Hive, Queen, and Country

Vehicle Design Rules V0.9

November 13, 2012

A Warning

The Design Rules in this document are detailed and require knowledge of basic algebra (addition, subtraction, multiplication, use of formulas and functions). There is nothing that a scientific calculator or spreadsheet program can't cope with, but this sort of recreational math is anathema to you, this is probably not the rule system for you. You may want the Basic Design Rules, which will be available on http://www.hivequeenandcountry.com/

Thanks

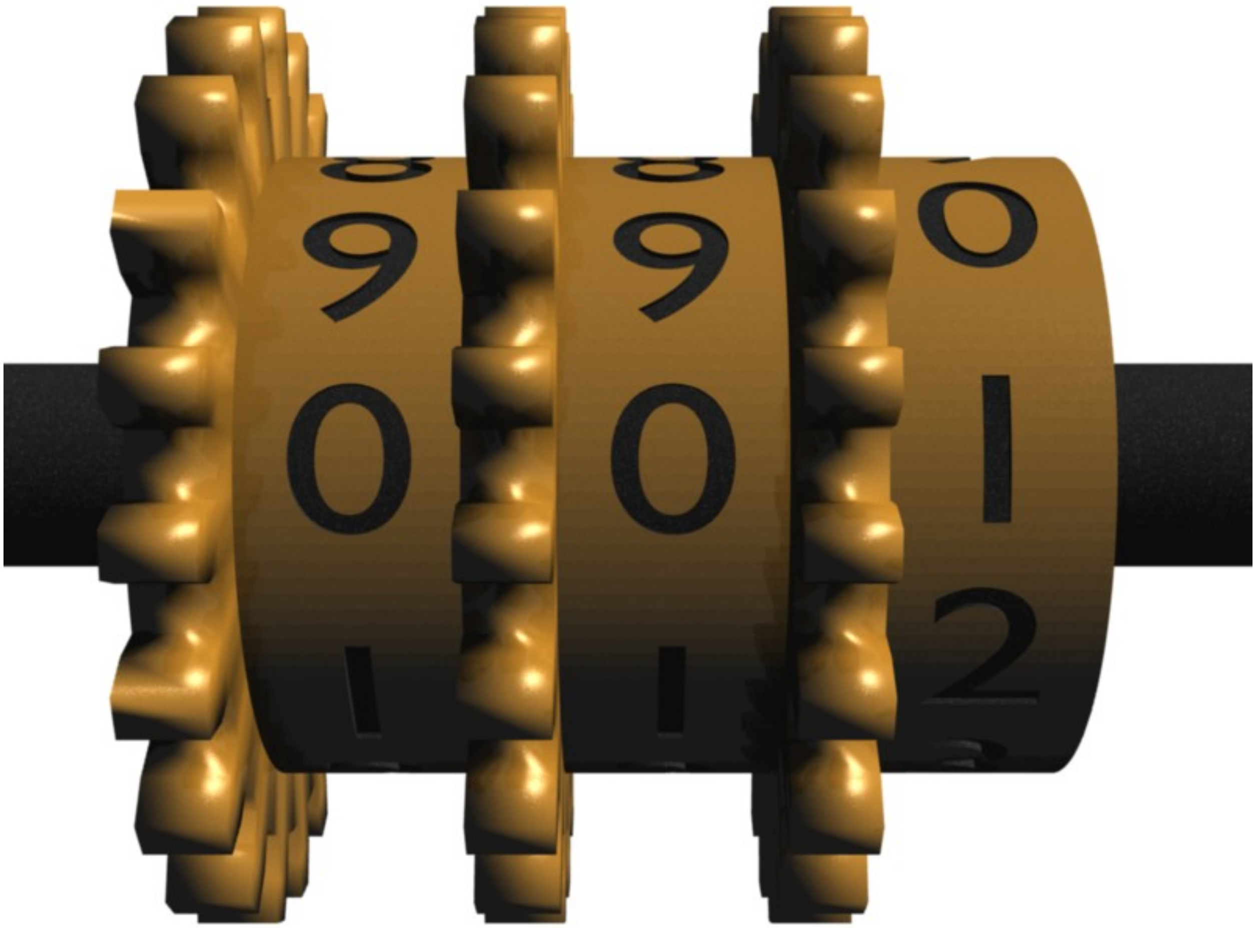
Photography by Terry Sofian and Shannon Sofian

Thanks go out to the amazing folks from the Hive, Queen and Country Yahoo! Group. Everyone there contributed but particular mention is deserved by: Alan Hamilton, Michael Fischer, Thomas Barnes, Donald McDonald, Brian Barrett, Phyllis G. Crecelius, David Tanner, Andrew Webb, Paul Mannering, Jon Klement, David Tanner, Gorka Martinez Mezo, Nick Johnston, David Schuey, Mike Creek, Raymond Parks, Dirk Festerling, Grant McKenna and Doug Holverson

Table of Contents

List of Tables

1.Introduction



1.1 What's in this Book

This book is a supplementary text for the Stars of Empire Roleplaying Game [***1***], and the *Flying Machines of the Worlds: 1902* source book [***2***]. This book provides the detailed design rules for aircraft in the Hive, Queen, and Country setting. It includes:

- A detailed system to design your own aircraft (Sections 2-3)
- Example designs (Section 4)
- A system for designing custom vehicle components such as engines and airfoils (Section 5)

1.2 A Note on the Current Date for Players and Referees:

All the Hive, Queen, and Country products are set in an imaginary timeline that diverges from our own in the late 1700s and becomes increasingly different as it moves forward. The original campaigns were set in the years 1891-1893 which were those of the original Hive War, which latterly became known as the First Hive War or Anglo-Hive War. Stars of Empire is explicitly set in the years before 1894. All timelines march forward and that of the HQC Universe is no exception. This book is set in the year 1902, when the Second Hive War is at its peak, and covers many of the flying machines used in that conflict.

The people of Hive, Queen, and Country have been flying since the 1860s, and had mechanical computers since the 1830s. By the 1900s, aircraft have been being designed for 40 years, and computation has advanced the state of the art by another 5-10 years. Thus, the ships of the 1900s are in many ways more advanced than the aircraft of the late 1930s in our timeline (OTL). Unlike OTL, air travel has caught on much more quickly because Aerolyth is so much more effective. Additionally, with space travel being a reality, the people of HQC have discovered some aspects of high-speed aerodynamics. Even though steam engines and internal combustion engines (ICE) are only 10-15 years more advanced than our time line, the aircraft are much more aerodynamic.

1.3 Flying Machines of the Worlds: 1902

This book is a free supplement for *Flying Machines of the Worlds: 1902, a* source book for the Hive, Queen and Country Universe. *Flying Machines* introduces Victorian Science Fiction Roleplayers and War Gamers to the many aerial vessels of that Universe. Whether in the skies of Earth, Mars or Venus these powerful machines provide swift transport or deadly combat capabilities. This volume, heavily illustrated in full color, is modeled on period publications such as Jane's or The Naval Annual; Flying Machines of the Worlds features designs for 111 ships for use in any Steampunk or Victorian Science Fiction setting. In Hive, Queen and Country these are the vessels that patrol the skies of Earth, have fought with the Hives and are now opening the frontiers of Mars and Venus to colonization.

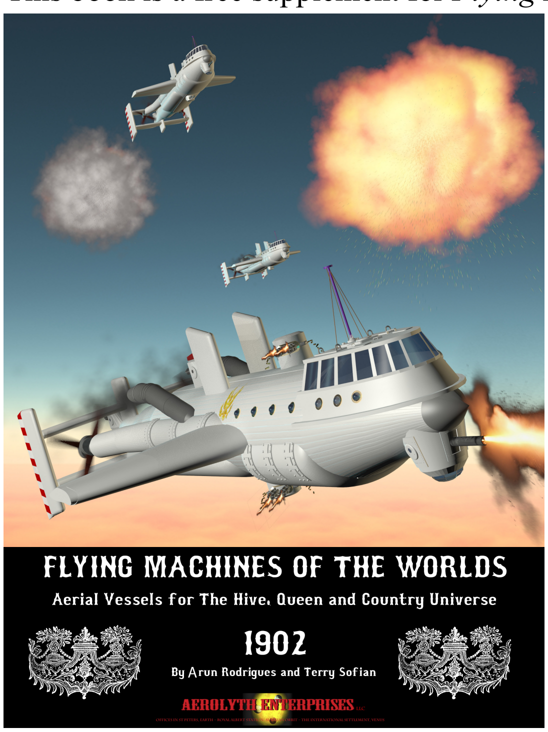


Figure 1: Flying Machines of the Worlds: 1902

This 256 page full color book includes:

- Details on the aerospace technology and how it can used in a Stars of Empire adventure
- Descriptions of many of the ships which populate the skies of the HQC Universe
- Real World Vehicle Statistics to allow conversion to any combat rules
- Notes on Currency and Unit conversions
- Referee's information on the HQC universe

- A scratchbuiling/kitbashing chapter including detailed directions on how to build your own Shakespeare Class Aerolyth Flyer

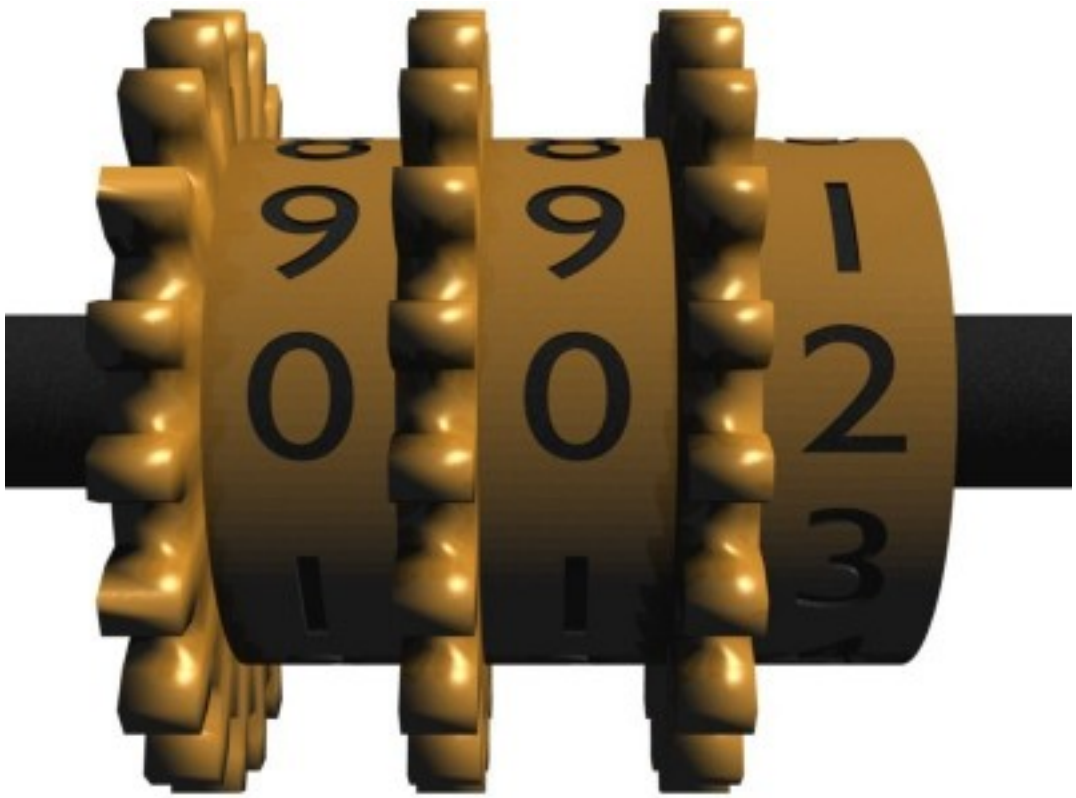
Flying Machines is available from:

- **Createspace**: https://www.createspace.com/4015022
- **Amazon**: http://www.amazon.com/Flying-Machines-Worlds-1902-Universe/dp/1480035815/
- **RPGNow**: http://www.rpgnow.com/product/106515/Flying-Machines-of-the-Worlds-1902

A line of miniatures based on the ships from the book are available from:

- **Objects May Appear…**: http://www.shapeways.com/shops/objects

2.Key Principles in Vehicle Design



The process of vehicle design is an extension of the “Inventions and Major Projects” system found in the core Stars of Empire game book. The goal of this process is not simply to allow the player to generate a bland series of statistics, but to create a vehicle with **personality**. Engineering a complicated system like a vehicle is never a straightforward process where the end result is simply the sum of the individual parts. Complicated systems always end up behaving slightly differently from their expectations, sometimes better, sometimes worse.

For this design system, the basic process is that the player comes up with a high level design for the ship (Historically known as a “Spring Style” in the United States) that is handed off to low-level designers to “fill in the details.” These designers finish the design and hand it off to builders who actually construct the ship.

The most important thing in the design process is that these rules are only a starting point. The Player and Game Master should feel free to add to them, expand on them, or ignore the rules as best fits their game and playing style.

Sidebar: The Design Process
The process of designing and producing a ship can be a lengthy one (see Sidebar, page 11). For a certain type of gamer this will be seen as a positive thing, but for others it will be seen as a daunting task. Understanding these rules will require roughly 8th Grade (US) math skills. It is thus left to the GM to simplify the process as needed to fit the occasion and temperament of the end consumer. In other words, feel free to skip the dull bits.

2.1 Design Process

The process of designing a ship involves several steps:

1. **Create Requirements** (3.1, p14): Deciding what the ship should do.
2. **Assemble Design Team** (3.2, p15): Finding a team to do the low-level design work
3. **Create "Spring Style"** (3.3, p19): Creating a high level design for the ship. This is the major task in the design process, and involves selecting all of the major components and systems for the ship.
4. **Calculate Performance** (3.4, p68): Calculating the performance of the "spring style" design. This computes the maximum speed, altitude, and maneuverability of the craft. Afterwards, if the performance does not meet expectations, it may be necessary to modify the Spring Style.
5. **Design the Ship** (3.5, p72): The Spring Style is handed over the to low-level design team to turn it into a complete design. Depending on the skill of the design team, they may introduce faults or make improvements.
6. **Build the Ship** (3.6, p74): The ship is built and its total cost determined.

2.2 Units & Notation

Unless otherwise specified the convention is to use the following units:

- Watts (W) for Power.
- Kilograms (kg) for mass
- Cubic Meters (m^3 or m^3) for volume
- Square Meters (m^2 or m^2) for area
- Instructions Per Minute (IPM) for compute power
- Drag is specified in a unit that is equal to square meters times a drag coefficient.

Sidebar: The Design Rules' Design Rules
Playability & Game Balance
Allow Big Machines
Keep things Victorian: Prefer mechanical to electrical, steam to gas
Bend the Laws of Physics, but try not to break them
Pictures are pretty, not schematic
Designs are "Geometry Neutral"
"Two Level" design

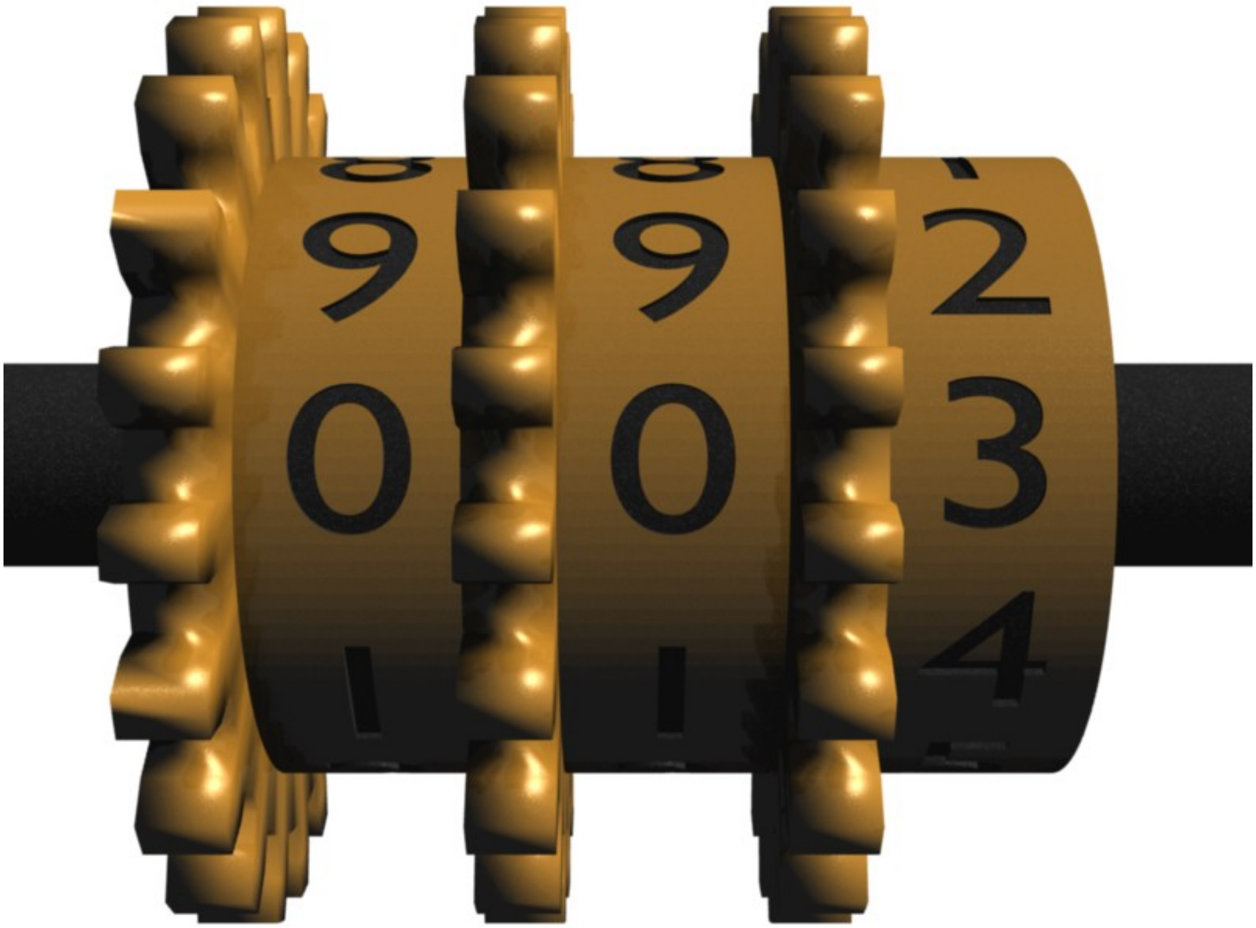
Equations used in this section use the following notation:

- x^y or x^y: raise the variable x to the y^{th} power.
- ceil(x) or $\lceil x \rceil$: Round the variable x up to the next highest integer. E.g. ceil(3.4) = 4.
- floor(x) or $\lfloor x \rfloor$: Round the variable x down to the next smallest integer. E.g. floor(3.4)=3.
- max(x,y): Choose the higher of two or more values. E.g. max(3,7)=7

2.3 A Note on Roll Modifiers & Rule Systems

These design rules are generally designed to be generic and not tied to a specific set of wargame or role-playing rules. However, some roll modifiers for vehicles are provided which can be used as a guide for conversion to specific game systems. These modifers are based on a d20 system, so, as a rough guide, a +1 is a 5% increase in probability.
Specific conversions to other rule systems can be found at
http://www.hivequeenandcountry.com/

3.The Vehicle Design Process



3.1 Create Requirements

The Player should first decide what they want the vehicle to do, how they will go about building it, and who will be using it. If part of an adventure, this may lead to further diversions – if designing a military ship, the Player may have to convince a Government to provide backing. If the ship contains some exotic technology, like Venusian

Sidebar: Design Checklist
1. Create Requirements (3.1, p14)
2. Assemble Design Team (3.2, p15)
3. Create "Spring Style" (3.3, p19)
4. Calculate Performance (3.4, p68)
5. Design the Ship (3.5, p72)
6. Build the Ship (3.6, p74)

Lightning Guns, they may have to secure a source. The player will also have to decide how such a vehicle will be funded and secure that funding.

3.2 Assemble Design Team

Assembling a design team is a crucial part of the vehicle making process. A large vehicle may require a team of hundreds of engineers, draftsmen, and senior designers. Their skill will largely determine how well the high-level design is translated into a full set of blueprints.
Each design team is defined by four characteristics, the number of cards they can draw during the design phase, their modifier, their effective size, and their cost per week. Note, the "Effective Size" is not simply the number of individuals in the team, but an amalgamation of the number of individuals, their skill level, and the facilities available to them.

3.2.1 Existing Design Teams

A number of companies keep large design teams on staff. They are summarized in Table 1.

Table 1: Design Teams

Team Name	Cards	Modifier	Eff. Size	Cost/week	Notes
Sea King Air Guild	2	+5	75	£350	
Harper's Ferry Arsenal (<1895)	2	+10	120	£700	Larger Cayleys (>200m^3) (+5)
Harper's Ferry Arsenal (>1895)	3	+15	150	£875	Larger Cayleys (>200m^3) (+5)
Springfield Armory (>1893)	3	+15	75	£450	
Union Iron Works, St. Louis	3	+15	100	£800	
Union Iron Works, San Francisco	3	+12	275	£2300	Ships over 30m length only.
Union Iron Works, San Francisco + ABM	3	+12	410	£4500	+3 on automation systems
Detroit Dry Dock Company & Engine Works	3	+10	400	£3800	+4 on ships > 500 tons
Jiangnan Arsenal, China	2	+13	150	£1000	+2 for wooden framed ships
Fuzhou Arsenal, China					
Yokosuka Naval Yard, Japan	3	+13	350	£2200	
Mitsubishi (pre-1890)	2	+10	250	£1900	+1 for small craft (<1000m^3)
Mitsubishi (post-1890)	3	+14	350	£2600	+2 for small craft (<1000m^3)

Team Name	Cards	Modifier	Eff. Size	Cost/week	Notes
Buchanan Motor Works	2	+10	15	£135	+2 for single panel ships
C&R I (<1885)	2	+12	320	£2400	
Piaggio (<1895)	2	+12	60	£560	
Piaggio (>1895)	3	+12	240	£2250	+2 for air forts; +3 for fast Cayleys
Good	3	+15			
Ejército de Tierra (<1884)	2	+10	75	£560	
Ejército de Tierra (>=1884)	3	+12	225	£2000	
Armada Design	3	+10	250	£2500	
Herreshoff 1	3	+10	50	£400	Specialist in craft < 30m long (+5)
Admiralty Red	3	+15	500	£3500	
Admiralty Green	3	+10	250	£1600	+2 to Hybrid Air/Aerolyth ships
Admiralty Blue	3	+10	120	£760	
Royal Army Design Center	3	+12	120	£800	
Bureau Aerospatial	3	+13	75	£495	
Tata Design Center (Delhi)	3	+10	50	£350	
Tata Design Center (Bombay)	3	+10	50	£350	+3 to Zeppelin
Krupp Light Vehic	3	+10	60	£380	+5 to Cayley
Krupp Heavy	3	+15	300	£2000	
Thornecraft	3	+16	3000	£2200	
Hotchkiss	3	+12	250	£1800	+2 to Hybrid
Armstrong	3	+11	300	£1900	
Vickers	3	+15	200	£1600	
American Flyer Company Ltd.					
Imperial Russia	3	+12			
Specialist	3	+10			Specialists in engines (+7)
Omen Industries	3	+10	300	£1850	Elusive
Wadia	3	+10	400	£2600	
Wadia Light Craft	3	+12	150	£1050	

3.2.2 Designing a Design Team

A new design team can be created from scratch to work on a problem. The quality of a design team is determined by five factors: The workforce, the senior designer, use of Babbage machines, difficulty of the design, and “undefinables”. These characteristics determine the number of cards, the modifier, the effective size, and the cost per week of a team.

3.2.2.1 Workforce

The workforce includes the engineers, draftsmen, and technicians who convert the “Spring Style” into blueprints that the airyard can use to build the craft. The number of designers determines the base **Effective Size** of the design team. Their experience determines the base **modifier** and the **cost** per week per designer:

Designer	Cards	Modifier	Eff. Size	Cost/Wk
Novice		+4	1	£2 / designer
Early		+7	1	£4 / designer
Veteran		+8	1	£5 / designer
Exceptional		+9	1	£8 / designer

3.2.2.2 Senior Designer

The Senior Designer directs the team and determines the number of cards the design team is rated at. The senior designer determines the number of **cards** the design team has. The minimum number of cards for a design team is 2, the maximum is 4. When rolling for the number of cards, fractions should be rounded up.

Designers	Cards	Modifier	Eff. Size	Cost/Wk
Untried	1d20/8			£24
Mature	1+1d20/7			£80
Veteran	2+1d20/7			£250

3.2.2.3 Babbage Machines

Use of Babbage machines is de rigueur for any respectable design team. Babbage machines change the **modifier** and **Effective Size** for a design team. The change to the modifier and effective size is multiplicative. The cost is increased by an amount per designer and a fixed amount.

Designers	Cards	Modifier	Eff. Size	Cost/Wk
No Babbage Machines		*0.7	*0.9	0£
Limited Babbage		*1.0	*1.0	£3 / designer + £50
Advanced Babbage		*1.2	*1.1	£4 / designer + £100

3.2.2.4 Difficulty of Design

The difficulty of the design has an impact on the **modifier** and **Effective Size** for a design team. The change to the modifier and effective size is multiplicative. The effect is determined by the Game Master. As a rough guide, simple modifications to an existing design would be a simple design, and a difficult design would include using unusual technologies.

Designers	Cards	Modifier	Eff. Size	Cost/Wk
Simple Modification		*1.4	*1.4	
Normal Design		*1.2	*1.2	
Difficult Design		*1.0	*1.0	

3.2.2.5 "Undefineables"

There are a number of "undefinables" that determine how a team works together. Leadership, teamwork, and luck all play a role. These affect the **modifier** and **Effective Size** for a design team.

Designers	Cards	Modifier	Eff. Size	Cost/Wk
"Undefinables"		*1.02-1.4	*1.02-1.4	

To determine the multiplier, roll 2d20, divide by 100, and add this to 1.0. For example, a roll of 6 and 12 would mean a multiplier of 1.18. The "undefinable" effects are multiplied by the "Difficulty of Design" and "Babbage" effects, which are modified by the base designer modifiers and effective size. The result is rounded up.

Example: A small, talented design team.

	Cards	Modifier	Eff. Size	Cost/Wk
100 Exceptional Designers		+9	100	£800
Mature Senior Designer	3			£80
Advanced Babbage		*1.2	*1.1	£450
Modification		*1.4	*1.4	
Undefineables		*1.24	*1.21	

ceil

Team Name	Cards	Modifier	Eff. Size	Cost/week
	3	+19	187	£1330

Example: A larger, low cost design team

	Cards	Modifier	Eff. Size	Cost/Wk
300 Novice Designers		+4	300	£600
Untried Senior Designer	2			£24
No Babbage		*0.8		
Normal Design		*1.2	*1.2	
		*1.3	*1.35	

Team Name	Cards	Modifier	Eff. Size	Cost/week
	2	+5	486	£624

3.2.3 Party as Design Team

A character may also act as a senior designer. Use the rules from p155 of the Stars of Empire book to calculate the number of cards, treating the design process as a "hard" or "masterful" invention, depending on the difficulty of the design.

3.3 Create "Spring Style" Design

The most important part of the design process is creating the high-level design, or "Spring Style." The Spring Style design is a specification of the different components that make up a ship. For this design system, it is not necessary to specify exactly how the components fit together or where they are located in relation to each other.

For each system, note the volume, the mass, and the power. Some systems may have additional requirements such as crew and "IPM". IPM stands for "Instructions per Minute" and is an indication of how much computing power is required to operate that system.

For most system, the player has the option of selecting a commodity component, or designing a component from scratch using the rules in Section 5.

Example: A spreadsheet program can be very useful for the design process. There are several free spreadsheet programs available, such as OpenOffice, Google Docs, Zoho Sheet, or Gnumeric. At the very least, a calculator would be handy. A spreadsheet allows the designer to keep track of the Mass, Volume, Power, and Crew requirements for different ship systems.

A convenient notation is to set up columns for the name, mass, volume, and power of all the systems in a ship. To make the 'accounting' easier, the designer can use a negative number for the hull volume and power produced by the engine. Any system that consumes volume or power is a positive number. Then, simply sum the 'Volume' and 'Power' columns. If the result is less than or equal to zero, the design is acceptable. If these columns sum is greater than zero, they need a bigger hull or power powerful engine.

For example, part of the spreadsheet for a small aircraft may look like this:

System Name	Mass	Volume	Power	Crew	IPM
Hull Frame	100	-3.05			
3cyl 3L ICE Engine	60.5	0.1815	-17500		
Propeller (post-1885)	12.25	0.0175	15500		
Generator 1 KW (1875)	9	0.019	1000		
Cargo	500	1	1000		
Crew Station	15	1.5			
Crew	95	0.005			
SUM	791.75	-0.327	0		

In this example, the hull volume is negative, and the ship has about 0.3m^3 of space left at the end of the design. The engine power is also negative. The generator's overhead is counted as power consumption (i.e. a positive value) as is their cargo's power consumption.

3.3.1 The Hull & Armor

3.3.1.1 Hull Frames

Select a Hull Frame from Table 2 or design one from Section 5.1. The Carried Mass of a hull is the maximum it can safely carry. The Volume of a hull is found by multiplying its Length (L), Height (H), and Width (W).

Table 2: Hull Frames

Design School	Material	L	H	W	Carried Mass	Mass	Build hours	Drag
Cayley	Iron	2.5	1.3	2	4991	214	713	0.21
Cayley	Steel	2.65	1	1.15	590	100	1000	0.092
Cayley	Steel	2.94	2	Open	9982	268	894	0.78
Cayley	Steel	3.14	2	2.44	6229	265	885	0.78
Cayley	Steel	4.88	1.86	2.44	21464	577	1921	0.36
Naval	Steel	4.88	2	2.44	19964	534	1778	0.39
Cayley	Steel	6	1.5	2	3950	408	2312	0.24
Cayley	Wood	6.5	1	1	3935	1769	2948	0.08
Cayley	Steel	7	1.5	2	4800	498	2822	0.24
Cayley	Steel	7	1.5	1	4000	775	4391	0.12
Cayley	Steel	8	2.5	2	15000	976	5530	0.4
Cayley	Steel	8.02	2	2.44	18700	859	2860	0.78
Cayley	Steel	8.85	1.3	1.5	10600	1054	7018	0.156
Cayley	Steel	9	1.5	2	3950	612	3468	0.24
Naval	Steel	9.76	3.9	2.4	34900	3777	6420	5.71
Naval	Iron	9.8	1.3	3	19964	3142	3142	2.34
Arch.	Steel	9.8	5.1	9.8	247600	4958	13387	52.4
Cayley	Steel	11	1.2	1	2940	728	2432	0.1
Cayley	Steel	11.4	1	1	2402	827	2754	.08
Cayley	Steel	12	2	2	3950	1026	5814	0.32
Cayley	Steel	13.5	3	1.5	6480	825	5500	0.36
Cayley	Steel	14.7	4.82	3.66	83062	3328	11100	1.41
Naval	Steel	17.1	3.8	4.9	129000	12768	21704	11.24
Cayley	Steel	17.1	7.32	7.32	204632	9460	63000	4.3
Cayley	Al	17.25	4.88	4.6	155000	4740	45820	1.8
Naval	Iron	19.6	2.5	4	79856	8925	8925	6
Zepp	Steel	20	5	2.5	40000	4933	25158	1.5
Naval	Steel	24.4	3.7	4.9	227500	31280	53175	10.84
Cayley	Steel	24.4	6.44	4.88	201350	11109	74000	2.51
Naval	Steel	26.9	7.2	13.5	604000	32668	32700	58.0
Naval	Iron	29.3	3.7	4	179676	20123	20123	8.88
Naval	iron	30	5	3	215612	28464	28464	9
Naval	Steel	30	5	4.88	344400	34816	118400	14.64
Cayley	Steel	34.6	4	7.7	187000	19214	57641	3.7
Naval	Steel	36.6	4.4	8.5	572000	56270	95700	22.54
Naval	Steel	43.9	4	11	955000	101283	172200	26.4
Naval	Steel	43.9	5.5	7.4	873000	72182	122708	24.16
Naval	Wood	54	12	13.5	958200	93000	46492	97.0

Design School	Material	L	H	W	Carried Mass	Mass	Build hours	Drag
Naval	Steel	56.6	8	7.6	921400	98300	167000	36.34
Naval	Iron	61	8.6	4	873428	110434	110434	20.64
Naval	Iron	63.5	8.6	3.9	908365	110395	110395	20.12
Naval	Steel	73.2	12	18.3	1820000	283400	850000	131.8
Naval	Steel	87.9	6	11	1607108	251054	426800	39.5
Naval	Iron	92.8	9.8	4	1517270	299562	299562	23.52
Arch.	Steel Rein-forced Concrete	109	107	28	$1.66*10^6$	$3115 * 10^3$	$4673 * 10^3$	3193

3.3.1.2 Special Hulls

Some non-standard hull features that may be selected:

- **Pressure Hulls**: Hulls that need to operate above 3,000 meters may need, and hulls which operate above 7,900 meters require a pressurized hull or pressure suits for the crew. Rules for this can be found in the section "Pressure Hulls" on page 82.
- **Modular Hulls**: Ships can be constructed so they can be broken down and reassembled. This is particularly useful for ships built on Earth and shipped in parts to other planets. The effects of a modular hull are summarized Table 3. Semi-Modular hulls are broken down slightly to allow for easier shipping and require a substantial shipyard to assemble. Standard modular hulls are broken into roughly 3m cubes, suitable for shipping off-planet and assembly with some tools. Man portable machines are broken into 35kg parts that can be transported by a person and assembled without specialized tools.
- **Open Deck**: Some vehicles have only a single deck, with the crew standing on top. These open-decked craft have their drag doubled. Their volume is calculated as if the height was 2m.

