Matthew DeBell's Technical PAQ List
Version 1.0, 28 July 2002.

Corrections, comments, questions and suggestions are welcome. Please send them to md@vanguardrpg.com

This is my own Previously Asked Questions (PAQ) list created for the purposes of developing plausible science fiction stories. It contains some references to my SF background that will not make sense to a general audience, but most of it should be clear.

In my notes over the years I've paid more attention to content than attributions, and sources of information have been omitted in several cases. I apologize to those who are slighted. No doubt some of them are regular contributors to the Usenet newsgroup rec.arts.sf.science.

Contents

1. General Formulae and Conversion Factors

Basic kinematics equations: $v=at$, $x = .5\ at^2$, $v^2 = 2ax$

Power (Watts) = Energy (Joules) / Time (seconds)

Surface area of a sphere $a = 4 * PI * r^2$
Volume of sphere $v = (4/3) * PI * r^3$
Circle circumference = $2(pi)r$
Circle A = $(pi)r^2$
Cylinder Volume = $PI \times r^2 \times h$
The surface area of a cylinder is $(2*PI*r*h) + (2*PI*r^2)$

Compound interest: FV = PV(1+interest rate)^# of years
Simple Interest- I = P I N
I- interest
P- principal
I - Fractional interest rate
N - Number of years

Kelvin = Celsius +273
Celsius = (Fahrenheit -32)/1.8
Fahrenheit = (1.8)* Celsius +32

Speed of light in vacuum = c = 300,000km/s.

2. Power and Energy

Material energy density: Gasoline holds 43.2MJ/kg. Relative to gasoline, energy density of coal is .77; alcohol .66, wood .4, TNT .14. Current photovoltaic technology will provide only about 21 watts per kilogram of solar cells.

Reactors

Very small fission reactor: “the mass of the reactor is less than 3 metric tons and … it will produce 100kw for at least 7 years.”

“Brookhaven National Laboratory has built a gas core particle bed reactor that can produce 200Mw from a 300kg 1.0 by 0.56 meter package.” [72, p.302 of an unknown source]

Compact fission reactors in submarines produce on the order of 20MW and weigh about 10^6kg (1000 tons), for power/mass ratio of only ~20W/kg. W/O radiation shielding etc. the power/mass ratio would be mord b1 br5o1 b.4-3.3((ce])]TJ3.5928 -1.1497 TD-0.0001 Tc0.0016 TAcw[ding-5(a the)n.8(f)-3a the)r-5(s4-1.c0.1ors

V = flight velocity / knots

For propellers, to convert power to approximate thrust:
T = 325 * P * e / V
where
T = thrust/pounds
P = brake horsepower
e = propeller efficiency, which ranges from about 0.7 in climb to 0.85 in cruise
V = flight velocity/knots

4. Astronomy

Oribts: velocity & altitude formulae
Circular orbit velocity = sqrt (GM/r), where G is the gravitational constant (6.67x10^-11), M is the mass of the planet, and r is the radius to the planet's center.

Escape velocity = sqrt (2GM/r), or 1.414 times circular orbit velocity.

orbital period = 2 (pi) r / v
Earth's geostationary altitiude is 35,868km (22k miles)

Delta-V of Orbits
LEO >= 9.5 km/s
LEO to equatorial geostationary orbit from a 30 degree inclined parking orbit 4.2 km/s
additional for Mars fly-by 3.4 km/s
additional for solar-system escape 8.5 km/s
Earth's orbital speed around the sun is about 30km/s.

