equal to TL or less on 3d of stopping any given attack. Increase DR by 50%.The flicker effect can be turned on or off at the start of a turn; if off, it acts as a barrier screen.

Holographic: The field can change color, allowing it to create holographic disguises. Requires a perception roll to spot as fake; if built as a stealth field, the stealth modifies the perception roll. Double cost. This is not very useful unless it is also shaped.

Holoventure Field (Generator Only; TL13): A holoventure field creates a virtual reality within its area composed of solid force field objects. Since force fields are not edible and don't usually have a smell, it also includes total life support. 20 × weight, 50 × cost, 4 × power, has life support for 1 person per 400 kW power. Normally built into a hall; per hall unit (15,000 cf) it is 2,000 lbs., $2.5 million, 2 MW, and has life support for 5 people. Force objects have a ST of (TL-11) × 5 and a DR of (TL-11) × 15, both multiplied by size in hexes; an object that takes enough damage to penetrate its DR winks out, but can be recreated the next turn.

Impermeable: An impermeable screen stops gases, but can still be walked though at low speed. Increase cost by 20%.

Invisible: The screen does not change color when it gains energy levels; no effect on cost, etc., but the GM may rule that this option is not available.

Kinetic Screen: The reverse of an energy screen. It has full effect against explosions, guns, fire, flamers, stunners, screamers, plasma weapons, gravitic weapons, and fusion weapons. However, it provides no defense against lasers, X-ray lasers, grasers, or particle beams, antiparticle/pulsar weapons, or disintegrators. +50% to DR.

Manipulator (Generator Only; TL13): A manipulator field may be used to form force limbs which can move objects about. ST is FSR × (TL-11) × 10; reduced DR shields have the same reduction in ST. Manipulator fields

must have the shaped and either barrier or shield options. Double cost and weight. For an additional doubling in cost, the field can form cutting claws, which do swing/cut or thrust/impale with an armor divisor of 5.

Opaque: An opaque screen blocks any attempt to see through the screen. Normal sensors cannot penetrate the screen; sensors which can penetrate walls go through the screen as if it were a wall of equivalent DR. If the screen blocks vision into but not out of the field, add +100% to weight, cost, and power. If the screen blocks vision both into and out of the field, add +50% to weight, cost, and power.

Projection (Generator Only): The field can be projected to surround other objects. For double cost, weight, and power consumption, the field can be projected (FSR) yards away; each additional doubling multiplies range by 10. A projection screen can be set to keep things in, rather than out, if desired.

Proportional: A proportional screen lets a fraction of the damage through. Multiply DR by 1.5 if 1/10 of damage gets through, by 2 if 1/5 gets through, by 3 if 1/3 gets through, and by 5 if 1/2 gets through.

Reduced DR (Generator Only): It has only 10%-99% of the normal DR that its FSR would otherwise provide. Multiply cost, weight, and power use by the same percentage.

Reflector: If the screen successfully stops an attack, the attack is sent back in the direction it came from. This generally hits the attacker if he is using a beam weapon or is within half damage range. The GM may rule otherwise in the case of rapidly moving vehicles, as the attack will be reflected to where the attacker was when he fired the weapon. Double weight, cost, power consumption.

Shaped (Generator Only; TL13): The field can be reshaped into a variety of forms, provided the total area of the screen does not exceed the normal size limit. For double cost and weight, only simple shapes may be formed (this is sufficient to give the equivalent of superior streamlining, fine hydrodynamic lines, or submarine lines). For triple normal cost and weight, complex shapes may be formed (almost any shape, though complex shapes may take a while to program in).

Stealth: As an opaque screen, but the screen itself is nearly invisible, subtracting (TL-4) × 2 from all sensor rolls to detect it. As opaque, but add a further 100% to base weight, cost, and power. A stealth screen may be detected if it occludes other objects.

Crew and Passengers

Two alternatives to conventional crews or robotic vehicles are found below.

Remote Control

A remote control vehicle is not necessarily a robot. Remotely piloted vehicles are available as early as TL6, and can be as simple as a radio-controlled model aircraft or car.

To build a remote control vehicle, install mechanical, electronic, or computerized controls, but don't place crew stations aboard. Instead, install one communicator (radio, laser, neutrino, etc.) per crew station that the vehicle would require, and place the actual stations and the same number of communicators somewhere else. If a vehicle has mechanical controls, it may only be remotely controlled by TL6 simple remote control.

Vehicle operation skills used through a remote control link normally suffer a -1 (or greater) *telepresence penalty* representing the difficulty of controlling a vehicle without being aboard it. However, if the round-trip signal lag exceeds 0.1 seconds (9,300 miles range for light-speed communications) this penalty may increase substantially.

Where possible, it's a good idea to install an autopilot or small computer with vehicle-operation software to take control if the communications link goes down. If no such a system is available, loss of signal is treated like any other loss of operator (p. VE152).