Table 3: Modular Hull Effects

Effect	Semi-Modular	Standard	Man Portable
Hull Mass increased by …	5%	10%	15%
Ship Design Time increased by…	5%	10%	35%
Hull Build Hours increased by…	25%	100%	200%
Total ship labor hours increased by…	5%	10%	30%
Reassembly requires labor equal to _____ of the original build costs	25%	10%	5%

Example: A Standard 11*1.2*1m Cayley Steel Hull has a mass of 728kg and requires 2432 hours to build. To make this hull Man-Portable the Hull mass would increase by (728*0.15)=109.2kg and its build hours would increase by (2432*2)=4863 hours. Its volume is 13.2 m^3.

3.3.1.3 Cladding / Armor

The hull may be covered to reduce aerodynamic drag and provide protection against the elements or hostile intent. Light coverings, such as canvas or aircraft fabric, provide protection against the elements, but only marginal protection against anything else. Heavier protection – armor – is required for more protection. To determine the mass of light coverings, multiply the covered area by the appropriate value from Table 4. To determine the mass of armor, determine the required thickness of the armor by the covered area and the appropriate value in Table 4. To determine the area to be covered, consult Table 5 for the calculation for the appropriate facing.

Vehicles can be made "open topped" by not including any top cladding or armor. This doubles the hull's drag.

Ramming Plates: A ship may be equipped with a ramming plate. This counts at 4.5 cm of steel armor across the front of the ship.

Table 4: Cladding and Armor Mass

Covering	kg/m^2	kg/m^3
Light weight aircraft fabric	0.11	
Light canvas	0.15	
Medium canvas	0.25	
Heavy canvas	0.35	
Teak		680
Pine		560
Elm		570
Oak		760
Concrete		2400
Granite		2700
Iron		7870
Steel		7900
Aluminum		2700

Table 5: Area Computations

Facing	Area Computation
Front	Width*Height
Back	Width*Height
Top	Width*Length
Bottom	Width*Length
Both Sides	2*Length*Height

Example: A hull has the dimensions 26.9*7.2*13.5 (L*H*W), in meters, and the following armor scheme.

Facing	Area	Covering	Mass Calculation	Mass (kg)
Front	13.5*7.2=97.2	Ramming Plate (4.5cm steel)	0.045*97.2*7900	34554.6
Back	13.5*7.2=97.2	Heavy Canvas	0.35*97.2	34.02
Top	13.5*26.9=363.15	2cm Steel	0.02*363.15*7900	57377.7
Bottom	13.5*26.9=363.15	2cm Steel	0.02*363.15*7900	57377.7
Sides	2*26.9*7.2= 387.36	2cm Steel + 1cm Elm	0.02*387.36*7900 + 0.01*387.36*570	63410.8
		Total		212754.82

Armor strength is a factor of material density, flow or plastic yield strength, and shear yield strength [*3*].

3.3.2 Lift Systems

To fly, an aircraft must produce lift. The available lift systems are Aerolyth, Aerodynamic Lift (Cayleys), and lighter-than-Air lift.

3.3.2.1 Lift systems: Aerolyth

Aerolyth is generally produced in standard panels that are 2.44m by 1.22m by 47.5mm and masses 405.8kg (0.141m^3). The panels are polished to a high sheen to maximize lift. Scratching or chipping of the panels reduces this lift considerably, so it is customary to provide a 5% margin of safety in lift. An Aerolyth panel produces a fixed amount of lift when supplied with electricity, causing the craft to rise to a certain altitude above sea level (see Table 6). A charged Aerolyth panel produces a lifting force of 48912 N on Earth. The force produced on other planets is proportional to the local gravitational field. I.e. a panel on Mars, with a gravitational force of 0.376 g, would produce 18391N. Multiple panels must be combined together in an "array" that uses specialized braces to avoid damaging Aerolyth interactions. The design of these arrays is a major expense. To compute the mass that an Aerolyth panel can lift, divide its lift in Newtons by the acceleration of gravity in the local environment (i.e. 9.8 on Earth, 3.7 on Mars, 8.9 on Venus, or 1.6 on the Moon).

Non-standard panels are less efficient, but are sometimes used. They can be designed using the rules in Section 5.1.

Table 6: Aerolyth Altitude Levels

Input power	Lift / Panel	Earth Altitude	Moon Alt.	Mars Altitude	Venus Alt.
1kW/Panel	48912N /g	2 kft / 610m	0.5 kft / 150m	1 kft/ 300m	
2kW/Panel	48912N /g	12 kft / 3660m	3 kft / 910m	6 kft/ 1830m	
4kW/Panel	48912N /g	45 kft / 13720m	12.25 kft / 3730m	22.5 kft / 6860m	
8kW/Panel	48912N /g	600 kft / 182880m	150 kft/ 45720m	300 kft / 91440m	

A ship can only carry a single layer of panels. To determine the maximum number of panels that can be placed on a ship, use the formula: floor(L/2.44)*floor(W/1.22); where L is the ship length in meters, W is the ship width in meters.

Example: A hull has the dimensions 26.9*7.2*13.5 (L*H*W). The number of Aerolyth panels it can house is floor(26.9/2.44)*floor(13.5/1.22)=11*11=121. These 121 panels mass 405.8*121=49101.8kg. If they are supplied with 484 kW (4 kW/panel) on Earth they can rise to an altitude of 13720m and lift 603913kg.

3.3.2.2 Lift systems: Aerodynamic/Cayley

Select a wing from Table 7 or design a custom wing with Section 5.1.4.

Table 7: Wings

Name	Dimensions (span*chord) (m)	Stall Speed (m/s)	Mass (kg)	Drag (C_d*S)	Max Lift (kg)
1870-High Lift-	7.5*1.5	27.7	688	0.87	3935

Name	Dimensions (span*chord) (m)	Stall Speed (m/s)	Mass (kg)	Drag (C_d*S)	Max Lift (kg)
triplane					
1870-High Lift-biplane	7*1.167	19.4	319	0.416	980
1875-Low Drag-monoplane	7.25*1.813	24	255	0.193	788
1880-High Lift-biplane	9*1.5	12.7	538	1.179	2160
1885-Low Drag-monoplane	7.75*1.938	14.5	294	0.566	1201
1890-High Lift-biplane	11*1.833	15.8	884	1.273	4033
1895-Low Drag-monoplane	8.25*2.063	20	353	0.336	1701
1880-High Lift-monoplane-tapered	15*5	36.0	2019	3.92	39375
1880-High Lift-monoplane-tapered	6.75*1.5	33.9	229	0.46	5315
1880-High Lift Mono	24.5*15.3	19.7	31650	53.5	49000
1880-High Lift – monoplane	2.6*1.7	20.3	69	0.32	590
1885-Low Drag-monoplane-tapered	10.5*3	43.8	820	0.906	18900
1885-Low Drag-biplane	8*2	21.5	643	0.943	4800
1890-High Lift – monoplane	19.52*4.88	27.3	2540	3.0	23200
1890-High Lift – monoplane - tapered	16.95*6.78	20.0	1753	4.08	12834
1890-High Lift-Biplane	33*4.6	16.5	8148	21.45	58100
1890-High Lift-Quadruplane	10.95*5.475	14.1	3767	7.1	9982
1890-High Lift-Monoplane- tapered	4.8*3.2	43.3	212	0.62	6800

Name	Dimensions (span*chord) (m)	Stall Speed (m/s)	Mass (kg)	Drag (C_d*S)	Max Lift (kg)
1890-High Lift – Triplane	4.5*3.25	13.6	676	1.4	1500
1895-Low Drag – Monoplane	6.52*5.87	29	600	0.77	4125
1895-Low Drag-Biplane	7.9*3.6	27.6	920	1.0	6900
1895-Low Drag-Monoplane	6*2.7	61	331	0.37	12000
1895-Low Drag-Monoplane	9.3*5.6	34.7	878	1.16	10600

Wings can be armored using the “Cladding/Armor” Rules above. The Surface area of a wing is the span*chord*2.
Craft may have multiple sets of wings, but the sum of the chords of the wings must be less than 1/3 of the ship length.

3.3.2.3 Lift Systems: Lighter-than-air

Some vehicles use buoyancy to maintain lift rather than other more “active” systems like Aerolyth. To design a lighter-than-air lift system, use Table 8 and the following procedure:

1. Choose the type of gas used to provide lift. Hydrogen is relatively rare in Earth vehicles, but is commonly used by some communities on Venus.
2. Compute the necessary lift in Newtons by multiplying the maximum mass of the vehicle (in kg) by the acceleration due to gravity (9.8 for Earth, 8.9 for Venus, 3.7 for Mars).
3. Compute the necessary volume for the lifting bag by dividing the necessary lift by the gas lift (column 4 in Table 8). Note: this volume is usually placed outside the vehicle body and this does not count against the frame’s volume, but can be placed inside.
4. Choose the shape of the lift bag: sphere or cylinder. For a cylinder, choose the length of the cylinder in meters.
5. Compute the surface area of the lifting bag using the equations below, where V is the volume of the bag, L is the length of a cylinder, and pi is 3.14159.
    a. For a sphere, the area is $4\pi * (\frac{3}{4\pi}V)^{\frac{2}{3}}$
    b. For a cylinder: 2*pi*L*(((V/l)/pi)^(1/2))
6. Compute the mass and power requirements for the gasbags using Table 8.
7. Compute any additional (optional) outer surface covering by multiplying the surface area (computed in step 5) by a cladding mass from Table 4.
8. Compute gasbag support structures from Table 9. L=bag length, D=diameter.
    a. For a sphere, D=2*((3/(4*pi))*V)^(1/3)
    b. For a cylinder: D=2*(((V/L)/pi)^(1/2))
9. Compute drag, using the equations below where C=0.18 for Earth designs and C=0.1 for Venusian Sky Pirate Designs.
    a. For a sphere: C*pi*((3/(4*pi))*V)^(2/3)

    b. For a cylinder: C*pi*(((V/L)/pi))
10. The total effective mass of the lift system is the combination of the lift bag and support structures

Example: A lighter-than-air lift system for a ship with a mass of 5000kg on Earth.

1. This system will use Helium
2. The necessary lift is (9.8*5000)=49000N
3. The necessary volume is (49000/10.01)= 4895.1m^3
4. The lift bag will be a cylinder 30m long.
5. (b) The Surface area is 2*pi*30*(((4895.1/30)/pi)^(1/2)) = 1358.44m^2
6. The mass required for the lift bag is (0.29*1358.44) = 393.948kg
7. There is no additional covering
8. The Diameter of the bag is 2*(((4895.1/30)/3.14159)^(1/2))=14.41m. Longitudinal Framing requires ($3.0*10^{-5}$ * 30^3 * 14.41)=11.7 kg. Transverse Framing requires ($1.3*10^{-3}$ * 30 * 14.41^3)=116.7kg. Netting & Wires require ($7.5*10^{-4}$ * 30 * 14.41^3)=67.3kg.
9. (b) Drag is 0.18*3.14159*(((4895.1/30)/3.1415))=29.37
10. The total effective mass of the lift system is the combination of the lift bag and the support structures: (393.948+11.7+116.7+63.7)= 586.048kg

Table 8: Lighter-than-air Lift Systems

Gas Type	Mass (kg/m^2)	Power (W/m^2)	Gas Lift N/m^3
Hot Air 100°C	0.11	1900	3.15
Hot Air 150°C	0.15	2250	4.17
Hot Air 200°C	0.19	2450	4.97
Hydrogen	0.29	0	10.88
Hot Hydrogen	0.29	100	11.38
Helium	0.29	0	10.01
Coal Gas	0.15	0	7.16

Table 9: Gas bag Support structures

Support Structure	Mass (kg)	Notes
Longitudinal Framing	$3.0*10^{-5}$ * L^3 * D	Required on Cylindrical Gas Bags
Transverse Framing	$1.3*10^{-3}$ * L * D^3	Required on Cylindrical Gas Bags
Netting & Wires	$7.5*10^{-4}$ * L * D^3	Required on Spherical and Cylindrical Gas Bags

For more on lighter-than-air design, see [*4*].

Replacement Compressed Gas canisters can also be added to a ship with their mass and volume as listed in Table 10.

Table 10: Compressed Gas

Gas Type	Mass (kg)	Volume (m^3)
Hydrogen 100m^3	150	0.5
Helium 100m^3	160	0.5
Coal Gas 100m^3	180	0.5

3.3.2.4 Landing System

It may be desirable for a craft to have a landing system. If one is not included, it is assumed the ship can only land on flat prepared surfaces. Craft that rely upon aerodynamic lift to maintain buoyancy require a landing system. Select a landing system from Table 11.

Table 11: Landing Systems

Name	Mass	Vol	Notes
Skids	1% of hull max mass	0	Add 1m^2 of surface area * Cd per 200kg
Retractable Skids	1.5% of hull max mass	1m^3 per 600kg of skid mass	
Wheels	2% of hull max mass	0	Add 1m^2 of surface area * Cd per 150kg
Retractable Wheels	2.5% of hull max mass	1m^3 per 500kg of wheel mass	
Ruggedized Wheels	2.5% of hull max mass	0	Allow landing on irregular surfaces; 1 m^2 of surface area *Cd per 150kg
Ruggedized Retractable Wheels	3.0% of hull max	1m3 per 500kg of wheel mass	
Pontoons	5% of maximum ship mass	0	Allow landing on water. Add 1m^2 of surface area * Cd per 150kg
Inflatable Pontoons	10kg + 5% of maximum ship mass	.001 m^3 / kg of pontoon	Allow landing on water

3.3.3 The Engine(s)

Engines provide mechanical power that can then be turned into propulsive force (e.g. by turning propellers) or electrical power (by turning a generator). There are five types of engine in common use in SoE aerial vehicles: Internal combustion engines (ICE), Steam, Electric, Venusian heat engines, and Venusian spring engines. Of these, Steam, Internal combustion, and electric dominate Earth-build vessels. Steam is the preferred mechanism for Naval School vessels, internal combustion for Cayley, and electric or internal combustion for the Zeppelin School. Each type of engine has different tradeoffs. For example, IC engines tend to have higher power-to-weight ratios, though they require a lot of maintenance, while steam engines are heavier, but easier to maintain. Select one or more engines from Table 12,

Sidebar: Engine Notes
The engines of SoE are considerably more advanced than in OTL, due in part to many novel features which appear earlier. Some abbreviations used in the tables below:
WC = Water Cooled
S = Supercharged
MS= Mechanical Stoker
AL= Aluminum construction
Forced = Forced Air
Oil = Oil burning steam engine

Table 13, Table 14, Table 15, or design a custom engine using Section 5.2. Note, the output and fuel flow for ICE are given for maximum and cruising speed. It is assumed the Internal Combustion engines use gasoline as their fuel and steam engines use coal unless otherwise noted. Other materials (see Table 16, column 4) may be substituted, but they generally have a lower energy density. The fuel required per hour listed in the engine table should be divided by the relative energy density in Table 16 to determine the alternative fuel flow. For example, a steam plant that requires 200 kg/hr of coal would require 400 kg/hr of wood (200/0.5).

Table 12: Internal Combustion Engines

Name	Year	Output (kW)	Mass (kg)	Volume (m^3)	Crew	Fuel Flow (kg/hr)
2cyl 2.3L	1865	6.5/5.2	51.5	0.1555	0.1	12/7.7
3cyl 3.1L	1870	11/8.8	69	0.2075	0.2	19/12.2
3cyl 3.7L	1870	13/10.4	78.5	0.2355	0.2	22.5/14.4
4cyl 4.8L	1875	20/16	98.5	0.2955	0.3	34.5/22.1
5cyl 6.7L WC	1875	29.5/23.6	138.5	0.415	0.4	50.5/32.3
5cyl 6.2L	1880	31/24.8	121	0.3635	0.4	52.5/33.6
3cyl 3L	1885	17.5/14	60.5	0.182	0.3	22/14
4cyl 4L	1885	23.5/18.8	80.5	242	0.4	29/18.6
6cyl 5.5L	1885	32.5/26	114.5	0.343	0.4	40/25.6
12cyl 38.25L WC	1885	239/191.2	541.5	1.622	4	289/185
7cyl 7L	1890	49/39.2	136	0.4085	0.5	43/27.5
10cyl 11.6L S	1890	102.5/82	250.5	0.7505	1.3	98.5/63
10cyl 13.8L	1890	97.5/78	242	0.7245	1.1	84.5/54.1
14cyl 43.5L WC	1890	322.5/258	577.5	1.730	3.9	278.5/178.2
16cyl 48.3L WC	1890	358.5/286.8	640.5	1.919	5.8	309/197.8
8cyl 10.3L WC	1895	90.5/72.4	183.5	0.5495	0.9	61/39
8cyl 9.4L WC	1895	82.5/66	172	0.516	0.9	55.5/35.5
8cyl 11.9L WC	1895	104.5/83.6	203	0.6085	1.1	70.5/45.1
16cyl 53.1L WC	1895	468/374.4	667	1.998	6.4	313.5/200.6
16cyl 43.8L S WC	1895	482.5/386	689.5	2.065	7.6	359.5/230.1
32cyl 110.7L S WC	1895	1219.5/975.6	1841.5	5.515	26.5	908/581.1
10cyl 26L S	1898	317.5/254	394	1.18	11	208.5/133.44

Name	Year	Output (kW)	Mass (kg)	Volume (m^3)	Crew	Fuel Flow (kg/hr)
WC						
8cyl 7.2L S WC	1898	87.5/70	163.5	490.5	2.8	58/37.12
20cyl 55L S	1898	639.5/511.5	794	2.378	24.7	420/268.8

In addition to fuel (coal or oil), steam engines also require feed water, as their condensers are not able to capture and condense all of the steam they produce. Steam engines also have two types of crew. The maintenance crew is the same as other engines. In addition, they may require stokers or firemen – crew who manually shovel coal into the boilers. When computing the final crew complement, stokers are accounted separately (see Crew Accommodations, page 61).