Earth to Moon delta velocities
Earth to low earth orbit (LEO) 9300 m/s
Trans-Lunar injection (TLI) 3200 m/s
Mid course correction 80 m/s
Lunar orbit insertion (LOI) 800 m/s
Lunar landing 2100 m/s
total dv = 15480 m/s

`Lewis and Lewis give the following delta velocities to a few selected Apollo asteroids.  (It takes a delta velocity of about 6000 m/s to go from LEO to the surface of the moon.)`

`*  Table 10.1-2  Delta velocities of Apollo asteroids (from LEO)`

Asteroid	dv out m/s	flight time days	dv back m/s	flight time days
1982 DB	4450	210	60	480
1982 XB	5300	220	220	470
1982 HR	5300	180	260	320
1980 AA	5400	690	360	450
Anteros	5270	390	390	290

"The velocity change required to go from low earth orbit (LEO) to Phobos is about 4.37 kilometers per second [LB1, p.812]. The velocity change to return to LEO is about 3.54 kilometers per second [LB1, p.812]. "

Mining the Moon

Resources in regolith:

Element	Symbol	Percent(by wt)
Oxygen	O	42.26
Silicon	Si	19.68
Iron	Fe	11.92
Calcium	Ca	8.53
Aluminum	Al	7.20
Magnesium	Mg	4.68
Titanium	Ti	4.65
Sodium	Na	0.35
Manganese	Mn	0.15
Chromium	Cr	0.10
Total		99.52

Trace elements include hydrogen, helium.

Lunar base at the poles offers continuous sunlight, plus continuous darkness in polar craters, where water ice is located.
The moon offers low gravity and hard vacuum, remoteness, and helium-3. Far side of moon has 3 times the 3He as near side. It is estimated that there are about 1 million metric tons of helium-3 in the lunar regolith. Producing 1kg of helium 3 requires mining 120,000 tons of regolith. This would also yield 3300 kg of helium 4, 500kg of nitrogen, >4000kg of carbon monoxide and carbon dioxide, 6100kg of hydrogen.
The value of Helium 3 is estimated as at least $1 billion per ton.

1000 ton mining equipment mines 700 tons per hour using 2000kW of power. [This would produces about a kg of helium3 every 9 days.]

Regolith mining lifts the first few meters of soil, heats it to boil off gasses, passes it through electrostatic and electromagnetic sieves, and dumps it back on the surface.

Hypothetical Lunar mining machine:
Mass: 200 tons.
Cost: $10 million.
Operating life: 10 years.
Operating/support cost: $1 million/year.
Power consumption: 1.5MW.
Operating the machine costs about $2 million/year (counting purchase price).
It yields the following:
helium 3: 35kg.
helium: 100,000 tons
nitrogen: 130,000 tons
hydrogen: 200,000 tons
iron: >40,000 tons
titanium: >40,000 tons
oxygen: >40,000 tons

Assume iron is worth $15 per ton, titanium $50, gases (except helium 3) $1 per ton.
Then the lot would yield $1.2 million for metals, about 500,000 for gases, needing $800,000 for the helium 3, or >$20,000 per kilogram.

Lunar settlements on the near and far side.
“It makes little sense to refer to the “dark side of the moon.” Both sides of the moon have day and night of the same duration. However, because the moon is “tidally locked” to the earth, the near side always faces earth while the far side never does. The near side thus benefits from “earthlight,” the reflection of sunlight from the earth to the moon’s surface. Earthlight is much brighter than moonlight.”

Lunar pollution: rockets pollute the moon. In contrast to Earth, where we worry about polluting the atmosphere, on the moon we worry about creating an atmosphere.

“Assuming the launcher can be rotated, it could be advantageous to place the rail launch facility at the Lunar pole, because the pole launcher can be rotated to point roughly towards earth at all times.”

Initially, helium-3 is many times more valuable than gold. Its price has dropped considerably as electric power prices have fallen and as helium-3 mining has matured.
A lunar mining facility has many large tanks, silos, and warehouses to store the materials refined from regolith.

Radiation

The following is typical of solar activity:

* Tabel 9.0-4

Frequency per solar cycle	Dosage
1 or 2	5000 rads(fatal)
2 to 5	500-1000 rads(fatal)
20 to 30	50-100 rads

Source: [17, p.479]

A solar cycle is 11 years.

interplanetary radiation: 30 millirads per day
mars surface: 15 millirads per day

Meteors and Asteroids

Meteorite class distribution Meteorite class Percentage (approx)
carbonaceous chondrite 5 ordinary chondrite 81 achondrite 9 stoney iron 1 iron 4

Carbonaceous chondrites avg. 10% water, 3-5% carbon.