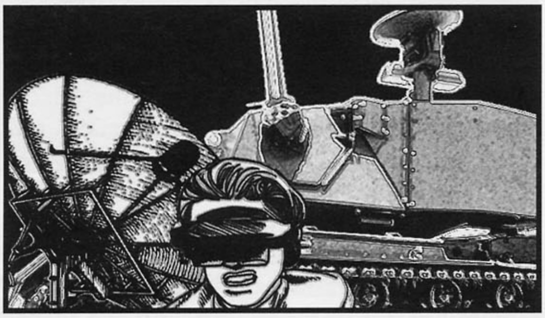
Remote Control Consoles

These may be installed in a vehicle or structure, or, if small enough, simply be carried by an operator (often with a built-in communicator). The weight, volume, and cost of consoles (including remote control programs) is halved one TL after the system first appears, and halved again two or more TLs after it appears. A communicator is not included.

Simple Remote Control (TL6): The operator controls the remotely operated vehicle using analog controls, such as a joystick. The operator must have the vehicle in sight (or tracked by line of sight sensors) to control it. No crew station is required. There is a -4 telepresence penalty. $100, 4 lbs.

Basic Remote Control (TL7): As above, but the operator can receive direct sensor transmissions from the remote vehicle (if it has any), allowing him to control it even if the vehicle leaves his line of sight. This also lets him perform observation tasks from the vehicle, fire its weapons (if any), etc. The penalty remains -4. The console may be any crew station with a computer terminal and Complexity 2 or higher computer, and must run Datalink and Basic Remote Control ($400, Complexity 2) programs.

Advanced Remote Control (TL7): As above, but with more sophisticated sensory feedback. The telepresence penalty is -3. A Complexity 3+ computer is required, and must run Datalink and Advanced Remote Control ($2,000, Complexity 3) programs.



Basic VR Console (TL8): The operator "gets inside" the remote vehicle using a virtual-reality rig. Through feedback, the operator actually experiences the vehicle's sensory impressions rather than relying on instrument readouts. The telepresence penalty is only -2, or -1 if the remote vehicle is similar in shape and size to the teleoperator. The console is a specialized VR rig ($2,500, 30 lbs., 1.5 cf) attached to any computer terminal and Complexity 4 or higher computer running both the Datalink and VR Remote Control ($5,000, Complexity 4) programs.

Neural-Interface Console (TL varies, usually TL10): The operator controls the remote vehicle through a direct brain link. The telepresence penalty is only -1, or 0 if the vehicle has the same size, shape, and number of limbs as the operator. A typical system is the TL10 neural-interface helmet ($10,000, 3 lbs., .06 cf) attached to a console, which may be a computer terminal and any Complexity 4 or higher computer running both the Datalink and Interface Remote Control ($5,000, Complexity 4) programs.

Power and Fuel

This section provides additional rules and design options for power plants and fuel.

External Combustion Engines

These are all power plants that rely on an external heat source (such as a boiler) for energy. They include conventional steam engines and more exotic variations.

Compound Steam Engines (TL5): Compound engines, such as the triple-expansion engine (pp. VE82-83), can actually have a varying number of stages of expansion (cylinders). Two-cylinder engines were experimented with in 1854 and generally adopted in 1874. Triple-expansion engines followed in 1885, and German shipbuilders produced quadruple-expansion engines from 1897 through 1906. Such engines were mainly used on ships or in factories. No one actually built a sextuple-expansion steam engine, but someone might have tried had the steam turbine (pp. VE82-83) not been developed.

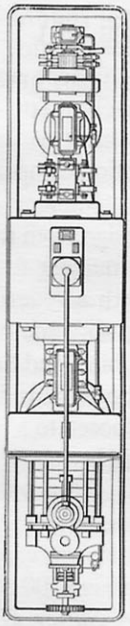
Vapor Cycle (Rankine) Engines (TL6): These are external combustion engines which recycle the working fluid. Vapor cycle turbines sacrifice some fuel efficiency for reduced weight and complexity and rapid start-up. Often the working fluid is not steam; the most common alternatives are ammonia, halobenzenes, or mercury. Automobiles and even aircraft were once built with vapor engines, but internal combustion won out.

Stirling Cycle Heat Engines (TL5): A closed thermodynamic cycle engine in which a working gas is alternately compressed at low temperature and expanded at high temperature, producing work. A Stirling engine is very quiet and has superior fuel economy. Original designs (dating to 1816) used low-pressure air as the gas, but in modern designs the pistons are filled with pressurized hydrogen or helium, for greatly increased efficiency.

External Combustion Engine Table

TL	Engine Type	Weight if output is under 5 kW	5 kW or more	Cost	Fuel Used
5	Double-expansion	112 × kW	(56 × kW)+280	$0.6	0.04C/0.16Wd
5	Quadruple-expansion	94 × kW	(47 × kW)+235	$1	0.02C/0.08Wd
(5+1)	Sextuple-expansion	88 × kW	(44 × kW)+220	$1.4	0.015C/0.06Wd
6	Vapor Cycle	35 × kW	(15 × kW) + 100	$4	0.025C/0.05M
7	Vapor Cycle	20 × kW	(10 × kW) + 50	$6	0.02C/0.04M
8	Vapor Cycle	15 × kW	(8 × kW) + 35	$8	0.016C/0.033M
5	Stirling	150 × kW	(60 × kW) + 450	$2	0.04C/0.08M
7	Stirling	20 × kW	(15 × kW) + 25	$10	0.0125C/0.026M
8+	Stirling	10 × kW	(8 × kW) + 16	$5	0.0085C/0.016M

The power output of the engine in kW determines its weight in pounds. There are two columns for use in calculating weight: one for engines with output under 5 kW, the other for larger engines. Divide weight by 50 to find volume in cf. Cost is in dollars per pound of engine weight. Fuel use is per kW, in cf per hour for coal (C) or wood (Wd) or multi-fuel (M) which allows use of gasoline or diesel fuel. If two fuels are listed, the engine can use either.