Table 13: Steam Engines

Name	Year	Output (kW)	Mass (kg)	Volume (m^3)	Crew (maint/stokers)	Fuel (kg/hr) (coal/water)
2.5L 2x 147psi M.S. forced	1859	65	2600	8.6	1/0.1	390/383
3L 2x 161psi forced	1860	81	5100	24.9	1/0.5	480/11
8.6L 2x 140psi M.S. forced	1860	203	12300	68	2/0.2	1280/29
36.7L 2x 156psi forced	1860	900	50900	308.6	7/3.5	5760/130
49L 2x 185psi forced	1861	1350	72900	442.9	10/5	8170/186
117.7L 2x 162psi M.S. forced	1859	2740	160300	1033.2	22/2.2	18940/423
6.9L 2x 175psi M.S. forced	1866	199	11200	59.5	2/0.2	1070/26
45.9L 2x 170psi M.S. forced	1865	1210	65100	398.5	11/0.8	7080/168
9.2L 2x 202psi forced	1870	299	15400	83.3	3/1	1450/36
5.7L 3x 233psi AL forced	1870	478	4200	17.2	5/1	950/24
27.4L 3x 216psi AL M.S. forced	1876	2140	15700	83.5	23/0.5	4200/110
6L 3x 233psi forced	1875	520	10500	41.4	5/1	960/166
82.8L 2x 214psi AL forced	1875	2640	39600	248.4	23/7.5	12780/332
7.7L 2x 257psi AL M.S. forced	1880	309	4600	22	4/0.2	1220/33

Name	Year	Output (kW)	Mass (kg)	Volume (m^3)	Crew (maint/stokers)	Fuel (kg/hr) (coal/water)
3.5L 4x 260psi M.S. forced	1880	540	8200	26.1	7/0.1	560/100
3L 3x 251psi not Cond forced	1880	319	3300	3.3	3/0.5	480/3779
0.3L 3x 245psi AL oil forced	1881	28	501	1	1/0	30/1
51.1L 3x 256psi AL oil forced	1879	4670	25700	149.6	41/0	5550/219
42.8L 4x 248psi AL M.S. forced	1880	6160	27700	147.9	57/0.8	6680/181
33L 4x 240psi AL forced	1880	4610	21300	111	41/3	5090/138
1.2L 3x 268psi M.S. forced	1885	121	3500	12.5	2/0.1	180/5
1.8L 4x 266psi AL M.S. forced	1880	283	2100	6.3	4/0.1	290/8
120.2L 4x 282psi AL forced	1881	19300	78600	459.4	96/11	19510/532
7L 3x 268psi AL M.S. forced	1885	700	5100	21.7	9/0.2	1080/30
51.6L 3x 282psi AL oil forced	1885	5240	26200	153.7	45/0	5520/228
89.2L 4x 263psi AL M.S. forced	1884	13580	55800	323.3	91/1.6	13750/385
39.8L 4x 300psi AL oil forced	1890	7100	24500	128.7	60/0	4180/180
1.7L 4x 292psi AL forced	1889	300	2200	6.8	4/0.5	260/1
8.2L 4x 294psi AL oil forced	1890	1450	6200	25.6	17/0	850/37
36.8L 5x 317psi AL oil forced	1891	9650	27100	130.2	76/0	3910/169
129.6L 6x 329psi AL forced	1890	44330	110100	577.2	142/11.5	20610/603
5L 4x 293psi forced	1890	890	11500	37.9	9/0.5	760/149
15L 4x 294psi AL M.S. forced	1891	2640	12500	60.8	30/0.3	2270/10
15L 5x 309psi forced	1890	3870	34700	120.9	34/1.5	2330/456

Name	Year	Output (kW)	Mass (kg)	Volume (m^3)	Crew (maint/stokers)	Fuel (kg/hr) (coal/water)
89.5L 5x 288psi AL oil M.S. forced	1890	21110	56200	316.1	123/0	9260/399
2.3L 3x 240psi forced	1890	213	5500	22.3	2/0.5	330/10
1.5L 3x 294psi forced	1890	167	3700	11	2/0.5	230/45
1.5L 3x 297psi not Cond M.S. forced	1890	193	2200	2	3/0.1	230/2000
10L 4x 319psi oil forced	1892	1940	20700	75.6	19/0	1060/307
20L 4x 327psi forced	1893	3960	40500	159	32/2	3100/619
6L 4x 305psi forced	1893	1120	13700	46	11/1	910/182
114.8L 4x 313psi AL oil M.S. forced	1895	21380	65300	387.4	119/0	11750/526
15L 4x 328psi M.S. forced	1895	2980	37500	166.2	30/0.3	2290/70
42.5L 4x 325psi AL oil forced	1895	8300	27100	140.1	66/0	4410/197
3.5L 5x 336psi oil forced	1895	1000	10400	27.8	12/0	370/109
4L 4x 324psi AL oil forced	1895	790	3500	10.2	10/0	410/123
30L 5x 313psi M.S. forced	1895	7930	63800	244.3	64/0.6	4510/916
57.7L 5x 353psi AL oil forced	1895	16930	43000	212.4	103/0	6160/275
2.5L 4x 319psi forced	1895	487	8000	27.3	5/0.5	380/12
10L 5x 323psi M.S. forced	1896	2740	25100	81.3	29/0.2	1510/308
30.8L 4x 194psi oil forced	1896	3710	51900	277.6	33/0	2610/119
90.2L 3x 223psi oil M.S. forced	1896	7610	138300	843.3	59/0	8080/367
40L 4x 204psi oil forced	1897	5050	67800	367.8	42/0	3430/158

Name	Year	Output (kW)	Mass (kg)	Volume (m^3)	Crew (maint/stokers)	Fuel (kg/hr) (coal/water)
4L 3x 337psi M.S. forced	1897	510	10500	43.5	6/0.1	610/19
43.1L 5x 342psi AL oil forced	1901	12490	32100	154.6	89/0	4380/203
105.6L 5x 353psi AL oil M.S. forced	1899	31240	73700	394.4	143/0	10930/503
3.2L 4x 311psi AL oil M.S. forced	1885	590	3100	10.5	8/0	350/15
2L 3x 329psi forced	1895	249	4900	15.1	3/0.5	310/62
2L 3x 337psi not Cond forced	1895	294	2900	2.2	3/0.5	310/2779

Table 14: Venusian Engines

Name	Output (kW)	Mass (kg)	Volume (m^3)	Crew	Drag	Fuel (kg/hr)
Large Heat Engine	12600	4700	0	50	32.2	15.5 (H_2)
Medium Heat Engine	1710	700	0	14	4.77	2.4 (H_2)
Attack Heat Engine	627	257	0	4	1.94	0.64 (H_2)
Small Heat Engine	79	33	0	1	.44	0.11 (H_2)
Sea King Spring Engine	100	500	4	5	0	265 (Spring)

Electric motors require electrical power that must come from a battery (See Section 3.3.9.1) or be generated by a generator that is powered by a mechanical engine (i.e. ICE, steam, etc…)

Table 15: Electric Motors

Name	Year	Output	Mass	Volume	Crew	Input	Overhead kW
Motor	1865	1	15	0.019	0.1	2	1
Motor	1875	1	10	0.019	0.1	2	1
Motor	1890	40	199	.752	0.2	53.5	13.5
Motor	1895	100	404	1.878	0.3	125	25
Motor	Venus	100	200	0.5	0.2	105	5

3.3.3.1 Fuel system

To size the fuel system, decide what the endurance should be, in hours. Multiply this by the fuel flow rate to determine the mass of fuel needed. To determine the volume, divide the fuel mass by the fuel density from Table 16. Additionally, add mass for the storage containers and handling equipment by multiplying by the value in column 3 of the Table. For example, to store 500 kg of Coal would require 0.45 m^3 and would require 505kg total.

Table 16: Fuel Densities and Storage Requirements

Engine Type	Fuel Density (kg/m^3)	Storage Overhead	Relative energy density (per unit mass)
Internal Combustion (Gasoline)	750	0.10	1.0
Internal Combustion (Alcohol)	790	0.10	0.92
Super Oxygen	1000	0.10	2.67 kg/kg Fuel
Steam (Oil)	990	0.10	1.35
Steam (Coal)	1105	0.01	1.0
Steam (Water)	1000	0.05	NA
Steam (Wood)	480	0.10	0.5
Steam (Plant Husks)	300	0.10	0.5
Whale Oil	925	0.10	0.94
Venusian Springs	2000?	0.25	NA
Venusian Heat Engine (H_2)	21	13.2	NA

3.3.4 Propulsion

The propulsion system turns raw mechanical power from the engine into useful thrust. The designer should decide how much power from the engines is fed to the propulsion system, keeping in mind that other systems may also require power. The mass and volume for different propulsion systems can be found in Table 17 and are based on the number of kilowatts of power input to the engine. In addition to the mass and volume for each propulsion system [*5*], different propulsion systems have different efficiencies. The efficiency of a propulsion system determines how much of the input energy is turned into actual propulsive force, which is used to calculate speed in Section 3.4.

Table 17: Propulsion Systems

Propulsion System	Mass kg/kW input	Volume m3/kW input	Efficiency
Propeller (pre-1870)	1.0	.001	0.667
Propeller (1870-1885)	0.8	.001	0.77
Propeller (post-1885)	0.7	.001	0.833
Ducted Propeller (post-1880) *	1.2	.001	0.87
Venusian Ducted Propeller*	0.7	.001	0.90
Air Jet **	1.6	.05	0.67
Flapping Wings [*6*]***	3.0	.05	0.70****

* = reroll critical hits to "propulsion" a second "propulsion" roll does count
** = reroll critical hits to "propulsion" a second "propulsion" roll does count
*** = Requires 1 extra crew per 1000 kg, rounded up
**** = Flapping wings can be used to generate lift at a rate of input(in W)*0.15=lift (in N)

Example: An Air Jet system takes an input of 15500 W or 15.5kW. Its characteristics:

Mass	Volume	Output
15.5*1.6= 24.8 kg	15.5*.001= 0.0155 m^3	15500*0.67= 10385 W

3.3.5 Generators

Power that is not directed to the propulsion system can be fed into electrical generators to create power to operate other ship's systems. Like propellers and propulsion systems, electrical generators are not perfectly efficient. A generator's mechanical input is greater than its electrical output. The difference, the generator's overhead, is listed in the last column in Table 18.

Table 18: Electric Generators

Name	Year	Output	Mass	Volume	Crew	Input	Overhead kW
generator	1865	1	13	0.019	0.1	2	1
generator	1865	6	77	0.113	0.1	12	6
generator	1865	50	636	0.939	0.2	100	50
generator	1875	1	9	0.019	0.1	2	1
generator	1875	12	101	0.2255	0.1	20	8
generator	1875	100	838	1.878	0.3	167	67
generator	1880	20	136	0.053	0.1	31	11
generator	1880	50	340	0.939	0.2	77	25
generator	1890	20	90	0.053	0.1	27	7
generator	1890	50	224	0.939	0.2	67	17
generator	1890	200	896	3.756	0.6	267	67
generator	1895	20	73	0.053	0.1	25	5
generator	1895	100	364	0.659	0.3	125	25
generator	1895	200	727	3.756	0.6	250	50
generator	1895	500	1817	9.389	1.5	625	125
generator	Venus	50	100	0.2	0.3	56	6

Example: A ship uses two "1.7L 4x 292psi AL forced (1889)" steam engines that produce 600kW of power. 400 kW are diverted for propulsion, leaving 200kW of mechanical energy to convert to electricity. To do this, the designer chooses three 50KW-output 1890 generators. These generators have a 17kW overhead each (total 51), so 149kW of electricity is produced.

3.3.6 Payloads

A portion of the ship may be reserved for cargo or other payload.

3.3.6.1 Cargo & Cargo Handling

The volume of the cargo will depend on what is carried. One rule of thumb to determine the volume of the cargo in m^3 is to divide the mass (in kilograms) by 250 for light cargo (textiles, finished goods, etc…) or 1500 for food or liquids.

In addition, the ship may carry other payload handling equipment from Table 19. For the systems in Table 19, they can be human operated or computer-operated. If they are human operated the payload crew is increased by the amount found in the last column, if they are computer operated, the computer must devote the specified number of operations per minute (IPM) to running the given system.

The mass and power for a Refrigerated cargo space is based on the volume of the space.

Table 19: Cargo Handling Equipment

Name	Mass (kg)	Volume (m^3)	Power (W)	Crew/IPM
Crane, 1000 kg capacity	250	10	6000	2 / 40
Crane, 100 kg capacity	50	1	600	1 / 20
Pulley System, 100kg capacity	10	0.5	300	1 / 10
Steam Shovel, 100kg	100	1	400	1 / 30
Steam Shovel, 1000kg	1000	4	1000	2 / 60
Steam Shovel, 10000kg	10000	25	2500	3 / 90
Powered Ramp, Personnel	100	1	400	0 / 10
Powered Ramp, Vehicle	1000	4	1000	1 / 10
Refrigerated cargo space	$50*V^{0.67}*8$	V	$53*V^{0.67}*8$	
Mechanical Arm, Simple, 10kg	25	1.5	320	1 / 40
Mechanical Arm, Simple, 100kg	200	2.0	800	1 / 50
Mechanical Arm, Simple, 1000kg	1600	3.0	5300	1 / 100
Mechanical Arm, Complex, 10kg	40	2.5	480	2 / 100

Note: The dedicated crew is only required if they equipment is frequently used. For example, a crane used to load a ship while in port would not require extra crew allotment. Crew can be replaced by computer control if the device is performing simple, repetitive tasks. Sources: [*7*] [***8***]

3.3.6.2 Water production

Steam engines require feed water to function and humans require water to drink. To produce water while in-transit it is possible to use a desalinization plant [***9***] that converts impure water (e.g. salt water) to potable water. If the ship wishes to acquire untreated water without landing, a pump may be used. Mass, volume, and power for plants and pumps can be found in Table 20.

Regular desalinization plants assume the input water is seawater or other mildly impure water. For plants that receive more fouled water (e.g. swamp water or recycled urine) the requirements are increased. For example, a plant capable of processing 1000 kg of fouled water an hour would require 7000kg, 60 m3, and 150kW.

Table 20: Water Purification Plants

	Mass kg/kg/hr	Vol m^3/kg/hr	Power W/kg/hr
Desalinization Plant (<500 kg/hr)	6	0.08	150
Desalinization Plant (>500 kg/hr)	4	0.04	75
Fouled Water Plant	*1.75	*1.5	*2.0

Pump 50m	0.15	.002	0.5
Pump 600m	1.15	.02	4.0

Example: A 300 kg/hr Fouled Water Plant:

Mass	Vol	Power
(300*6*1.75) = 3150 kg	(300*0.08*1.5) = 36 m^3	(300*150*2) = 90000W

To feed this, a 600m pump:

Mass	Vol	Power
(300*1.15) = 345 kg	(300*0.02) = 6 m^3	(300*4) = 1200W

3.3.6.3 Vulnerability Reduction

Ships may include systems designed to reduce their vulnerability to damage [***10***]. These systems effect the ship's Hit Points, calculated in Section **Error! Reference source not found.**, or how it reacts to damage.

Table 21: Vulnerability Reduction Systems

Name	Mass (kg)	Volume (m^3)	Notes
Redundant System	As Original System		Mass and volume as the original system to be replicated. The first critical hit to this system is ignored.
Hardened System	25% of Original System		The first critical hit to this system is ignored in a roll of 10 or greater on a d20
Improved Component Location		10% of ship	Less critical components are used to screen and protect critical ones. Effects the whole ship. Improves hit points by 10%
Internal Armor	$420 * V^{(2/3)}$		V= System Volume. The first two critical hits to this system is ignored.
Firewalls	V*40	V*.01	V= Ship volume. Fire damage is reduced by 50%.
Blast screen	50*L		For magazines and fuel storage. The first time a critical hit causing an explosion occurs, damage is only one tenth. Each system can only be used once. FM=Fuel Mass; FV=Fuel Volume; L=length of ship in meters
Fuel cutoffs	25+ FM* .05		
Partitioned fuel tanks	FM*.05	FV*.05	
Jettisonable fuel tank	FM*.05	0.1	
Redundant Oil Sumps	EM*.10	EV*.10	EM=Engine Mass, EV=Engine Volume. The first time an "engine disabled" critical hit occurs, the engine is able to continue working.
Crew armor	20*C	C/200	C=crew; Flak jackets and helmets for crew, as well as protected crew stations. Halves damage from 'Crew Damage' critical damage

<table>
<tr><th>Name</th><th>Mass (kg)</th><th>Volume (m^3)</th><th>Notes</th></tr>
<tr><td>Strengthened Hull 1</td><td>HM* 0.25</td><td>V*0.04</td><td>HM=Hull Mass; V=Ship Volume; Collision damage is halved. Increase hit points by 20%.</td></tr>
<tr><td>Strengthened Hull 2</td><td>HM</td><td>V*0.20</td><td>HM=Hull Mass; V=Ship Volume; Collision damage is halved. Increase hit points by 30%</td></tr>
<tr><td>Increased Compartmentalization 1</td><td>V*12</td><td>V*0.05</td><td>V=Ship Volume in m^3; Increase hit points by 30%. Fire damaged is reduced by 20%.