‟Perhaps the most important of these groups is the carbonaceous chondrites. The reason is that they contain up to 22% water [38, p.102] although they average about 10% water [14, p.229]. Water is extremely important because of its ability to sustain life and its potential is a rocket propellant. These asteroids also contain carbon - as their name indicates. Carbonaceous chondrite meteorites contain 3-5% carbon [114, p.31].

"The chemical composition of chondritic meteorites closely matches that of the sun, suggesting that such meteorites represent primitive materials that have survived without significant change since the formation of the solar system [34, p.42]."

The class called ordinary chondrites is further subdivided into three subgroups depending upon the concentration of iron in the meteorite: H - high iron, L - low iron, and LL - very low iron. These meteorites and corresponding asteroids are of special interest because of their high concentrations of the platinum group metals. Lewis and Lewis give the following table of concentrations of metals in ordinary chondrites [14, p.257].

* Table 10.1-4 Concentrations of Platinum group metals in ppm

		chondrite sub-class		
Element	Symbol	LL	L	H
Ruthenium	Ru	12	8	5.7
Rhenium	Re	1	0.6	0.5
Osmium	Os	10	6	4.7

Iridium	Ir	10	5	4.8
Platinum	Pt	21	13	11
total		54	32.6	26.7

.

Consider a one kilometer diameter asteroid. At a density of four grams per cubic centimeter it would weigh about 2 billion metric tons. The metal percentages in ordinary chondrites are: H = 16+/-3; L = 9+/-2; LL = 4+/-1 [14, p.257]. Thus this written by Geoffrey Landis, describes a "magnetic/ electrostatic plasma shield in which an electrostatic field shields the crew from positively charged particles while a magnetic field confines electrons from the space plasma to provide charge neutrality" [SM 47, p.383]. Such a shield might allow us to visit even Io."

"Large amounts of ice are believed to be present on Ganymede and Callisto. They both have densities which are less than 2 grams per cubic centimeter and both are estimated to consist of more than 60% water-ice by John Lewis and Mark Lupo [3, p.172]. Pictures of Callisto show how recent impacts have exposed the underlying ice. Evidently, the surface is covered by as little as a few centimeters of dark dust and debris and below that lie many kilometers of ice.

We suggest the north pole of Callisto as the tentative site for the first Jovian base. This site would allow continuous observation of the Jovian system from a site of comparative safety. It would also have direct access to the ice from which LOX and LH2 propellants would be made.

From Callisto, the planet Jupiter would appear about 4.35 degrees wide as compared to about 0.5 degrees for the moon as viewed from earth. The amount of sunlight received at Callisto (or Jupiter) is only about 3.7% of what we get on earth. All life support systems must be prepared for temperatures of about -173 degrees Celsius [41, p.122]."

"Callisto is moving at about 8.2 kilometers per second around Jupiter."

"12.4 Recovering helium-3 from Jupiter

One of the discoveries made by Voyager 1 was that about 11% by volume of the atmosphere of Jupiter is helium [96, p.87]. This closely matches the percent of helium found on the sun, indicating that Jupiter is a good sample of the primordial nebula from which the solar system formed.

Between 1973 and 1978 some members of the British Interplanetary Society worked on a project called Daedalus. It was an interstellar spacecraft which was intended to run on deuterium and helium-3 [66, p.68]. Their intention was to "mine" the helium-3 from the atmosphere of Jupiter.

Even assuming a low concentration of helium-3, it is easily calculated that there is more helium-3 on Jupiter than there is water in all oceans of earth (roughly 100 times more). Although some recent papers such as "Helium-3 Mining of Uranus" by Dani Eder which appeared in volume 8 of "Space Manufacturing", prefer Uranus to Jupiter, we prefer Jupiter. After all, it is much closer and far more interesting than Uranus."

Ganymede and Callisto are iceballs.

5. Spacecraft

Rocket Equation, etc.

The non-relativistic version of the rocket equation is $\Delta V = Ve \ln R$ (delta vee equals the exhaust velocity times the natural log of the mass ratio, i.e. initial mass to mass at burn-out). This is reasonably accurate up to a large fraction of the speed of light.