Boiler Explosions

Steam and most other external combustion engines can be pushed beyond their rated maximum power output. This dramatically increases the chances of a breakdown or explosion. Power may be increased above the rated maximum in 10% increments. Increased power allows increased speed, according to the following table.

Steam Power Beyond Rated Maximum

Power Increase	Water Speed Increase	Air/Ground Speed Increase
10%	3%	5%
20%	6%	10%
30%	9%	14%
40%	12%	18%
50%	14%	22%
60%	17%	26%
70%	19%	30%
80%	22%	34%
90%	24%	38%
100%	26%	41%

This increase requires an Engineer roll at -1 per 10% increase. On a critical success, the engine functions perfectly. On an ordinary success, it functions safely but needs immediate maintenance afterward. On an ordinary failure, it breaks down – gears jam, pipes burst, or the like. On a critical failure, it explodes. On an 18, the explosion is immediate; on any other critical failure, there is a moment's warning, during which bystanders may dive for cover – or a heroic engineer may try to prevent the explosion with an Engineer-5 roll, with no opportunity to avoid injury if the attempt fails.

If a pipe leaks or bursts, escaping steam causes 1d-1 burn damage to a randomly chosen victim in the engine room. He may attempt to dodge the steam.

If a steam engine explodes, it causes concussion damage equal to 6d per 50 kW for a low-pressure engine, 6d per 10 kW for any expansively worked engine, or 6d per 2 kW for a turbine. The full damage is applied to anyone within 2 yards of the engine. For each 2 yards out, divide damage by 4. Superheated steam also scalds anyone close enough to suffer concussion damage, inflicting 1d-1 damage from burns. Fragmentation damage occurs in hexes adjacent to the engine on a 17 or less, with a -1 modifier per hex farther out; fragmentation damage is 1d cutting.

Solar External Combustion Engines

These systems can provide power to spacecraft or space stations, using the intense solar radiation in outer space as a heat source.

This system has two parts. One is equivalent to a standard external combustion engine, but with weight, volume, and cost reduced by 20% and no fuel consumption. The other is one or more mirrors.

Mirror area needed per kW is 2,500 times the coal consumption (in cf/hour) of the engine. Mirrors weigh 1 lb. and cost $0.04 per sf.

Mirrors must be mounted on masts; maximum area of mirrors equals (average mast length) squared × number of masts/2.

Compute crewmen needed to align the mirrors as for sails (p. VE75). TL depends on the TL of the engine.

Reactors

These are different approaches to power reactors (pp. VE85-86) that may prove more suitable to some alternative history or science fiction campaigns.

Nuclear Air Turbine (TL7): An optimistic design from the early days of atomic energy, prior to nuclear fears. Air is heated by direct contact with a reactor core made of highly enriched bomb-grade plutonium, then expanded through a turbine, and finally vented back to the atmosphere. The turbine is shielded, but operators may be exposed to a few dozen rads per year. The system will last about 20 years before it requires disposal.

Experimental Fusion Reactor (TL8): This models near-future and prototype fusion designs. They are very heavy and expensive. Minimum cost is $100 million.

Super MHD Fusion (TL9): Basic fusion rockets (p. VE36) are extremely efficient. If these rockets exist, a fusion generator can be designed that uses their exhaust to vaporize a working fluid in a MHD generator, generating power. The result is an expensive but highly compact fusion reactor. Super MHD Fusion is a "superscience" system, but can simulate many optimistic SF power plants.

Lightfield Reactor (TL12): These superscience reactors are a logical offshoot of transparent deflectors or force screens effective against energy. The reactor core is a screen filled with enough fission fuel to go incandescent. Light from the glowing core passes through the screen and heats a working fluid. Such screens greatly simplify fission reactor design: material temperature and radiation tolerances no longer matter, radiation shielding is simple, and the reaction can be controlled by adjusting neutron reflection of the innermost screen. An operating lightfield reactor, if disabled or destroyed, explodes for 6d × 10 damage per kW and contaminates the blast radius to several hundred rads/hour. Lightfield reactors consume 0.003 lbs. of fission fuel per kW-yr.

Extra Detail – Unshielded Fission Plants

Any TL7+ fission reactor, nuclear air turbine, or lightfield reactor can be built with minimal shielding, as can any fission rocket or fission air-ram. This halves the weight, volume, and cost, but makes the device very dangerous. It is safe until turned on, but while operating it gives off a lethal radiation flux (6,000 rads/second at 1 yard, decreasing with the inverse square of distance). Once used it remains highly radioactive for the next few thousand years. However, the worst waste products will decay after a few weeks of disuse, dropping the radiation to 2,000 rads/hour (at one yard).