E.g.: A ship with a 10,000 m^3 volume masses 1300 tons normally has 612 points. Compartmentalization adds 120 tons to the mass of the ship (1420 tons). The number of hit points is increased to 612*1.3=796.</td></tr>
<tr><td>Increased Compartmentalization 2</td><td>V*30</td><td>V*0.10</td><td>V=Ship Volume in m^3; Increase hit points by 40%. Fire damaged is reduced by 30%.</td></tr>
<tr><td>Emergency Lift System (1 Panel)</td><td>75</td><td>0.1</td><td>An emergency lift system deploys a small wing to provide temporary aerodynamic lift equivalent to one Aerolyth panel. It only functions on craft capable of maintaining a speed of 25m/s. It also limits speed to 30m/s. The emergency lift system is fragile and will fail after a few (1d20) hours of use.</td></tr>
<tr><td>Internal Defensive Positions</td><td>V*20</td><td>V*.10</td><td>Internal defensive positions provide positions inside a ship to defend against and repel boarders. See Section Error! Reference source not found..</td></tr>
<tr><td>Automated Defenses</td><td>3.0*V</td><td>.025*V</td><td>V= Ship volume; Requires (50 + 10 * V) Watts of power and 1*V IPM.</td></tr>
<tr><td>Barbed Wire</td><td>A*7</td><td>0</td><td>A=Area to be covered (in m^2). Deters boarders (animal or human). Adds 10% to body drag</td></tr>
<tr><td>Electric Fencing</td><td>A*1+ Energizer</td><td>0.1+.005 *A</td><td>A=Area to be covered (in m^2). Deters boarders (animal or human). Adds 5% to body drag. The power and mass for the energizer depend on the strength of the shock delivered.
<table>
<tr><th>Shock Level</th><th>Power (W/m^2)</th><th>Mass (kg/m^2)</th></tr>
<tr><td>No Injury</td><td>1</td><td>0.05</td></tr>
<tr><td>Injury</td><td>2</td><td>0.1</td></tr>
<tr><td>Lethal</td><td>10</td><td>0.35</td></tr>
</table>
Note: The power is only consumed when the fence is active (i.e. shocking something). Normal power loads are negligible. Electrical</td></tr>
</table>

Name	Mass (kg)	Volume (m^3)	Notes
			fences can be overloaded if a large body (or several bodies) touches them.
Smoke Screen Dispenser	50	0.15	160 kg and $0.15m^3$ per "reload"
Torpedo Net	25 kg /m^2		A coarse metal net, to catch rockets. Adds 25% to body drag. 1 extra crew per $300m^2$ of netting.
Fireproofing	6.5*V	0.02*V	V=Ship Volume. The use of cutting edge materials (asbestos) to reduce the effect of fire by 20%.
Heavy Fireproofing	45*V	0.03*V	V=Ship Volume. The use of cutting edge materials (more asbestos) to reduce the effect of fire by 40%.

3.3.6.4 Damage Control and Escape

When things break on a flying vehicle, fixing them can become an urgent priority. When fixing fails, escape is sometimes needed.

Table 22: Damage Control and Escape Systems

Name	Mass (kg)	Volume (m^3)	Notes
Personal Parachute	21	0.1	Exiting a ship above about 6000m without protection will usually result in unconsciousness, above 18000m (the Armstrong Limit), may result in death as the body's fluids boil. Enclosed escape pods will prevent this, as well as at least attempting to cushion the occupant's landing.
Escape Pod (1 person)	460	0.5	
Escape Pod (4 person)	1100	2	
Safety Parachute	30	0.2	Simple to-use single use parachute that requires little training to use. Designed for commercial ship passengers.
High Altitude Paradrop kit	72	0.2	A heated pressure suit with integral mult-stage parachute, allowing escape from over 6000m
Armored Gondola	2200	6	An armored compartment that can be lowered from the ship for observation purposes. It includes a telescope and simple telegraph for communication with the main ship and about 2cm of steel armor. Note: this still requires winches or pulley systems to lift and lower the gondola.
Wingsuit & Parachute	40	.2	Allows semi-controlled downward descent
Fire Sprinkler System (per 200 m^3 of ship)	140	0.75	Fire extinguishing systems provide a +5 to 'extinguish fire' rolls. Sprinkler systems are automatic (i.e. no action points), while Fire ex-
Fire Extinguishers (per	12	0.05	

Name	Mass (kg)	Volume (m^3)	Notes
10 m^3 of ship)			tinguishers require crew to use. These systems can only be used once, but redundant systems can be carried, allowing multiple uses.
Shoring Kits (per 2500m^3)	200	0.25	Shoring kits provide a +2 to damage control rolls.
Structural Repair Kit	S/250	S/250000	Structural repair kits provide a +5 to damage control rolls. The mass required is the ship's mass divided by 250. The Volume is the ship's mass divided by 250000
Self-Destruction System (incapacity)	50	0.1	Self-destruction systems come in two forms. "Incapacity" systems destroy control linkages and computer systems only, making the ship unusable, but not completely destroyed. "Total" destruct systems reduce the craft to small pieces, making it totally unrecoverable. "Total" destruction systems are based on the ship's total mass.
Self-Destruction System (total)	S/500	S/1000000	

3.3.6.5 *Carried Land Vehicles*

Flying vehicles may also carry Land vehicles. The exact specifics of land vehicles are beyond the scope of this book, but some general requirements are given in Table 23. For fast deployment, it may be good to add a powered vehicle ramp as well.

Table 23: Land Vehicles

Name	Mass (kg)	Volume (m^3)	Power (W)	Crew
Pack Howitzer (10 pounder)	400	0.7	0	3
Walker	4500	13.25	0	1
Armored Car	8500	34	0	1
Land Destroyer	47000	86	0	3
Land Cruiser	94000	157	0	8
Truck	11000	64	0	1
Horses	800	46	0	1
Horse & Carriage	1300	71	0	2

3.3.6.6 *Carried Flying Vehicles*

Large vehicles may carry, launch, and retrieve other flying vehicles. Due to Aerolyth interactions, Aerolyth vehicles cannot carry other Aerolyth vehicles, but they can carry aerodynamic or floatation-based craft. To carry subordinate vehicles requires a **Vehicle Storage Area**, which provides room to maintain, reorganize, and store spares. If the vehicles are stored externally, they produce drag equal to twice the carried vehicle's drag. To launch the vehicles while airborne, a **Vehicle Deployment Area** is required. Landing and Launch areas are determined by the stall speed of the craft. If the vehicles need to be refueled, **Extra Fuel** should be carried. Multiple

Vehicle Deployment Areas can be included to allow several vehicles to be deployed or retrieved simultaneously. If the stall speed of the carried aircraft is more than 10 m/s greater than the carrying vehicle's maximum speed, the Vehicle Deployment Area requires arresting nets. The mass, volume, power, and crew requirements for the carried vehicle support systems can be found in Table 25, which uses the variables defined in Table 24. Note, this does include the mass of the carried vehicle itself.

Table 24: Variables used in Table 25

Variable	Meaning
S	Carried vehicle's mass in tons
P	Number of vehicles carried
N	Number of Vehicle Deployment Areas
V	Volume footprint of one carried vehicle. The Volume footprint is the product of the maximum vehicle length, width, and height (i.e. for aerodynamic lift the hull length * wingspan * height).
C	Launch Area Crew

Table 25: Carried Vehicle Support Systems.

	Mass (kg)	Volume (m^3)	Power (W)	Crew
Vehicle Storage Area				
Vehicle Storage, Long Duration or >10 Vehicles	5*V*P + S*P*1000	3.25*V*P	0	ceil(S*P/5)
Vehicle Storage	4*V/4*P + S*P*1000	2*V*P	0	ceil(S*N/5)
Vehicle Storage, external	6*V/4*P + S*P*1000	0.5*V*P	0	ceil(S*N/5)
Extra Fuel				
Extra Fuel	As per Table 16			0
Vehicle Deployment Areas				
Landing/Launch Areas – >30m/s	150*C	C + V*10	0	ceil(4N+(P*S)/15 + S/10)
Landing/Launch Areas – <30m/s	150*C	C + V * 5		ceil(4N+(P*S)/15 + S/10)
Landing/Launch Areas – <15m/s	200*C	C + V * 2.5		ceil(4N+(P*S)/15 + S/10)
Launch Only Areas	100*C	C + V*2	0	ceil(N+(P*S)/15 + S/20)
External Launch Area	200*C	0		ceil(N+(P*S)/15 + S/20)
Arresting Net	N*(1000+40*S)	N*(1000+40*S)/ 1200	1000 * N * S	

Example: A vehicle wants to carry two Omen Light Fighter 2s (See Section 5.20, page 64 in *Flying Machines of the Worlds: 1902*). It has only one launch area. The Omen's stall speed is about 20m/s, so it can use the "Landing/Launch Areas – <30m/s" entry. The Table 24 variables are:

Variable	Meaning	Omen Light 2
S	Carried vehicle's mass in tons	4
P	Number of vehicles carried	2
N	Number of Vehicle Deployment Areas	1
V	Volume footprint of one carried vehicle.	(7.5*7.5*2)= 112.5
C	Launch Area Crew (Landing/Launch Areas – <30m/s)	ceil(4*1+(2*4)/15 + 4/10) = 5

The characteristics of the support systems:

	Mass (kg)	Volume (m^3)	Power (W)	Crew
Vehicle Storage	4*112.5/4*2+4*2*1000 = 8225	2*112.5*2 = 450	0	ceil(4*1/5) = 1
Landing/Launch Areas – <30m/s	150*5 = 750	5 + 112.5 * 5 = 567.5		ceil(4*1+(2*4)/15 + 4/10) = 5
Arresting Net	1*(1000+40*4) = 1160	1*(1000+40*4)/ 1200 = 0.97	1000 * 1 * 4 = 4000	
Totals	2910 kg	1018 m^3	4000	6

3.3.6.7 Other Payloads

A variety of other "active" payloads can also be carried.

Table 26: Active Payloads

Name	Mass (kg)	Volume (m^3)	Power (W)	Crew	Notes
Repair & Replenishment Facilities					
Mini Shop	7000	8	1000	1	*Provides +3 to repair rolls.*
Field Shop	30000	25	3000	4	*Provides +5 to repair rolls. Increase repair rate by 1d20*
Portable Maintenance facilities [*11*]	115000	85	8000	12	*Provides +7 to repair rolls. Increase repair rate by 2d20.*
Forward Maintenance facilities	350000	260	33000	40	*Provides +10 to repair rolls. Increase repair rate by 6d20.*
Bakery	5000	125	20000	12	Capable of producing 1000kg of bread per day
Logistics stores	M	M/3000			*
Refueling boom (oil)	900	10	1500	0	A rigid tube allowing liquid (usually fuel) to be sent from one ship to another at a rate of 8000 kg/hr

Name	Mass (kg)	Volume (m^3)	Power (W)	Crew	Notes
Refueling boom (coal)	1800	12	2000	1	A rigid tube & conveyor system allowing bulk matter (usually coal) to be sent from one ship to another at a rate of 6000 kg/hr
Refueling port	200	1	0	0	A port allowing a ship to accept transfers in mid-air from a refueling boom. Adds 0.25 drag
Secure Rooms					
Brig/Safe Room, 1 person	350	3.5	0	0	Secure holding cell with heavy reinforcement and a locking door. The difference between a brig and a safe room is if the lock is on the inside or the outside
Brig/Safe Room, 4 person	1700	25	0	0	
Concealed Door	20	0			External concealed door, possibly with hidden latch
Priest Hole	175	3.5			Small hidden room, with soundproof padding
Medical Facilities					
Single Sick Bed	100	12	0	0	Includes minimal stores and examination facilities. 1 bed.
Simple Sick Bay	1000	40	100	0.05	4 beds, includes basic stores and examination facilities. *Provides a +1 to medical treatments.*
Medical Bay	5000	300	700	2	10 beds + stores, minimal surgical facilities and examination facilities. *Provides a +2 to medical treatments.*
Brunel "Hut"	24400	1265	3500	7	52 beds + stores, surgical room, and examination facilities. *Provides a +3 to medical treatments.*
½ Hospital	97600	5060	14000	26	200 beds + stores, surgical room, and examination facilities. *Provides a +4 to medical treatments.*
Field Hospital	244000	12650	35000	62	520 beds+ stores, surgical room, sterile laundry, and examination facilities. *Provides a +5 to medical treatments.*

Name	Mass (kg)	Volume (m^3)	Power (W)	Crew	Notes
Mobile Renkioi Hospital	512400	26500	80000	124	31 Doctors/physicians, etc… 93 nurses & assistants. 988 beds *Provides a +5 to medical treatments.* [***12***]
Autodoc	500	25	500	1	Automated medical system. Requires 1000 IPM of computing power. *Provides a +3 to medical treatments.*
Recreational Facilities					
Musical Organ	2000	10	5000		A must have for super-scientists
Large Musical Organ	10000	45	19000		A must have for super-super-scientists
Exercise Room	400	40	0		Provides exercise facilities for long-duration flights
Auto-fencer	500	80	500		An automaton for practicing fencing against multiple opponents. Requires 2000 IPM of computing power.
Laboratory Facilities					
Science Kit	50	1	0/500**	1	Simple tools for investigation of a single field (i.e. chemical, electrical, biological). *Provides +2 to science rolls.*
Science Field Kit	250	6	0/2000**	2	Modular container with Basic tools for investigation of a single field. *Provides +5 to science rolls.*
Photography Darkroom	200	8	500	1	Allows development and processing of photographic film, including magnification
Chemical/Geologic laboratory	10000	120	5000	8	Support for 4 researchers, plus 4 assistants. *Provides +10 to science rolls.*
Electrical laboratory	20000	120	13000	8	Support for 4 researchers, plus 4 assistants. *Provides +10 to science rolls.*
Biological laboratory	6000	180	4000	8	Support for 4 researchers, plus 4 assistants. Includes $60m^3$ of specimen containment. *Provides +10 to science rolls.*

Name	Mass (kg)	Volume (m^3)	Power (W)	Crew	Notes
Library, Single Subject	1200	6	0	0	*Provides +2 to knowledge roll in a given knowledge Area*
Library, Dual Sub-ject	1800	10	0	0	*Provides +2 to knowledge roll in two given knowledge Areas, or +3 in a single area*
Library, 4 subject	2700	14	0	0	*Provides +2 to knowledge roll in four given knowledge Areas, +3 in two areas, or +4 in one area*
Command Facilities					
Commodore's Flag Bridge	600	20	50	5	For commands of up to 3 ships or 500 soldiers *Provides +3*** to command rolls for ships in the command.*
Real Admiral Flag Bridge	4500	150	375	30	For commands of up to 10 ships or 2000 soldiers. *Provides +2*** to command rolls for ships in the command.*
Vice Admiral Flag Bridge	13500	450	1125	80	For commands of up to 20 ships or 4000 soldiers. *Provides +2*** to command rolls for ships in the command.*
Automated VA Bridge	5600	210	1000	50	For commands of up to 20 ships or 4000 soldiers. Requires 2000 IPM. *Provides +2*** to com-mand rolls for ships in the com-mand.*
Fleet Flag Bridge	27000	900	2700	150	For commands of up to 30 ships or 10000 soldiers. Includes brief-ing rooms. *Provides +2*** to command rolls for ships in the command.*
Automated Fleet Flag Bridge	16200	520	1000	90	For commands of up to 30 ships or 10000 soldiers. Includes brief-ing rooms. Requires 8000 IPM. *Provides +2*** to command rolls for ships in the command.*

Name	Mass (kg)	Volume (m^3)	Power (W)	Crew	Notes
Forward Command	84000	2800	8400	350	For commands of up to 60 ships or 30000 soldiers. Able to coordinate large ground-based or air-based attacks as well. Includes large briefing rooms. *Provides +2*** to command rolls for ships in the command.*
War Rooms	210000	6000	24000	600	Able to command multiple fleets and ground actions across a large area, including interfacing with political figures
Miscellaneous					
Slide-out Rooms	20+3*V	0.25*V	15 * V		V = Final expanded volume; Allows a portion of the vehicle to expand, allowing larger internal space.
Atomizer	160	0.35	5000	1	Capable of spraying 20 m^3/hr of a liquid (pesticide, fertilizer, nerve agent, water). Storage for the liquid should be provisioned as per Table 16.