The relativistic rocket equation is

$$dv = Ve \ln R/[1 + (Ve^2/c^2) (\ln R)^2]$$

Thrust = exhaust velocity times exhaust mass per second.
The power of a drive system equals the kinetic energy of the exhaust. power = .5 (mass per sec) v^2
The power per unit exhaust is limited by the energy of the fuel. Given the energy density of the fuel, solve for velocity per unit mass using formula for KE.

Another expression of ship power:

$P = (1/2 * g * F * Isp)/n$
where
g = acceleration of the rocket
F = thrust
Isp= specific impulse (in seconds)
n = efficiency of your power plant

This means that when power is constant, thrust is inversely proportional to Isp.

Very large ships can’t dump heat very well because of relatively low surface area. Therefore they’re relatively slow.

Daedalus was to carry 50,000 tons of D and 3He fuel in 2800 tons of tanks, engines, and structure.

Rocket fuel

Low mass reaction mass (hydrogen) allows the highest exhaust velocity.

Hydrogen may be obtained by electrolyzing water. Requires $1.3\text{x}10^7$ Joules per kg of water. Launching a kg of payload to space requires about 10^8 J of energy, requires electrolysis of the order 100kg of water, requiring $\sim10^9$ J of energy. p203.
Deuterium is easily obtainable in massive quantities, since it makes up roughly 1 part in 6,000 of the hydrogen in water hereon Earth.23 Deuterium oxide, D_2O, heavy water, costs from $0.06 to$1/gram depending upon quantity and purity.23

optimal chemical exhaust is about 4.5km/sec. Hydrogen and oxygen burning is almost as good as fluroine. hydrogen and oxygen produce about 13 megajoules per kg.
escape (11km/s) requires about 63 MJ of KE per kg, or about 17 kW/hrs.

Space Shuttle
Space shuttle main engine delivers 2090 kN thrust, fuel flow rate 468 kg/s, exhaust v approx 4400m/s.
shuttle liftoff, 8tons per second at 3.5km/sec
The space shuttle’s payload bay doors double as radiators; if the payload doors do not open, the shuttle must return to earth to avoid overheating.
Dry mass of shuttle external tank is 30 tons.
Orbiter mass close to 70 tons, payload 30 tons.
The shuttle’s fuel tank’s gross mass is 6.6% structure, remainder fuel. This tolerates acceleration of 4g but is discarded after liftoff.

“The [Space Shuttle] ET is 47 meters long and 8.5 meters in diameter. It carries 145,138 gallons of liquid oxygen weighing about 627 metric tons and 390,139 gallons of liquid hydrogen weighing about 104 metric tons - for a total of 731 metric tons of fuel. The original tanks weighed 76,000 pounds but current ones weigh only 66,000 pounds. McCown says they could shave another 4,000-7,000 pounds off by using aluminum-lithium alloys in part of the structure. (At what exorbitant price one instantly wonders.)”

Simulated Gravity

Reports on coriolis “force” for simulated gravity say that RPM must not exceed 2-4. People would tend to get sick if they frequently traverse the truss from the simulated-g habitat to the rest of the ship.

Food

“for any trip longer than about 254 days, it is cheaper to grow your food than to carry it.” [Estimates 620kg per person required for food growth, and a 620 kg food supply lasts 254 days.]
[estimate 1 ton mass per person, though structure mass of about 120kg may have to be adjusted upward]

Spacecraft detection range

```
(probably from John Schilling)
The general equation, if you are interested, is

       Rd = 17.8E6 ( Ms*As*Isp*(1-Nd)*(1-Ns) )**0.5

       Rd = detection range, kilometers

       Ms = spacecraft mass, tons

       As = spacecraft acceleration, G

       Is = drive specific impulse, seconds

       Nd = drive efficiency

       Ns = "stealth efficiency", i.e. fraction of waste energy which
             can be magically shielded from enemy detectors.
```

Spaceship Combat

Subj: he who radiates is lost
b.evill@spamblocker.tyndale.apana.org.au (Brett Evill) wrote in rec.arts.sf.science:

>So, what are plausible technologies and tactics for space combat?
>
>Missiles/torpedoes will be vulnerable to ECM, I guess. Will it be possible
>to have guided-missile frigates in space with buckets of ECCM, guiding
>their torpedoes by remote control?