Nuclear, Antimatter, and Mass Conversion Reactors Table

TL	Type	Weight if output is under 5kW	Weight if output is 5 kW or more	Cost	Years
7	Nuclear Air Turbine	no	(1.5 × kW) + 250	$20	20
8	Experimental Fusion	no	(2 × kW) + 2 million	$50	0.5
9	Super MHD Fusion	no	(0.5 × kW) + 100	$65	200
10+	Super MHD Fusion	no	(0.4 × kW) + 90	$50	2
12	Nuclear Lightfield	no	(0.15 × kW) + 100	$40	special
13+	Nuclear Lightfield	no	(0.075 × kW) + 50	$40	special

Weight, cost, etc. are as per the table on p. VE86.

Perpetual Motion Engines and Other Exotica

Over the centuries, inventors have looked for a power source that could operate without requiring fuel. Cosmic power plants (p. VE85) and mana engines (p. VE86) are examples, but may be too fantastic for a divergent-technology alternate Earth or a weird-science campaign with a historical or modern-day setting. This section presents a series of lower-technology "free energy" power plants, many of them based on historical frauds and errors. Most violate one or more thermodynamic laws, although some draw on invisible energy reserves, making the accounting uncertain.

Self-moving Wheels (TL(2+1)): These are the oldest perpetual motion design. Movable weights are arranged around a wheel so that there is always more weight on one side of the wheel than the other. Weights sliding on spokes or mounted on pivoting arms, balls rolling in curved sectors, and tubes partly filled with mercury are typical approaches; waterwheels turned by water lifted by a pump driven by the wheel are a variation. Modern versions may substitute attraction between permanent magnets for the gravitational attraction on the weights, allowing the wheel to turn horizontally. None actually provide perpetual motion, but until mid-TL5 it is unclear why. A method of altering the force of gravity on part of the wheel – artificial gravity, gravity screens, or contragravity fields that can switch on and off – would allow this to work. This is one reason why most gravity control technology breaks physical law.

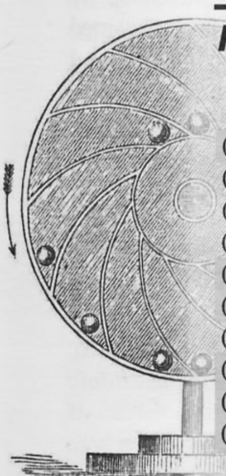
Zero Motors (TL(5+1)): These use heat from the air to boil a working fluid – typically ammonia in the 19th century and liquid air, freon, or carbon dioxide in the 20th. The vapor expands through a turbine and is recondensed and recycled. The motor requires a thin or denser atmosphere that is warmer than the working fluid's boiling point. The original zero motor examined by the U.S. Navy in the 1880s operated near zero Fahrenheit, hence the name. Zero motors violate the second law of thermodynamics rather than conservation of energy. In the real world, recondensation requires a heat sink colder than the boiling point, or a compressor using more power than the turbine produces.

Demonic Pumps (TL(5+1)): These openly violate the second law of thermodynamics by exploiting its statistical nature. In the classic thought experiment, Maxwell's Demon opens a stopcock only when a hot molecule approaches from one side or a cold molecule from the other. The demonic pump uses some form of superscience filter to direct molecular motion. Other versions create a pressure difference (allowing any molecule to pass, but only in one direction), or use Brownian motion to wind a spring (using a ratchet lock as the one-way device). The key feature of demonic pumps is that molecular-level activity happens only in one direction, something that (in reality) normally requires energy.

Electrical Multipliers (TL(6+1)): These devices use electric power to produce more electricity than they consume. They use no fuel, but do require power supplied by another power plant. A typical system uses an electromechanical device to convert a constant current flow into rapid pulses of energy with a net gain in output. In the real world, the inventor was usually confused by a measuring error such as equating voltage with power, or more subtly by confusing reactive power with real power or assuming sinusoidal relationships hold for non-sinusoidal waveforms.

Zero Point Energy (ZPE) (TL(7+1)): A power plant that draws energy from the random electromagnetic fluctuations which exist even at absolute zero. If the energy for all the possible frequencies is summed up, the result is can be interpreted as large (for some methods of calculation, infinite) energy density present even in vacuum. Because the energy densities are higher the smaller the wavelengths, ZPE devices usually claim to exploit phenomena occurring in small cavities – rapidly collapsing sonoluminescene bubbles, the interstices between atoms in close-packed metals, and so on. Statistics are for a typical late TL7 power plant. Superscience ZPE devices can be treated as TL9+ NPUs with +25% cost and "infinite" years, or as cosmic power plants (p. VE86).