*= Logistics facilities generally require 10 kg of raw materials per person per hour for repair work. For example, 2100 man-hours of repair work would require 21000 kg.
** = Electrical kits require 2000W of power to operate.
*** = Flag bridges can also be installed as Marine command posts. A command post is capable of coordinating 35 marines for each ship a flag bridge could command. For example, a Fleet Flag Bridge could command (30*35) 1050 marines.

Example: A ship needs a Fleet Flag Bridge for use as a Marine command post. It will only be used when on the ground, so a slide-out room is chosen. A Fleet Flag Bridge is normally 900m^3. In a slide-out configuration, the characteristics of the bridge and slide-out system would be:

Name	Mass (kg)	Volume (m^3)	Power (W)
Fleet Flag Bridge	27000		2700
Slide-out Rooms	20+3*900 = 2720	0.25*900 = 225	15 * 900 = 13500
Total	29720	225	16200

3.3.7 Weapons

There are some tough worlds out there, and it is often necessary for even merchant ships to carry a variety of weapons. The Hive War led to the development of small-caliber, rapid-fire weapons, chief amongst them the Gatling gun. However, many aerial combat theoreticians believe the fu-

ture of air combat belongs to large caliber guns or rockets. Venusian weapons are electricity based.
Weapons can be selected from Table 27. Ammunition is assumed to have a density of 4000 kg/m3. Bomb racks are sized based on their payload, so a rack capable of carrying 1000 kg of bombs would mass 10kg and consume $0.5m^3$. If carried internally, bombs have a density of 5000 kg/m^3. If carried externally, they add drag of (V^(2/3))*0.1.

Table 27: List of Weapon Systems

Name	Mass (kg)	Volume (m^3)	Power (W)	kg/round	Crew
1-inch Nordfelt gun	203	0.23	0	.21	3
11-inch 25ton RML	25000	28		243	33
BL 12 inch naval gun	47000	35.0		324	38
BL 13.5 inch naval gun Mk I	67000	55		570	55
BL 4-inch/25 gun Mk I	1148	2.5	0	11.4	4
BL 6-inch/25.5 gun Mk III	5000	4.4	0	45.36	5
BLR gun, 10-inch	26500	27.5		340	25
BLR gun, 12-inch	40000	32.8		580	36
BLR gun, 14-inch	68200	58.6		920	59
BLR gun, 16-inch	100000	68.6		1400	86
BLR gun, 3-inch	650	1.5		15	3
BLR gun, 5-inch	2800	3.8		40	5
BLR gun, 6-inch	5000	8.5		68	7
BLR gun, 8-inch	12700	13.9		170	13
Bomb Rack, Low-Perturbation	.05X	.01X			
Bomb Rack, Standard	.01X	.0005X	0		1
Flamethrower, Large	4450	4		40	10
Flamethrower, Small	750	1		10	5
Gatling Gun	270	0.80	0	.03	3
Grapple Arrow Gun	250	1.25		30	3
Hotchkiss Revolving Cannon 37mm/5	209	0.75		0.5	3
Hotchkiss Revolving Steam Cannon 37mm/5	500	1.5	500	0.5	2
Howell Torpedo Launcher	265	0.5	**	265***	1
Mallet Mortar	43000	40		1200	48
Maxim Gun	27.2	0.77	0	.01	3
QF 6 inch /40 naval	6600	5.5		45	6

Name	Mass (kg)	Volume (m^3)	Power (W)	kg/round	Crew
gun					
Rapid Fire Gun, 1-pounder	33	.8		0.6	3
Rapid Fire Gun, 3-pounder	230	.9		1.8	3
Rapid Fire Gun, 6-pounder	363	1.0		3.6	3
RBL 20 pounder Armstrong gun	660	1.8	0	10	2
RBL 40 pounder Armstrong gun	1626	4.0	0	18.5	3
RBL 7 inch Armstrong gun	3657	3.1	0	49.5	5
RML 16 inch 81 ton gun	81000	75		763	75
RML 17.7 inch	103000	100		910	90
Rocket Launcher, 12 inch	520	1.2		520***	28*****
Rocket Launcher, 12 pdr	14	0.04		14***	12*****
Rocket Launcher, 16 inch	1270	3.5		1270***	35*****
Rocket Launcher, 24 pdr	23	0.06		23***	14*****
Rocket Launcher, 6 inch	68	0.2		68***	18*****
Rocket Launcher, 6 pdr	5	0.02		5***	3*****
Rocket Launcher, 9 pdr	7	0.02		7***	6*****
Rocket Launcher, 9.2 inch	227	0.5		227***	24*****
Rocket, Bolshoi	1270	3.5		1270***	35*****
Rocket, Chetvert	68	0.2		68***	18*****
Rocket, Sazhen	520	1.2		520***	28*****
Sea King Ballista (ROF 0.2/min)	605	6.55	47000	20	5
Sea King Corvus (10m)	1900	8.2			2
Sea King Polybolos (ROF 0.25/min)	145	1.95	12000	3	3

Name	Mass (kg)	Volume (m^3)	Power (W)	kg/round	Crew
Torpedo Launcher, Whitehead 14-inch	295?	0.56		295***	1
Torpedo Launcher, Whitehead 15-inch	410?	0.85		410***	1
Venusian Lightning Rocket (3 charges)	41500	20.53	*	5.8	13
Venusian Railgun, Large (5 charges)	3350	1.00	*	25	7
Venusian Railgun, Small	430	0.56	4270	3	6

Sources: Penetration: [***13***] Hotchkiss [***14***] BLR & Rapid Guns: [***15***] Howell Torpedo: [***16***]
** = Torpedo stored energy is 33kJ. The power required the charge a torpedo depends on how quickly it needs to be recharged according to the formula P = 33000 / T, where T is the time in seconds and P is the power required.
*** = Torpedo density is 500 kg/m3, Rocket density is 400 kg/m3
*****= Rockets can be mounted in a launcher, or in fixed mounts. If in fixed external mounts, the crew is reduced to 1 and they add drag of (V^(2/3))*0.1 per rocket

3.3.7.1 Turrets, Mounts, & Ammunition Storage

Weapons may be **mount**ed in different sub structures to protect them (or their crew) or to provide a wider firing arc. The mass, volume, and power of these structures depends on the mass and volume of the weapon itself, multiplied by a factor found in Table 28. Table 29 has further details and examples of weapons mounts.

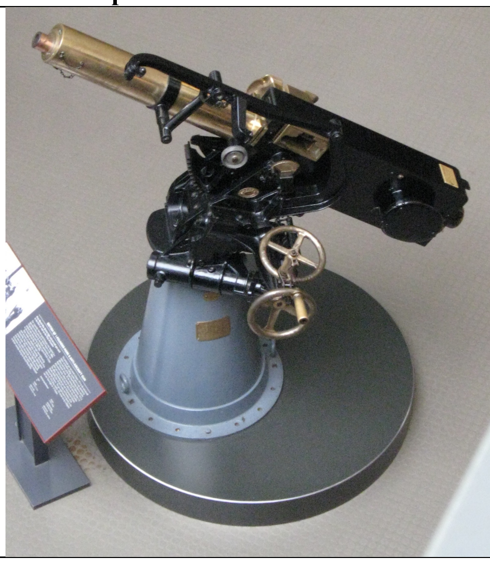
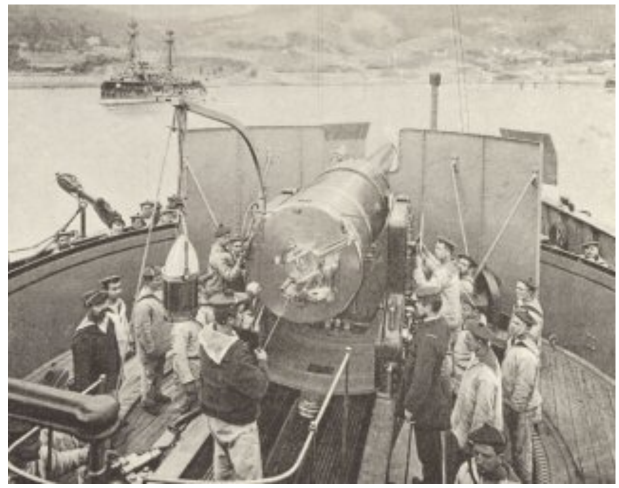
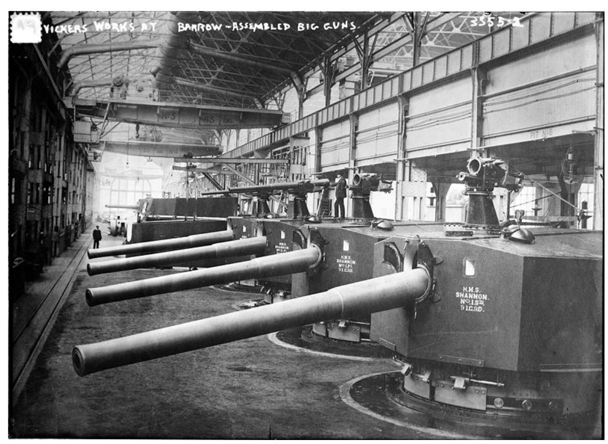
Table 28: Weapon Mounts

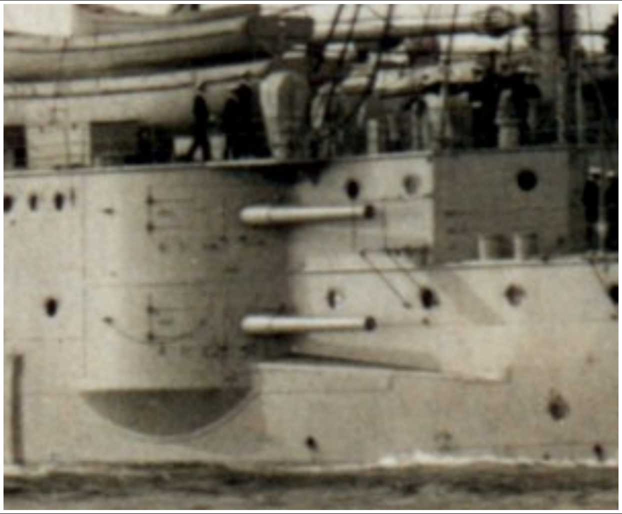
Mount Type	Mass Multiplier	Volume Multiplier	Power (if mass > 100kg)	Description & Notes
Pop-Up Turret	1.0	1.5	1.5 W/kg	A turret that can be concealed
Turret	0.5	1.0	1 W/kg	360-degree angle of fire
Barbette	0.25	0.75	0.5 W/kg	360-degree angle of fire
Casemate	0	0.5	0	90-degree angle of fire
External Fixed Mount	0	-0.25	0	Reduce weapon crew by 1, or 10%, which ever is greater
External Pintle	.05	0.25	0.1 W/kg	360-degree angle of fire. Suitable for weapons < 200kg.
Sponson	0.1	0.1	0.1 W/kg	90-140-degree angle of fire

Optionally, **Turrets** can be armored to provide protection for the occupants. To determine the mass of the armor multiply the surface area of the turret by the armor mass found in Table 4. The surface (in m^2) area of a turret is equal to $5*V^{0.67}$, where V is the volume of the turret in m^3. Turrets and barbettes also increase the drag of a ship by $0.5*V^{0.67}$ or by $0.1*V^{0.67}$ for Cayley or Zeppelin Schools. External mounts, Pintle and Sponsons increase drag by $0.25*V^{0.67}$* or by $0.05*V^{0.67}$ for Cayley or Zeppelin Schools.

Ammunition may be stored at hand near the weapon, or in a separate **magazine**, which may be armored for additional protection. The mass of a magazine's armor is found by multiplying the surface area of the magazine by the armor mass found in Table 4. The surface (in m^2) area of a magazine is equal to $6*(4*V)^{0.67}$, where V is the volume of the magazine in m^3.

Table 29: Weapon Mounts

	
External Pintels provide a wide angle of fire, and easy operation but offer little to no protection to the operator	The term "**Barbette**" is used to describe many different types of mountings. In this work, it refers to a semi-protected rotating gun.
	
A **casemate** is an opening in the hull of a ship through which a gun can be fired. E.g. the USS *Merrimack* / CSS *Virginia* used casemate mounts	A **Turret** offers 360-degree rotation and armored protection for the operator(s).



A **Sponson** is a (usually armored) projection from the side of a vehicle from which a weapon can fire.

A **Fixed External Mount** saves space, but can only be "aimed" by turning the entire craft.

Example: An 8-inch BLR Gun in a turret, with 1cm Steel armor. The Surface area of the turret is $(5*V^{0.67})$=29.16 m^2. If this is on a Naval ship, the extra drag is $(0.5*V^{0.67})$=5.83.

	Mass (kg)	Volume (m^3)	Power (W)
8-inch BLR	12700	13.9	
Turret	6350	13.9	12700
1cm Steel Turret Armor	29.16*.01*7900 = 2303.64		
Totals	21353.6	27.8	12700

3.3.8 Attitude Determination and Control System

Select Maneuver systems from Table 30 and navigation systems (if any) from Table 31.

Table 30: Maneuver Systems

Maneuverability System	Mass & Volume Required
Low	0.25% total ship mass
Medium	0.50% total ship mass + 10% of engine & propulsion mass
High	1.2% total ship mass + 20% of engine & propulsion mass
Aerolyth "Organ"	500kg, 4 m^3

Table 31: Navigation Systems

Name	Mass (kg)	Vol (m3)	Power (W)	Notes
Standard Flight Instruments	50	0.1	0	Altimeter, Attitude indicator, Airspeed. *Without at least Standard Flight Controls, the maneuver rat-*

Name	Mass (kg)	Vol (m3)	Power (W)	Notes
				ing is at –1
High Res. Flight Instruments.	250	0.4	50	Altimeter, Attitude indicator, Airspeed, variometer. Necessary for computer aided gunnery.
Compass	10	0.05	0	
Gyrocompass	25	0.1	10	
Celestial Navigation System	10	0.1	0	Sextant, etc… Helpful if navigating out of sight of land. Provides 500m accuracy under optimal conditions. *Provides +3 to Navigation Rolls.*
Large Celestial Navigation System	250	1	0	Large Sextant, etc… Provides 400m accuracy under optimal conditions. Requires 200 IPM of computing power. *Provides +4 to Navigation Rolls.*
V. Large Celestial Navigation System	1000	3	0	Crew of 3. Series of large sextants. Provides 250m accuracy. Requires 500 IPM. *Provides +6 to Navigation Rolls*
Telescope	5	0.05	0	Always handy. Telescopes can also be turret mounted
.25-m Telescope	81	1	0	
.33-m Telescope	140	1.8	0	
.5-m Telescope	647	8.2	0	
.75-m Telescope	2186	27.5	0	
1-m Telescope	5183	65		

3.3.9 Electricity

To provide electricity to a craft requires two things: a power source and a distribution system. A power source takes some form of energy (usually mechanical motion or chemical potential) and turns it in to electrical energy. Distribution systems transmit that electrical energy to where it is needed.

3.3.9.1 Power Source

A power source may be a battery, which stores energy, or a generator that converts mechanical energy into electrical energy. Often, vehicles will have both to provide redundancy. If a generator is used, it must be coupled to another engine that produces mechanical energy, such as an Internal Combustion Engine, or a steam engine. It is possible for an engine to divide its power between creating motive force and powering a generator.

To determine the size of a battery, first decide on the **power** the battery should produce (in Watts), and the **duration** it needs to supply this power (in seconds). Multiply the battery power

by the duration, and divide by 500,000. This is the mass of the battery in kilograms. Divide this mass by 6000 to find the volume (in m^3).
Generators may be chosen from Table 18.

3.3.9.2 Distribution System (Optional)

The distribution system requires power regulators and cabling. This system is optional, but improves the reliability and resiliency of the power system. If a power distribution system is included, the ship may ignore the first “Electrical Systems Disabled” critical hit in combat.
To determine the mass of the power regulators, divide the generated power (in kW) by 11.4. This is the mass in kg. Divide the mass by 1200 to determine the volume in m^3.
To determine the mass of the cabling, first find its length. The length of the cabling is the sum of the two longest ship dimensions multiplied by 5. Cabling weighs .3 kg/m. Divide the total cabling mass (in kg) by 6000 to find its volume in m^3.

Example: A ship measuring 19.5x4.15x4.9m has generators which can output 240000 W or 240kW. The length of cabling is (19.5+4.9)*5=122m.

	Mass (kg)	Volume (m^3)	Power (W)
Power Distribution	240/11.4=21.06	21.06/1200=.0175	
Cabling	122*0.3=36.6	36.6/6000=0.0061	
Totals	57.66	0.0236	

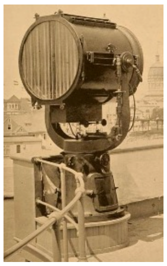
3.3.10 Command & Data Handling

Most C&DH systems in SoE are simple – speaking tubes, telephones or simple mechanical controls or servos. Ships with less than 25 crew do not require a C&DH system, unless they are using automation (see Section 5.3).
Standard C&DH systems can be selected from Table 32 or custom designed design using Section 5.3.