Lightspeed communications delay makes guiding anything by remote control pretty much unworkable. Everything must be self-guided over the sorts of distances likely to be involved.

ECM is of limited usefulness in space battles, where ships and weapons will be seperated by vast empty distances. It's harder to confuse the enemy about where you are in such an environment. Of course since ECM isn't tremendously hard, and the enemy is going to see you even if you don't use it, it will probably be used. Just not to huge effect.

>Will it be worth attempting stealth technologies to avoid observation, or
>is IR always going to give you away? How conspicuous will spaceships'
>drives be at range?

Stealth is only useful under very limited circumstances. You have to build a huge radiator structure to dissipate heat in one direction, you can't accelerate at any point in which you are in the enemy's view, and you are screwed if he has sensors in the direction you are radiating heat from. In other words, it could be useful to sneak your ships into close range from deep space for an intricately planned surprise attack (involving months drifting under special radiator shields, and then ditching the shields when you reach the point where you will be detected anyway). It is not a useful strategy in battle. Sensors small enough to be carried on board (large) ships could detect pretty much any engine in operation anywhere in the solar system.

>Will spaceships be painted black to prevent telescopic detection, or
>mirrored to bounce laser-beams?

A mirrored surface probably wouldn't be very useful. It would only affect lasers, and even then would only reduce the power of the laser attack for a fraction of a second before the mirror at that spot boiled away.

>Perhaps ships with heat-superconducting
>armour will not be susceptible to significant damage by laser beams,

"Heat-superconducting armor"? To my knowledge, no such thing exists. Normal superconductors superconduct electricity, but _not_ heat.

>How effective are nuclear warheads going to be in space?

They will destroy a ship if they explode very close to it. If they don't explode very close, then they are little more than an annoyance that blinds exposed sensors. Even the largest warheads won't seriously damage a shielded space warship if they explode over a kilometer away, and in space a kilometer is pretty short range.

>Sure they won't
>do blast damage, but neutrons and gamma-rays might still be effective.
>What about nuclear claymore mines? Nuke-pumped grasers?

Nuclear-pumped lasers would do impressive damage, if they hit. If you're in a situation where it is easier to evade beam weapons than to hit with them, and each side fires a hundred laser pulses for every one that hits, then nuke-pumped lasers aren't very useful because they only fire one shot, and a short one at that. Tremendous power only matters if you can be reasonably sure of a hit.

>Are KE weapons going to be effective, or is guidance and delivery going to
>cause problems? A ship might kill itself running into a crowbar, but how
>easy is it to get a crowbar in front of a ship?

Crowbar-sized objects would have to be guided, and subject to countermeasures. Filling the area around a ship with pebble-sized or smaller debris, however, will cause serious damage unless it can outright fly around the area.

>What ranges are plausible for engagement? Are these long enough that
>random evasion will be effective against beam weapons?

Range is entirely dependant on the sorts of weapons used. Spacecraft may launch missiles at _huge_ distances, depending on the technology, and most of the battle may consist of trying to keep the other guys' weapons out of range. Beam weapon engagements between opponents reasonably capable of manouvering, will happen at a few hundred thousand kilometers at most, otherwhise virtually every shot will miss.

At a guess, though, space battles will not involve a lot of strategic manouvering. Both sides know where the other guy is, where the other guy wants to go, and roughly what course he has to take to get there. If one side wants to completely avoid the other and has any capability of doing so, they do, and no battle happens. Otherwhise the "battle" is a pretty straighforward approach of the two forces, with both conducting small manouvers to make sure the enemy doesn't hit them from extreme range. At some point before firing starts, both sides launch their long-range missiles, and possibly a screen of interceptors. As the missiles and interceptors pass each other, they duke it out with energy weapons, kinetic-kill, and a few nukes and then whatever is left from each side's launch goes past toward the opposing fleet. Each fleet uses point-defense countermeasures against the enemy, tries last-minute invasions, and then takes whatever damage the missiles deal. Repeat this for multiple volleys of missiles, until the fleets are within a few hundred thousand kilometers when they start pelting each other with energy weapons. They can fly past each other shooting, in which case likely one side or the other will be utterly destroyed, or one side can decide it is defeated and try to break off from battle as quickly as possible, preserving what it has left. This may not be feasible depending on how remaining fuel reserves compare to their velocity.