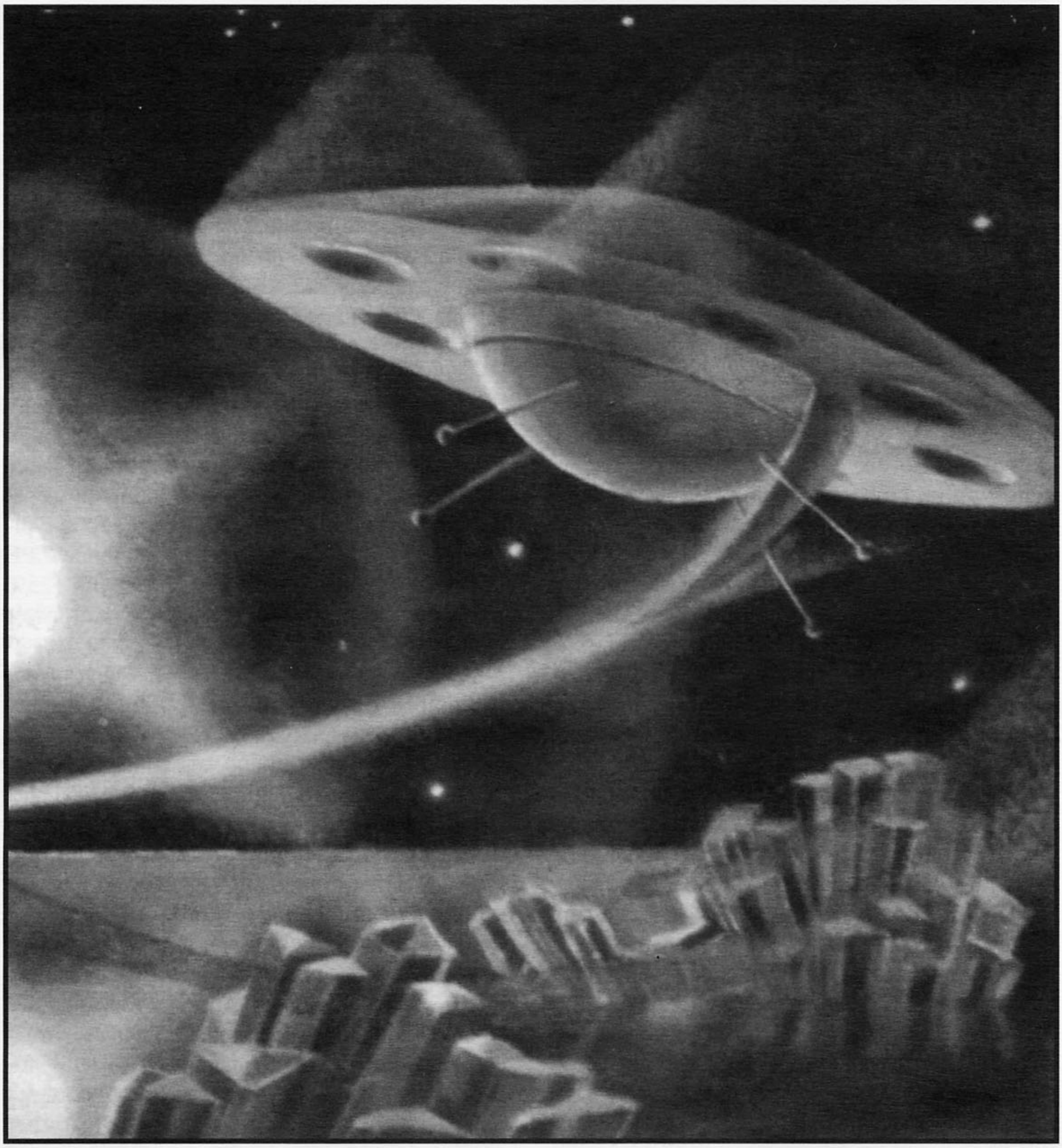
Orgone Engines (TL(6+1)): These use a technology distantly related to the Soulburner (p. VE86) to convert orgone (a type of life-force; see p. WT106) to electricity, sometimes expelling "Deadly Orgone Radiation" as a toxic exhaust (treat as 1.5 rads/hour per kilowatt to nearby living things, and see p. WT106 for *emotional plague*). Some orgone engines constantly expel such radiation; others do so only if damaged or irritated (and continue even if the irritation is removed) by the proximity of nuclear radiation, microwaves, and sometimes even radios or TV signals. Engine output assumes a living environment (such as Earth); an alternative is needed for deep-space operations. If orgone energy does not exist as such, use similar statistics for other engines that draw on a living world's life energy (psychic energy, chi, prana, etc.) for power and release antilife energy as exhaust.



Perpetual Motion Engines and Other Exotica Table

		Weight if output is			
TL	*Type*	*under 5kW*	*5 kW or more*	*Cost*	*Power*
(2+1)	Self-Moving Wheels	150 × kW	150 × kW	$0.5	0
(5+1)	Zero Motor or Demonic Pump	150 × kW	(80 × kW) + 350	$1	0
(6+1)	Zero Motor or Demonic Pump	40 × kW	(20 × kW) + 100	$4	0
(7+1)	Zero Motor or Demonic Pump	20 × kW	(10 × kW) + 50	$6	0
(6+1)	Electrical Multiplier	20 × kW	(4 × kW) + 80	$2	0.25 kW
(7+1)	Electrical Multiplier	10 × kW	(1 × kW) + 45	$10	0.1 kW
(7+1)	Zero Point Energy	50 × kW	(20 × kW) + 150	$20	0
(6+1)	Orgone Engine	no	0.05 × kW	$50	0
(6+2)	Orgone Engine	no	0.1 × kW	$100	0
(6+3)	Orgone Engine	no	0.005 × kW	$500	0

Weight, cost, etc. are as per the *Exotic Power Plants* table on p. VE87.