Table 32: C&DH Systems

Name			Mass (kg)	Volume (m^3)	Power (W)	Crew	Notes
Small	14	.05	20	.1	Usable on ships up to 25m long with up to 40 crew		
Simple	315	.17	0	0	*-5 on Command rolls.* Usable on ships up to 50m long and with up to 80 crew		
Advanced	137	1.0	50	.25	*+5 on Command rolls*. Usable on ships up to 50m long and with up to 80 crew		
Simple Large	274	1.84	150	0.75	Usable on ships up to 150m long and with up to 280 crew		
Advanced Large	3110	30.6	150	.75	*+5 on Command rolls*. Usable on ships up to 150m long and with up to 280 crew		

3.3.11 Computing, Communication, and Sensors



Select communication, sensor, and automation systems from Table 33. Radios are covered in Table 36. Many of these devices can be connected to a computer and use a system similar to a punch card reader for interfacing with the computer. Fire control systems have an Instruction Per Minute (IPM) listing if they are to be integrated into a computer-controlled fire control system. For example, if a ship wants to use Gunnery Software, all the range finders in a ship must be integrated and will consume IPM. Plotting tables and computer-assisted gunnery can be combined for best effect as it allows human feedback.

Other systems only require computer resources if they are replacing crew. For example, Aldis lamps and Tube Blinkers can be operated by a single crewmember or by allocating 20 IPM.

Table 33: Communication, Sensors, and Automation Systems

Name	Mass (kg)	Volume (m3)	Power (W)	Crew	IPM	Notes
Bomb sight	50	0.1	0	1	100	
Stadiametric rangefinder	25	0.1		1	30	Treat as 0.5m rangefinder
Coincidence rangefinder (1m base)	52	0.5		1	120	
CRF (2m)	173	0.6	0	1	140	
CRF (4m)	628	0.8	0	1	160	
CRF (8m)	2380	1.2	0	1	180	
Autopilot	50	0.1	50	*	100	Requires Standard Flight Instruments or better
Gunnery Software I	1			1	**	Ranges up to 5000m
Gunnery SW II	2			1	**	Ranges up to 10000m
Gunnery SW III	4			2	**	Ranges up to 20000m
Gunnery SW IV	8			2	**	Ranges up to 40000m
Aldis Lamp	25	0.1	150	1	20	Communications ***
Tube Blinker	21	0.01	90	1	20	Concealed communications (tight beam) ***
Signal Flags (Chappé Telegraph)	20	0.1	30	1	30	***
Homing Pigeon Coop (20 bird)	450	11	0	0.5		Homing pigeons provide one-way communication back to a known location. ★★★
Raven Coop (10 bird)	450	11	0	1		Trained ravens can provide more flexible communication. ★★★

Name	Mass (kg)	Volume (m3)	Power (W)	Crew	IPM	Notes
Avian Recon System	50	0.1	0	0		Allows small cameras to be attached to Pigeons or Ravens ★★★★★
Heliograph	20	0.1	10	1	20	*** Only works during the day
Skywriting System	300	0.25	1200	1	0	Can also be used to produce a smoke screen up to 5km in length. Refills are 250 kg.
AutoSkywriter System	350	0.30	1400	0	20	Computer controlled skywriting, produces more stable and readable skywriting. Requires gyrocompass
Fog Horn	300	0.3	100	0	0	3.5 km range [***17***]
Loudspeaker, 1km	5	0.3	250	0	20	
Loudspeaker, 5km	130	0.8	6500	0	20	
"Grappling Telegraph" Gun & Key, 1km	106	1.1	150	1	200	*** 1km Range, 1 round is 60kg. ★★★★
"Grappling Telegraph" Gun & Key, 4km	354	1.6	600	1	200	*** 4km Range, 1 round is 250 kg. ★★★★
"Grappling Telegraph" Net & Teletyper	10	1	20	1	200	*** ★★★★
Photophone	100	1	250	1	100	★★★★★★
24-in Arc Light	100	0.3	2700	1★	10	*Provides +5 to Observe rolls at night up to 4000m*; Increases C_d*S by 0.5 m^2
36-in Arc Light	300	1.0	15000	1★	10	*Provides +5 to Observe rolls at night up to 7500m;* Increases C_d*S by 1.0 m^2
60-in Arc Light	1100	3.0	25000	3★	10	*Provides +5 to Observe rolls at night up to 10000m*; Increases C_d*S by 2 m^2
Plotting Board MkI	2200	7.5	750	12	40	Available 1870. Plotting Factor 1.
Plotting Board MkII	3300	11	1200	13	100	Available 1875. Plotting Factor 2.
Plotting Board MkIII	4200	14	1700	15	250	Available 1880. Plotting Factor 4.

Name	Mass (kg)	Volume (m3)	Power (W)	Crew	IPM	Notes
Automated Plotting Board MkIII	4700	19	3200	10	2250	Available 1885. Plotting Factor 4. Requires Computer
Plotting Board MkIV	4650	15.5	2100	17	500	Available 1885. Plotting Factor 5.
Plotting Board MkV	5100	17	2400	18	600	Available 1890. Plotting Factor 6.
Gun Pointer	10	.01	10	0	30	Provides +2 to 'fire' rolls
Gun Control	20+ P/150	M/1000	20+ 1W/kg	****	****	† Provides +5 to 'to hit' rolls
Engine Control (1st third)	10	0.01	50	††	100	
Engine Control (2nd third)	75	0.1	150	††	400	
Maneuver Control			350	†††	50	
Automatic Damage Control	50	1	100	0	50	Per 100m^3 of ship. Improves damage control rolls by 5
Automated Aerolyth Controls	8*A	0.1*A	10*A	††††	20*A	††††
Watch Sensor Rig	3.6*P	.025*P	10*P	3	2*P	†††††
Computers	★★	★★	★★	★★	★★	★★

Further reading: Searchlights [***18***] Plotting Tables [***19***]

Table 34: Explanatory Notes for Automation Systems

Symbol	Meaning
*	Reduces helmsmen to 1 and removes need for navigation watch standers
**	The number of instructions to compute a firing solution depends on the range and type of software, based on the equation R/5*M where R is the range in meters and M is the software mark. For example, Mark II software, computing a trajectory for a 7000m target would require 2800 instructions. To determine how long a trajectory computation takes, first determine the "spare" IPM a computer system has by subtracting the computing requirements of all the systems which are automated from the computer's IPM rating. Then divide the instruction requirements of the trajectory by the number of "spare" cycles. This will determine the time to compute a solution in minutes.
***	If connected to a computer, these communication devices require no crew to send messages.
****	Any weapon with a Gun Control has its crew reduced according to the table below. Multiple gun controls can be applied to a single turret, with IPMs given below. For example, a single gun control applied to a weapon with an unmodified crew between 1 and 5, the crew is reduced by 1. If three gun controls are applied to a turret with a crew of 25, the crew would be reduced by 15. Fractional crew should be discarded (i.e. round down). A weapon cannot have its crew reduced

<table>
<tr><th>Symbol</th><th>Meaning</th></tr>
<tr><td></td><td>below zero.
<table>
<tr><th rowspan="2">Gun Controls</th><th rowspan="2">IPM</th><th colspan="3">Crew Reduction</th></tr>
<tr><th>1-5</th><th>6-10</th><th>>10</th></tr>
<tr><td>1</td><td>100</td><td>-1</td><td>-2</td><td>-35%</td></tr>
<tr><td>2</td><td>250</td><td>-2</td><td>-4</td><td>-50%</td></tr>
<tr><td>3</td><td>400</td><td>-3</td><td>-6</td><td>-60%</td></tr>
<tr><td>4</td><td>600</td><td>-3</td><td>-8</td><td>-70%</td></tr>
</table>
</td></tr>
<tr><td>†</td><td>Gun control is per turret. The power requirement is based on the mass of the guns controlled, not the turret or turret armor.
s</td></tr>
<tr><td>††</td><td>Engine or generator maintenance crew (i.e. not including stokers) is reduced by one crew member. The “1st third” option can be applied multiple times, up to 1/3 of the crew (rounded down), the “2nd third” option can be applied multiple times up to an additional 1/3 of the crew. E.g. an engine which requires 17 crew could apply the “1st third” automation 5 times to reduce the crew to 12, and the “2nd third” automation another 5 times to reduce the required engine crew to 7.</td></tr>
<tr><td>†††</td><td>Reduces Maneuver system by 20 tons for purposes of crew computation</td></tr>
<tr><td>††††</td><td>The mass, volume, power, and IPM for Aerolyth automation is based on the tons of Aerolyth (A). For example, 10 tons of Aerolyth would require an automation system of 80kg, 1m3, 100W, and 200 IPM. For the purposes of crew computation, Aerolyth automation reduces the mass of the Aerolyth by a factor of 5 for computing the electrical crew.</td></tr>
<tr><td>†††††</td><td>A watch sensor rig replaces the lookouts on a ship with a series of periscopes and relay lenses, controlled through a Babbage machine interface. The mass, power, and volume is based on the length of the ship’s perimeter. A sensor rig is not as effective as a non-automated watch (–1). If a sensor network is present, the crew for Arc Lights is reduced to one-third, rounding up. (i.e. if a ship has one 60-inch and two 24-inch lights, its normal arc light crew would be 3+2*1=5. With a sensor rig, it would be ceil(5/3)=2.</td></tr>
<tr><td>★</td><td>If a sensor network is present, the crew for Arc Lights is reduced to one-third, rounding up. (i.e. if a ship has one 60-inch and two 24-inch lights, its normal arc light crew would be 3+2*1=5. With a sensor rig, it would be ceiling(5/3)=2.</td></tr>
<tr><td>★★</td><td>If a given system is integrated with a computer for automation purposes, the computer must be able to devote some processing power to that device. For example, an 1861 Babbage Small Analytical engine has a maximum rating of 83 IPC. This means it could support two Stadiametric rangefinders, but not a coincidence range finder.
Computer mass, weight, etc... can be found in Table 35, below or designed from Section 5.4. The number of required computers is ceiling((IPM_ship / IPM_computer)^1.5).</td></tr>
<tr><td>★★★</td><td>Trained pigeons and ravens can be used to carry written messages from flying ships.</td></tr>
</table>

Symbol	Meaning
	Homing pigeons provide communication from a ship to a known (fixed) location on land, flying an average of 80 km/hr. To determine a pigeon's success, make an opposed roll at a +10 for every 100 km or fraction thereof. Trained ravens offer more flexible, though somewhat less reliable, communication. Ravens can be instructed to fly from a vehicle to another location in its line of sight. The destination can even be another flying vehicle, if that vehicle is moving at less than 15 m/s. However, raven's very intelligence also gives them a tendency to place their own self-preservation and simple curiosity over their delivery mission. To determine a raven's success, make an opposed roll at a +7 for every 4km or fraction thereof. If the destination is a moving target, subtract 5 from the roll. If the path the bird must take is dangerous (e.g. during a battle) subtract 10 from the roll. If the raven fails in its mission, it does not return.
★★★★	The Grappling Telegraph is a two-part system – a gun and net. The gun portion is a low-velocity mortar that fires a grappling hook that trails a signaling wire. The net is a large wire mesh that acts as a target for the grappling hook. Once the wire is established between the two ships, it is connected to a telegraph key and teleprinter, allowing communication between the two craft. [***20***]
★★★★★	The Avian Recon system provides storage for small cameras and harnesses to attach them to pigeons or ravens. It also provides a space to extract film from cameras and store it securely, but does not provide facilities to develop or print the film. This requires a darkroom (see Table 26)
★★★★★★	The photophone allows voice communication between two points through the modulation of light. During the day it uses reflected sunlight and can allow communication up to 350m on a clear day. At night, an Arc Lamp is required to provide illumination. The communication distance is 1/10 of the illumination distance for an Arc lamp. So, a 36-inch lamp can allow photophonic communication over 750m.

3.3.11.1 Computers

Table 35 is a listing of commonly available Babbage engines and their characteristics. Table Notes:

- Year: Official availability. Due to the limited manufacturing capabilities of the time, only the highest priority customers would be able to produce a machine for the first year or two after production.
- Mass & Volume: Include Mill, Store, and Printer
- IPM: Instructions per Minute.
- MTBF: Mean Time Between Failures
- Memory: The number of base-10 digits in the Store

Table 35: Catalog of Commonly Available Babbage Engines

Company	*Name*	*Year*	*Cost*	*Mass (kg)*	*Volume (m^3)*	*Power (kW)*	*IPM*	*MTBF (hr)*	*Memory (digits)*

Company	Name	Year	Cost	Mass (kg)	Volume (m^3)	Power (kW)	IPM	MTBF (hr)	Memory (digits)
Babbage	Analytical	1850	£13,002	181000	576.9	23.83	33	9	40000
Babbage	Analytical	1860	£8,000	100000	199.1	29.78	156	41	40000
Babbage	Analytical	1871	£5,900	56000	88.6	35.13	807	88	40000
Babbage	Analytical	1882	£4,200	25000	35.5	36.66	4524	212	40000
Babbage	Analytical	1891	£3,400	11000	14.7	44.49	28206	439	40000
Babbage	Analytical	1900	£2,250	3000	3.4	52.06	179848	789	40000
Babbage	Small Analytical	1851	£2,502	39000	9.9	0.48	21	37	1600
Babbage	Small Analytical	1861	£1,400	22000	4.6	0.60	83	78	1600
Babbage	Small Analytical	1871	£1300	15750	2.7	0.72	308	157	1600
Babbage	Small Analytical	1881	£1200	9125	1.5	0.72	1111	426	1600
Babbage	Small Analytical	1891	£1000	4200	0.7	0.87	5756	1100	1600
Babbage	Small Analytical	1901	£810	1250	0.02	1.04	31442	2615	1600
Babbage	Large Analytical	1850	£200,076	1180000	4245.6	464.97	231	1	400000
Babbage	Large Analytical	1860	£141,000	640000	1983.8	581.22	1160	26	400000
Babbage	Large Analytical	1870	£127,000	450000	1113.2	678.09	4966	39	400000
Babbage	Large Analytical	1880	£120,000	250000	574.2	697.46	22300	64	400000
Babbage	Large Analytical	1890	£91,200	105000	231.6	864.67	143705	200	400000
Babbage	Large Analytical	1900	£61,450	26500	50.3	1070.60	946910	281	400000
ABM	Thinking Machine 1	1853	£25,400	4000	1.45	0.05	15	39	300
ABM	Thinking Machine 2	1862	£800	2200	0.70	0.05	45	80	300
ABM	Thinking Machine 3	1871	£200	1000	0.26	0.06	213	160	300
ABM	Thinking Machine 4	1880	£120	600	1.4	0.07	783	435	300

Company	*Name*	*Year*	*Cost*	*Mass (kg)*	*Volume (m^3)*	*Power (kW)*	*IPM*	*MTBF (hr)*	*Memory (digits)*
ABM	Thinking Machine 5	1890	£40	175	0.4	0.07	3587	1145	300
ABM	Thinking Machine 6	1900	£50	81	0.1	0.07	16303	2893	300
Scheutzian	Calculator I	1850	£11,000	117000	343.3	42.65	38	17	24000
Scheutzian	Calculator II	1860	£4,600	57730	77.9	29.32	149	20	24000
Scheutzian	Calculator III	1870	£4,200	37000	40.7	34.21	472	8	24000
Scheutzian	Calculator IV	1882	£4,200	16000	17.3	35.18	1488	22	24000

3.3.11.2 Radios

Radios are available after 1897. They are, however, extremely unreliable and slow. Radios can be selected from Table 36, or designed in Section 5.4.3.

Table 36: Radios

Mass (kg)	Volume (m3)	Power (W)	Crew	Max Range (km)
60036	140.1	294000	31	3500
51020	119	250000	26	2260
27586	64.4	135000	15	1010
15015	35	73600	9	710
6803	15.9	33300	5	320
3781	8.8	18500	3	100

When using a radio, make an opposed roll, with the opposing roll modified as in Table 37.

Table 37: Radio roll opposing modifiers

Condition	Opposing Roll Modifier
Base	–5
<operator skill>	–<skill>
Daytime	+5
Range is 1/5 of Max Range or less	–5
Range is 1/25 of Max Range or less	–5

Example: A radio with a maximum range of 1010 km attempts to communicate, during the day, with another radio 50km away. 50km is less than 1/5 of the max range, but more than 1/25 of the max range, so the opposed roll is modified by –5 (–5 (base) +5 (daytime) –5 (range)).

3.3.12 Space Systems

Operating a ship outside of the atmosphere (i.e. about 100km or 300,000 feet) requires special propulsion, and heat control systems.

3.3.12.1 Engines

A rocket system is compromised of the rocket engine and fuel. Fuel is allotted in 60-second increments. The different types of engines are described in Table 38, with their mass and volume characteristics in Table 39 and their fuel requirements in Table 40.

Table 38: Space Engine Types

Type	Restart	Accuracy	Notes
Cold Gas	Auto	1%	Compressed gas. Provides very precise control, and instant on/off control
Solid	No	5%	Solid nitrocellulose in a binder. Once started, it cannot be extinguished until it runs its course.
Liquid	+5	5%	Liquid fueled rocket (Oxygen + Kerosene). Can be shut down and restarted (must win an opposed role at +5).