The dominant rules of space battle are:

1. You can't hide. The enemy probably knows where you are the moment you launch.

2. You can run or fight, but you will typically have to pick one of the two long before battle is joined, and then you're stuck with it.

3. There isn't much room for tactics and strategy. Pretty much everything is automated, and the what your computers calculate as the best possible attack strategy probably really is the best possible attack strategy. If battle is joined, and both sides have a good idea of what the capabilities of the other side's ships are, the result will be a lot more predictable than we are used to.

4. If the engagement moves into short range (ie beam weapon range), it will probably be decided in a single pass. This is because at those kinds of ranges, it is very easy to hit the enemy and very hard to avoid being hit. Both sides will keep hitting each other with deadly accuracy until one of them is no longer capable of shooting. The exception is if both sides pass each other at _extremely_ high speed, but this isn't

likely to happen if the primary objective of one side is to do as much damage to the other side as possible (in which case it will decelerate, slowing relative velocity).

5. You may know where the other guy is from extreme range, but due to lightspeed delay, none of your weapons actually have a chance of hitting him until they get fairly close. The range of the weapons themselves isn't the determing factor at all, range of engagement is determined by the size and manouverability of the enemy. Thus, your weapons are effective against large, stationary, or slow-moving targets at far, far longer ranges than they are against the average warship.

6. Anything which can't manouver had better be very heavily protected, or had better not let you get anywhere near it. This tends to elimenate the "happy medium" of space stations, they die if an enemy fleet gets in close. Anything that can't move, and move fast, had better have huge amounts of shielding and lots and lots of countermeasures, point-defense, and whatnot. Only fortified targets on planets, moons, or within large asteroids have a chance of surviving a close attack by an enemy space fleet. These bases will compensate for their lack of mobility with means of defense that spacecraft cannot have due to weight restrictions. They will be extremely heavily armored (probably with most of the important parts deep underground), and have large numbers of defensive batteries that can destroy spacecraft at long range simply by putting up so much fire that something is bound to be hit.

7. The most effective way to destroy planetary installations is not by using warships, but by using the warships to clear out enemy space forces so you can bombard the planet with asteroids or mass nuclear assault. Conventional invasion is effectively impossible, since the defenses will destroy your invasion force if they are stil functional, and the only reliable way to take out the defenses is with mass bombardment. A successful planetary assault will not allow you to capture any installations intact except those that are deep underground, and to capture those you have to send in ground forces that were very expensive to transport across space. This means capture of installations isn't really a viable alternative, unless you get the enemy to surrender upon the threat of destruction.

6. Weapons & Explosives

Contemporary Weapons

Note: all pistol figures assume JHP ammunition.

.357 Magnum	90	2.5	8
.40 S&W	92		
.45 ACP	90	2.4	8
.44 Magnum	88	2.9	
.223/5.56	96		
.308/7.62nato	98		
12ga slug	98	3.5	8
12ga buck	93	2	
12 ga bird	50???	1	2

“Stopping power” is probability of incapacitation within 10 seconds from one torso shot. This is from Marshal & Sanow, whose method is highly suspect and who refuse to submit their data for peer review, so it should be taken with a grain of salt.

Explosive Yield

TNT yields 4.5MJ/kg.

Objects moving at about 3km/s have ke roughly equal to the explosive energy yield of the object's mass of TNT.