Broadcast Power

This is the next step up from beamed power (p. VE87). It allows power to be transmitted to all points within range, rather to a specific location. There are two types:

Field-Based Electrical System (TL(6+1)): A divergent technology precursor to broadcast power, replacing wiring over short distances. It is common on UFOs and in worlds based on the assumption that Nikolai Tesla's theories result in practical inventions. Real attempts to generate broadcast power can't handle high power demands, require antennas heavier than the wires would be, waste power by heating anything metallic or otherwise conductive aboard, and are very sensitive to interference, making them impractical.

Broadcast Power (TL12): This superscience technology involves power being transmitted from a central station, and then picked up by small receivers at long distances. Unlike beamed power, it does not require line of sight and involves no hazardous energy beams.

Either broadcast power system's receiver weighs 0.25 lbs., occupies 0.005 cf, and costs $5 per kW it can pick up. A transmitter weighs 0.5 lbs., occupies 0.01 cf, and costs $5 per kW it can broadcast, plus $500. Select a maximum range for each transmitter, up to 0.05 miles × kW transmitted.

Broadcast receivers operate on specific channels and pull power from any available transmitter in range operating on that channel. If the total power drawn by all receivers in an area exceeds that available on their channel, the system browns out. Legal receivers are likely to have a built-in communicator link and GPS and talk to a scheduling computer to prevent overloads. Military and emergency vehicles rarely use broadcast power because of the risk that something will take down the network.

Fuel

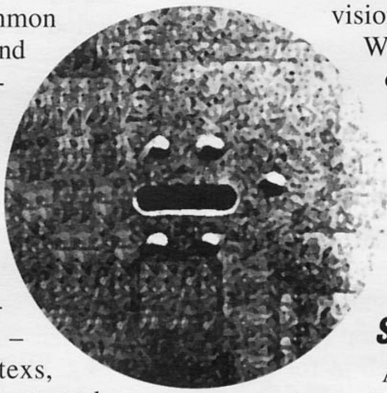
These rules add additional options and types of fuel or reaction mass.

Other Types of Liquid Fuel

Argon: This cryogenic noble gas is typically used as a reaction mass in cold gas thrusters and slow ion drives (see ***Vehicles Expansion 1***).

Hydrogen-Oxygen: A common and efficient chemical rocket fuel using liquid oxygen and liquid hydrogen.

Kerosene-Oxygen: Another common chemical rocket fuel using kerosene and liquid oxygen. It gives a lower specific impulse (fuel efficiency) than liquid hydrogen-liquid oxygen, but the higher density of fuel makes up for it, allowing a greater weight of fuel in a particular volume of tank.



Synthetic Biofuels: Cheap fuels may be produced from biomass, typically lightly processed plant oils – assorted triglycerides, terpenes, latexs, esters, and carboxylic acids. Peanuts and Chinese tallow trees are the best candidates, but soybeans, castor beans, rapeseed, and corn oils may be usable.

Light Biofuels can be burned in any multifuel engine, or any diesel or gasoline engine with small modifications (10% of engine cost).

Heavy Biofuels are denser, less volatile, or more viscous materials like unprocessed plant oils and the products of wood distillation or the pyrolysis of garbage. They are cheaper, but can only be burned in multifuel-capable engines, and require twice the normal fuel volumes.

Additional Fuel and Reaction Mass Table

Type	Weight	Cost	Fire
Synthetic Fuels			
Light Biofuels	6.5	$3	10
Heavy Biofuels	8	$0.5	8
Cryogenic Rocket Fuels			
Hydrogen-Oxygen (HO)	2.1	$0.1	13
Kerosene-Oxygen (KO)	8.5	$1	13
Cryogenic Reaction Mass			
Argon (Ar)	4.7	$4	–

Other Types of Solid Fuel

Ablative Plastic (AP): Used in laser rockets. Each pound of ablative plastic takes up 0.02 cf and costs $0.04. It is usually stored as cargo.

Surface and External Features

These features may be added to the exterior of a vehicle, as per ***GURPS Vehicles,*** Chapter 8. They may be added to a vehicle after the total surface area has been determined.

Gun Port (TL1)

Vehicles may have small openings through which an occupant of a vehicle can fire personal weapons while remaining protected by the vehicle's armor; he is subject to any vision penalties (see p. VE173). Weapons are limited to rifles or smaller. The firer is limited to a 15-degree arc of fire; the vehicle is not considered sealed when a gun port is in use.

The weight and cost are negligible.

Self-Sealing Hull (TL6)

A sealed hull may be designed to be self-sealing. This lets it automatically close small punctures in less than a second. The GM may declare major breaches beyond the ability of the hull, and corrosive atmospheres may reopen small punctures after a time as the corrosive dissolves the sealant, but ordinary leaks and flooding are prevented.

A self-sealing hull has double the cost of a sealed hull, and requires an extra 0.2 lbs. per sf at TL6. Halve weight at TL7, and halve again at TL8+.

Energy Phasing Surface (TL13)

The vehicle is surrounded by a superscience array of *force lenses*, which allow energy weapons mounted anywhere aboard to fire from any point on the surface. All energy weapons effectively have universal arcs of fire. It will also allow a sensor anywhere aboard to look out in any direction. Energy Phasing Surfaces can be installed on subassemblies as well, usually a pod, to allow weapons in the pod to fire on any arc not blocked by the rest of the vehicle. The surface weighs 0.25 lbs., costs $500, and requires 0.5 kW per square foot covered.

Performance and Operations 4

This chapter expands on Chapters 10 and 12 of ***GURPS Vehicles***, providing additional rules for specific situations and types of vehicles.

Aerial Performance – Gliders

A vehicle with wings, rotors (see *Auto-Rotation and Helicopters*, p. 31), or a lifting body but no functioning aerial propulsion system is a glider. The GM may wish to calculate glider performance for any aircraft with a stall speed, in the event of the craft losing power.

A glider has the same aerodynamic drag, Stall Speed, aMR, and aSR as any other aircraft, and it can fly if its speed exceeds its stall speed. A glider might reach its stall speed by using a powered propulsion system and then turning it off, or by being towed by another vehicle. The important statistics for a glider are its terminal velocity and top gliding speed, and its glide ratio.

Top Gliding Speed is the top speed the glider can theoretically reach in forward flight. It is calculated as follows:

Top glide speed = 0.4 × terminal velocity.

Terminal velocity is:

Square root of
(7,500 × Loaded Weight/Aerodynamic Drag).

Glide Ratio is the critical statistic for a gliding aircraft. It is the forward distance the aircraft can travel before losing a unit of height. Glide ratio is calculated as:

(Top glide speed/stall speed) squared.

E.g., one with a top glide speed of 120 mph and stall speed of 20 mph has a glide ratio of (120/20 = 6) squared = 36, or 36:1. It could fly 36 yards horizontally before losing a yard of altitude, go 3.6 miles before losing 0.1 mile altitude, etc.

Glider Flight

A glider flies like any other aircraft. It must be moving faster than its stall speed to stay in the air. The rule for aircraft deceleration (1 mph/s in forward flight; see *Change of Top Speed*, p. VE150) does not apply if using these glider rules, since the glider is always sinking. Even in forward flight, a glider will constantly lose altitude as determined by its glide ratio and forward speed.

Gliding speeds are relative to the air, not the ground, so any speed added from a tailwind (which adds to ground speed without increasing air speed) or subtracted from a headwind is not counted when determining altitude lost.

Thermals, downdrafts, and updrafts are also important, and increase or decrease altitude for a period of time, sometimes several minutes. A

Extra Detail – Aircraft Stall Speeds and Landing

For increased realism (and especially if using the glider rules) stall speeds should be calculated as follows:

Sl × Rs × square root of
[(Lwt. - Static Lift)/Lift Area].

Sl is 7 for fair streamlining or worse, 7.35 for good, 7.7 for very good, 8.05 for superior, 8.4 for excellent, and 9.1 for radical streamlining.

Rs is 2 mph for most vehicles, but 1.5 mph if the vehicle has a responsive structure.

Lift Area is calculated as per p. VE133: Add the entire combined surface area of all the wings and rotors to 10% of the area of the body (30% for lifting bodies). Treat STOL wings as having 1.5 times their actual area and flarecraft as 3 times their area for this purpose.

Static Lift is the total pounds of lift from ornithopter wings, helicopter rotors, lifting gas, Magnus effect drivetrains, vectored thrust used for lift, lift fans or engines, contragravity, and levitation.

Lwt. is loaded weight.

Stall Speed and Glider Terminal Velocity in Alien Environments: Multiply it by the square root of the local gravity and divide by the square root of local air density.

Rough Field Landings: For landing and take off purposes, a vehicle with up to Very High ground pressure can treat a level grassy field or a smooth, straight dirt road as hard terrain.

glider pilot can use Aviation skill to locate thermals and updrafts. They are rated for vertical or horizontal gain in yards/second. An updraft producing a change of 1-5 few yards/second is easy to find or avoid (no modifier to skill); up to 25 yards/second might occur in a storm.

Ceiling

An aircraft's maximum ceiling depends on three factors. The first is human: Can its occupants breathe? The second applies only to vehicles with air-breathing engines: Is the engine getting enough air? The third is aerodynamic: Is the air dense enough to allow it to fly? The lowest of the three limits determines the aircraft's ceiling.

Life Support Limit: For aircraft without life support systems carrying occupants who need to breathe, physiological factors usually set the ceiling. Safety tolerances for unacclimated humans restrict unsealed aircraft carrying commercial passengers to 3,500 yards, although up to 6,600 yards is possible, especially for acclimated individuals. Sealed vehicles can reach 8,000 yards. Sealed vehicles with life support have no specific limit.

Engine Limits: Any air-breathing engine will cease to function above a certain altitude. For aircraft with air-breathing power plants, such as propeller planes with internal combustion engines, air-breathing turbines or fuel cells, or jet engines, ceilings are limited to the point at which the air becomes too thin to support combustion. This averages 8,000 yards for most gasoline engines, fuel cells, or bioconvertors, 12,000 yards for supercharged, gas turbine, MHD turbine, and most jet engines, and 25,000 yards for ramjets or air-rams. These are rough figures; actual numbers vary considerably.