Armor penetration

Weapon	*HE mass*	*Diameter*	*Penetration*	*HEtoPen*	*Ratio Diameter to Pen*
RPG-7	2.25	85mm	400mm	178	4.7
AT-6 Spiral	8	140mm	800mm	100	5.7
AT-5 Spandrel	4?	155mm	750mm	188	4.8
AT-3 Sagger	3	119mm	410mm	137	3.44
M47 Dragon	2.45	127mm	600mm	245	4.7
TOW (Improved)	3.9	152mm	700mm	180	4.6
TOW 2	5.9	152mm	800mm	135	5.2
Mamba	2.7	120mm	500mm	185	4.2
MILAN	3		650mm	215	
HOT	6	165mm	800mm	133	4.8
Carl Gustav FV597	4	84mm	900mm	225	10.7
Carl Gustav FV551	3.1?	84mm	400mm	130	4.7
LAW80	4	94mm	600mm	150	6.3
55mm AP rocket	3	55mm	800		
30mm grenade	.5	30mm	140	250	
Medium AP rocket	4	125mm	1250	330	

data source Jane’s Infantry Weapons 1997; last three are fictional

Shaped charge explosives: Properly placed, 1kg HE will achieve a penetration (in one direction) of about 200mm steel.

Armor values

RHA = 3x Al = 2x Kevlar; e.g. 50mm RHA = 150mm Al = 100mm Kevlar

Optics: laser beam divergence angle, spot intensity, and telescope resolving power equations

$I=(P/[(L/F)(L/F)])/((R)(R))$

where

I= delivered energy intensity (watts/cm squared)
P= discharge energy (watts)
L = wavelength (cm)
F = focal value (cm)
R = range (cm)
L/F = divergence angle (radians)

Laser beam divergence and spot size:

theta = (wavelength * 720)/(pi^2)(beam diameter)

and

spot size = tan(theta) * range * 2

In the equations above, theta is beam divergence in degrees, other units are meters. Sample wavelengths: 400 nanometers (4.0x10^-7 m) is violet/near UV, 650nm is red.

Rule of thumb for visible-wavelength optics (accurate to a first order approximation, but neglecting wavelength and other factors):

spot size = distance/diameter/1,000,000

This works for laser spot size and telescope resolving power. It is probably optimistic by a factor of 2 or so.

Shipboard laser spot sizes (at 400nm) for optics diameter:
Shipboard 10m: 1m spot at 10,000km.
Shipboard 1m: 1m spot at 1,000km.

Smallarms laser spot sizes (at 400nm) for optics diameter:
10mm: 10mm spot at 100m.
20mm: 5mm spot at 100m; 20mm spot at 400m.
40mm: 5mm spot at 200m; 10mm spot at 400m.
100mm: 10mm spot at 1km.

Alternative formula
spot size = 2.44 x wavelength x distance / aperture.

(4x10^-7 = 400nanometers which is approximately the threshold between violet light and near UV. Red light is about 650 nm.)

7. Telescopes

Detection

Magnitude Table.
each magnitude is 2.512 times brighter than the next

Magnitude	watts per square meter	example/notes
-27	1000	the Sun from Earth
-17	.99	

-7	9.99x10e-6	
0	1.5x10e-8	
1	6x10^-9	
2	2x10^-9	
3	9.99x10^-19	
4	3.97x10^-10	
5	1.58x10^-10	
6	6.3x10^-11	
7	2.5x10^-11	limit of naked eye visibility
8	9.9x10^-12	
9	3.9x10^-12	visible in good binoculars
10	1.58x10^-12	
15	1.58x10^-14	visible in 12 in. telescope
20	1.58x10^-16	
25	1.58x10^-18	

Intensity of light at range: compute the area of the sphere (4(pi)r^2) with a radius equal to range. Divide light source intensity by area of sphere.

Resolving power

Rule of thumb for visible-wavelength optics (accurate to a first order approximation, but neglecting wavelength and other factors):

spot size = distance/diameter/1,000,000

This works for laser spot size and telescope resolving power. It is probably optimistic by a factor of 2 or so.

For recon satellites, a 1 meter telescope could resolve perhaps 20mm from LEO.

Alternative formula
spot size = 2.44 x wavelength x distance / aperture.

(4x10^-7 = 400nanometers which is approximately the threshold between violet light and near UV. Red light is about 650 nm.)