Aerodynamic Limits: The limit is set by the point at which the density of the air becomes too low to support the vehicle. For helicopters and vectored-thrust craft, the ceiling is 8,000 yards × natural log (Loaded weight/static lift in lbs.). For winged vehicles, the ceiling is 8,000 yards × natural log (top speed/stall speed).

Alien Environments: For worlds other than Earth, multiply the limits by mu/(29.2 × g), where mu is the average molecular weight of the local air and g is the local gravity. Multiply engine and life support limits by (% oxygen/20%). Sample mu values: 2 for pure hydrogen atmospheres, 2.3 for typical gas giant atmospheres, 16 for pure ammonia, 28 for pure nitrogen, 29.2 for oxygen/nitrogen with trace argon, 44 for pure carbon dioxide.

Vehicles which have life support and use propulsion and lift that do not depend on air have a theoretically unlimited ceiling, although vehicles with a total delta-V (p. 32) less than the local escape velocity will be unable to escape a planet's gravity into space.

Auto-Rotation and Helicopters

A helicopter that loses power to its rotors may avoid falling out of the sky by auto-rotating. The pilot gets one chance to recognize a complete power loss and react appropriately (by lowering the collective and entering auto-rotation). A second or two of delay will cause the rotor speed to decay to the point where the helicopter is unrecoverable. To enter auto-rotation, the pilot must make a successful hazard control roll (p. VE148); failure means that the pilot cannot recover control, and the helicopter will fall. If the pilot succeeds, calculate stall speed, etc., as an aircraft (using three times rotor area for lift area; static lift is zero), then work out performance statistics for it as if it were a glider (using the area of its rotors). Auto-rotating helicopters which drop below stall speed do not automatically crash, but descend at 0.25 × top glide speed (0.1 × terminal velocity).

Space Performance and Specific Impulse

Specific Impulse (Isp) is the standard measure of rocket performance quoted in technical sources. It measures how many seconds of thrust a given unit of reaction mass can provide, and thus determines how efficient a given space drive is.

Extra Detail – Superchargers and Propeller Aircraft

Historically, propeller planes with supercharged internal combustion engines outperformed those with internal combustion engines but no superchargers when operating at high altitude. To reflect this, aircraft whose propellers are driven by supercharged internal combustion engines get their full aAccel and Top Speed when above 3,333 yards (10,000 feet), while aircraft whose propellers are powered by internal combustion engines without superchargers get only half their aAccel and 2/3 of their original Top Speed. To refit a turbo-charged engine with a supercharger, add 10% to weight. The additional cost is equal to 50% of the original engine cost.

To find the specific impulse of a space drive or rocket engine rated in ***GURPS Vehicles*** terms, use this formula:

$$\textbf{Isp} = 3{,}600 / (F \times W).$$

F is the *Fuel Usage* value (in gph per pound of thrust) on space drive and rocket engine tables; see p. VE36). *W* is the weight of the fuel or reaction mass in lbs. per gallon: see p. VE90 and similar fuel tables.

For example, the Optimized Fusion engine on p. VE36 has a fuel usage of 0.004H (0.004 gallons of hydrogen) per hour per lb. of thrust. The table on p. VE90 shows that hydrogen weighs 0.58 lbs. per gallon. As such, the engine has an impressive Isp of $3{,}600/(0.004 \times 0.58) = 1{,}551{,}724$.

Realistic Delta-V

Specific impulse can be used to calculate a realistic delta-V, the total velocity change that a spacecraft can achieve using a particular load of fuel. Use this formula to find delta-V from specific impulse:

$$\text{Realistic Delta-V} = 21.8 \times \text{Isp} \times \text{natural log}\,(1 + [\text{fuel weight}/\text{dry weight}])\ \text{mph.}$$

Fuel weight is the total weight of fuel carried for that engine. *Dry weight* is the loaded weight of the vehicle minus the weight of its fuel for that engine. Delta-V is often given in miles per second (e.g., in ***Transhuman Space***). To get mps, divide delta-V in mph by 3,600.

Simplified Delta-V

GMs who want a simpler system for calculating delta-V without working out Isp and using natural logarithm functions can use this formula:

$$\text{Delta-V} = (\text{sAccel in G}) \times \text{endurance in hours} \times 21.8\ \text{mps.}$$

If doing this, calculate loaded mass as if the tanks carried only half the load of fuel. This will simulate the fact that the fuel load will be gradually burned away during flight.

Round Trips and Delta-V

A vehicle using a reaction drive (one that requires fuel) will usually accelerate to a speed equal to *half* its delta-V, burning just over half its fuel, travel for (miles to destination/speed) hours, then decelerate using the remainder of its fuel.

INDEX

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THE PROJECT TEAM:

Compiled by
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Edited by
Andrew Hackard and
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Cover design by
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Interior Design by
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First Edition, First Printing
Published February 2002

ISBN 1-55634-602-6

50895

9 781556 346026

SJG00895 **6542**

Printed in the USA