Table 39: Space Engines

Engine	Mass (kg)	Volume (m^3)	Power (W)	Crew/IPM	Isp	Thrust (N)
Cold Gas Small	1	.001	30	.1/10	50	1
Cold Gas Large	1	.001	30	.1/10	50	300
Solid Small	6	.006	0	0/10	200	8000
Liquid Small	18	0.075	30	.25/30	315.5	10000
Liquid Medium	27	0.1	30	0.5/60	315.5	40000
Liquid Large	59	0.1	30	1/150	315.5	160000
Liquid V. Large	182	0.2	30	2/400	315.5	640000

Table 40: Requirements for 60 seconds of fuel (including oxidizer)

	Mass (kg)	Volume (m3)	Dry mass
Cold Gas Small	2	.001	1.8
Cold Gas Large	36	0.3	46
Solid Small	276	0.2	32
Liquid Small Fuel	350	0.4	14
Liquid Medium	1397	1.6	47.2
Liquid Large	5585	6.2	161
Liquid V.Large	22330	24.4	550

Further reading: [*21*]

In addition to space engines, conventional steam engines or ICE engines require oxygen to operate at altitude. This may be necessary to generate mechanical force to run generators. The mass of oxygen is 3 kilograms of oxygen per kilogram of conventional fuel consumed while in space.

This oxygen is stored as a stable liquid, Super Oxygen (see Table 16 for storage and volume requirements).

Example: An 7cyl 7L Internal Combustion engine requires 43kg/hr of fuel to operate. In space it would require an additional 129kg of Super Oxygen per hour to operate. If 3 hours of operation was required, this would mean 387kg of Oxygen, which would require 0.387 m^3 and 38.7kg of storage overhead..

3.3.12.2 Thermal Systems

Spaceships will often have reflective coatings to deflect heat fro the sun, but without the atmosphere to remove excess heat, spaceships will quickly overheat from heat produced internally. To remain habitable, space ships must have special thermal control systems. To compute the mass and volume requirements of these systems, follow this procedure:

1. **Compute Thermal Power Influx**. This is equal to 0.5*P + 100C + 200(W*L), where P is the power produced by any conventional engines or batteries in the ship, C is the number of crew, W is the width of the ship in meters and L is the length in meters. The result is the power influx in Watts.
2. **Provision Radiators or Ablatives**. The incoming heat flux must be removed by using radiators or ablatives (i.e. things that evaporate and take heat with them).
    a. **Radiators** remove 200 W/m^2. To determine the area of radiator needed, divide the power influx by 200. Aluminum radiators mass 12kg/m^2 for folding panels or 3.3kg/m2 for fixed panels. Steel radiators mass 35kg/m^2 for folding panels and 10kg/m^2 for fixed panels. Fixed panels add 0.02 drag for each m^2.
    b. **Ablatives** are usually ammonia evaporators. To determine how much ammonia is needed, multiply the power influx in Watts by the time the ship will be in space, in seconds and divide this by 1200000. This is the mass, in kilograms, of the ammonia. Divide this mass by 682 to compute the volume in m^3.
3. **Add Heat pipes**. To collect and move the excess heat to the radiators requires heat pipes and cold plates. The mass of these systems, in kilograms, is: 0.4 * (W+L) * I + I/80; where W is the spacecraft width, L is the length, and I is the power influx. The volume is the mass divided by 100.

3.3.13 Crew Accommodations

Crew accommodations include living and working spaces, access spaces to machinery, and various tools and supplies for living and working.

To determine the accommodations, first compute the size of the crew. To do this, we must know the length of time that the vehicle will operate independently. For example, a long-range cruiser may go weeks or months between visits to a friendly port and maintenance faculties. Therefore, it must carry a number of engineers and technicians on board to conduct repairs while underway. In contrast, a short-range fighter craft may only be aloft for a few hours at a time before returning to base. Thus, it can dispense with much of the on-board maintenance duties and only carry a pilot. Additionally, a craft may need a number of crew who are not directly necessary to its functioning of the craft, such as stewards, marines, chaplains, and administrative staff. Ships may also carry paying passengers.

3.3.13.1 Crew Type

Determine the Crew Type from Table 41.

Table 41: Crew Type

Crew Type	Conditions
Very Short Duration	Operations <4 hour
Short Duration	Operations <24 hours
Medium Duration	Operations <1 week
Long Duration	Operations greater than one week

3.3.13.2 Crew computation

Compute the size of the crew for each department:

- **Hull**: Required for Medium or Long Duration craft. One crew member for every 900 tons of hull, wing, turret, and armor mass, rounded down.
- **Engines and Generators**: As per the engine table, minus any automation. Medium duration may divide the required crew by 3, rounding up. Short duration craft may divide the required crew by 10, rounding down. Very Short duration craft may divide by 50, rounding down. Note for steam engines: the number of stokers is **not** divided, but is used as is for very short and short duration craft. Medium and Long duration craft should multiple the number of stokers by 3 if they require the engines to burn all day. For example, a steam engine with 5 maintenance crew and 3 stokers would require 3 crew for a short duration craft (floor(5/10)+3), 10.67 crew for medium duration (5/3+3*3), or 14 crew for long duration (5+3*3).
- **Payload**: as per Table 26
- **Weapons**: As per the weapons table, minus any automation. Short duration craft by divide by 2, rounding down. Very Short Duration craft may divide by 4, rounding down. All non-fixed, non-automated weapons mounts must have at least one crewmember. (i.e. a double turret requires at least one crew member). Non-military craft, which are expected to use their weapons sparingly, may reduce their weapons crew by a factor of 3, rounding down. Note, fixed-mount weapons have their crew requirements reduced by one.
- **Navigation:** Medium and Long duration craft must have one navigator per 4000 tons of craft, rounded up. Long duration craft require 3 watch standers in addition to this unless they have an autopilot. Long duration commercial craft require 2 watch standers.
- **Maneuver**: Medium and Long duration craft require one Maneuver Crew for every 10 tons of maneuvering systems, plus any additional from Table 30, rounded down.
- **Electricity**: Medium and Long duration craft require one crew for every 10 tons of non-generator electrical equipment (Aerolyth, batteries, power regulation, cabling) rounding up. If computerized Aerolyth controls are included, the mass of the Aerolyth is divided by 5 for this computation. For example, a ship with 40 tons of Aerolyth and 10 tons of other electrical equipment would normally require 5 crew floor(((40+10)/10)). With Aerolyth automation, it would require 1 floor(((40/5+10)/10))
- **C&DH**: As per Table 32. Additionally, one crew member is required for every 2 tons of automation equipment and computers (e.g. gun controls, engine controls, Aerolyth auto-

mation), rounded down. Very Short, Short, and Medium duration craft may dispense with the C&DH crew.

- **Computing & Communication**:
  - **Operators**: As indicated in "Computing, Communication, and Sensors" p53. If communications equipment or sensors are not intended to be used frequently, the crew requirement may be divided by 5, rounded down.
  - **Maintainers**: Sufficient number to accommodate average failures. A common rule of thumb is 50/MTBF, rounded up. Generally only found on medium or long duration craft.
- **Thermal:** One per 5 Tons of thermal regulation equipment, rounded up
- **Operations Crew**: Provide control of the ship.
  - **Weather**: Required on Long Duration ships. 2 crew plus 1 additional per 5000 tons of craft, rounded down. Commercial Craft require 1.
  - **Lookouts**: Required on Medium and Long Duration craft. 3 crew plus 3 per 50 meters of hull perimeter (2 * (length + width)), rounded up. Commercial craft require 3 crew plus 3 per 400 meters of hull perimeter, rounded down
  - **Helmsman**: Required on Medium and Long Duration craft over 1000 tons. 3 crew, unless equipped with an autopilot. Commercial craft require 2 crew.
  - **Pilot**: Short and Very Short duration craft require 1 pilot
- **Deck Crew**: M misc. equipment and cleaning. Required for Medium and Long Duration craft over 500 tons. One crew per 400 tons of craft, plus 10% of all crew computed up to this point (i.e. Hull + Engine + Payload + Weapons, etc…), rounded down.
- **Payload Crew**: Including carried vehicle crew, science screw, etc… As section "Payload" on page 34.
- **Officers**: On Medium and Long duration craft over 100 tons, officers are computed separately from other crew. On these ships, one officer is required for every 20 regular crew, rounded down. On Long duration craft, if there are over 40 officers, one additional officer is required for every 20 officers, rounded down. For example, a Long duration ship with a crew of 1500 would require 78 officers (1500/20 + 75/20). Additional officers can be carried to improve coordination during combat.
- **Passengers**: Passengers are traditionally divided into three classes: 1st, 2nd, and steerage.
- **Marines/Security:** Optional. Additional Marines or Security personnel can be carried to assist in damage control.
- **Admin**: Handle paperwork and payroll for longer duration vessels
  - **Medium Duration:** One per 100 crew, rounded down
  - **Long Duration:** One per 20 crew, rounded down
- **Stewards & Supply**: Provides and oversees material for the operation of the ship and the needs of its crew and passengers. Includes cooks, barbers and laundry. Only required on Long and Medium duration ships, or ships with passengers.
  - **Passenger Ships**: One steward per 8 1st class passengers, One steward per 20 2nd class passengers, One steward per 40 steerage passengers. All stewards are summed and rounded up. Short and Very Short ships may divide stewards by 4.

  - **Medium Duration**: One Supply Crew per 40 crew computed to this point, rounded up
  - **Long Duration**: One Supply Crew per 10 crew computed to this point, rounded up
- **Medical**:
  - **Medium Duration**: One medical crew per 100 regular crew, rounded down. If specialized medical facilities are carried (see Table 26) the crew for these facilities are subtracted from the medical crew here.
  - **Long Duration**: As per Medium, plus one dentist per 500 crew, rounded down.
- **Chaplain**: Optional, depending on culture. One chaplain per 250 crew, rounded down. Long Duration Vessels only.

Crew Reduction Options

- **Generalist Crew**: Medium and Long duration commercial vessels may reduce their crew by "doubling up" duties among several crewmembers. This has the result of reducing crew reaction time and efficiency (-3 to command rolls), but reducing the overall crew size. If the generalist crew is used, the weapons, navigation, communication, operations, and deck crew departments are merged, and their total size is divided by 2, rounding up. E.g.: A given ship had a weapons crew of 2, navigation department of 3, 1 weather, 3 lookouts, and 2 helmsmen. The generalist crew would be ceil((2+3+1+3+2)/2) = 6.
- **Overworked Crew**: Large vessels (>20 crew) may reduce their crew by simply assigning more work to fewer people. Though this reduces the crew size, it has a negative effect on crew performance. Ships may also temporarily overwork their crew to free up crew for landing parties or other temporary assignments. If an overworked crew is used, Table 42 explains the effects. In Column 1, the percentage reduction of crew is listed. This reduction is applied to all non-officers or passengers, rounding up. Columns 2 and 3 list the effects on action points and command modifiers, as explained in Section **Error! Reference source not found.** on starting on page **Error! Bookmark not defined.**.

Table 42: Overworked Crew Effects

Crew Reduction	Action Point Reduction	Command Modifier Reduction
10%	–20%	–2
20%	–35%	–4
30%	–50%	–6

3.3.13.3 Accommodations

With the size of the crew computed, the accommodations can be provisioned.

- **Working Space:** Some portion of the ship will need to be set aside to allow access to machinery, hallways, ventilation, and meeting space. The volume which must be set aside is shown in Table 43.
- **Crew Space:** Space must be provided for the crew and passengers. Very Short duration craft need only provide seats/stations of 1.5m^3 per person, Short duration craft need 2.0 m^3 per person. Passengers (i.e. those not expected to help with the flying of the ship) on V.short duration craft may also use the "Standing Room Only" stations, which provide for little movement (Note: this space is quite cramped and passengers are prone to injury if the craft maneuvers much). For Medium and Long duration craft, bunks or staterooms

must be provided for rest **as well as** seats or stations for working. The volume and mass requirements are shown in Table 44. Note, it is possible for two enlisted (non-officers) crew to share a single bunk or stateroom for Long Duration ships and for three enlisted to share a single bunk or stateroom on medium duration ships.

- **Crew, Supplies & Equipment:** In addition to food and water, crews require other equipment such as hygiene supplies, showers, food preparation equipment and tools. The mass, volume, and power required for these are given as a function of the crew size and trip duration in Table 45, where the variable p is the number of persons and pd is the number of person-days. (Note, this also includes the mass of the crew themselves). Some crew may require special equipment. For example, marines or other soldiers require about 25 kilos and .1m^3 for equipment in addition to their regular crew accommodations.

Table 43: Volume of Ship Required for Working spaces

Type	Small Ship (<10,000 m^3)	Large Ship
Very Short Duration	0%	1%
Short Duration	5%	5%
Medium Duration	15%	20%
Long Duration	30%	35%

Table 44: Crew Spaces

	Mass	Volume
Standing Room Only (Cramped)	5	0.4
Standing Room Only (Avg.)	5	0.7
Unfurnished Space	5	1.0
Station (VShort)	15	1.5
Seat (Short)	20	2.0
Bunk	35	2.0
Hammock	15	1.5
Shared Small Stateroom (double occupancy)	120	12
Small Stateroom	100	10
Medium Stateroom	200	20
Large Stateroom	400	40

Table 45: Crew, Supplies, and Equipment

Notes	Duration	Mass kg	Volume m^3	Power (W)
	<1 day	95p	0.005p	0
Hot Meals	1 day	139+101p	2.44+.065p	26p
	1 day	89.18+100p	2.19+.06p	0
Hot Meals & Showers	1-5 days	239+130.5p	3.9+.23p	39.4p
Hot Meals	1-5 days	164+129p	2.48+.21p	26p

Notes	Duration	Mass kg	Volume m^3	Power (W)
Showers	1-5 days	189+129.5p	3.6+.22p	13p
	1-5 days	114+128.5p	2.23+.2p	0
Hot Meals & Show-ers	6-29 days	241+135p	3.9+.25p	39.4p
Hot Meals	6-29 days	166+132p	2.5+.22p	26p
Showers	6-29 days	191+132.7p	3.7+.24	13p
	6-29 days	116.5+131.5p	2.24+.22p	0
Hot Meals & Show-ers	30+ days	256+111.5p+.15pd	4+.25p+.001pd	40p
Showers	30+ days	216+111.5p+.15pd	3.8+.24p+.001pd	30p
	30+ days	132+111.5p+.15pd	2.34+.22p+.001pd	0p

Example: A ship with 250 crew wishes to provision supplies and equipment for 45 days. The ship provisions showers, but not hot meals.

	Mass (kg)	Volume (m^3)	Power (W)
Supplies & Equipment: Showers	216+111.5*250+.15*250*45 = 29778.5	3.8+.24*250+.001 250*45 = 63.8563	30*250 = 7500

3.3.14 Crew Support

If the craft will regularly venture beyond high above sea level, it is necessary to provide air for the crew. If compressor systems are used, tubing and gas masks and air tubing for the crew must be provided. Select one from Table 46.

Table 46: Air Systems. Mass and Volume given per person (p) or per person-day (p-d)

Name	Mass (kg)	Volume (m^3)	Power (W)	Crew	Notes
Low Altitude Compressor	.03*p+5	.001*p	4.5*p	0	Good to 4000m. Not strictly required for this altitude, crews without air at this level will re-ceive a -1 to Command rolls.
Medium Altitude Compressor	.12*p+10	.001*p	18.5*p	0	Good to 9000m. Crews without air will blackout in 1 to 3 minutes. Note: Pressurized hulls or pressure suite recommended at this altitude [*22*]

Name	Mass (kg)	Volume (m^3)	Power (W)	Crew	Notes
High Altitude Compressor	.15*p+20	.001*p	22.0*p	0	Good to 14000m. Crews without air will black out in under 10 seconds at this altitude. Note: hulls must be pressurized and have cabin heating or crew must wear heated pressure suits at this altitude.
Pressure Suits	15*p				
Heated Pressure Suits	25*p		100*p		
Cabin Heating	0.1V	.002V	2V	0	Circulates waste heat from the engine through the ship. Based on ship volume (V) in m^3
Gas mask	1*p	.001*p		0	
Tubing	.35*m	.001*m			Mass is per meter. Required distance is: ((longest dimension) + (shortest dimension)) + 2 meter per crew.
Closed O_2 system	2.2 * p-d	.0015 * p-d	10 * p	.01 * p	Uses LiH scrubber to remove carbon dioxide and stored O_2.

Craft that routinely travel for more than a few hours will require potable water for drinking. Craft that travel for more than a few days will have to carry food, and may also carry extra water for washing and personal hygiene. Table 47 contains a suitable range for the requirements per day.

Example: A ship with 28 crew is traveling for 15 days. The owner is stingy and provides minimal water (3kg per person per day) and food (1kg per person per day). However, he is more lavish with hygiene water (10kg per person per day). The total is 14kg per person per day and 0.015 m^3 per person per day. Over the course of the trip, this is 5880kg and 6.3m^3.

Table 47: Food and Water

	kg per person per day	m^3 per person per day
Potable Water	2.5-4.0	.0025-.004
Food	0.5-3	.001-.006
Hygiene Water	1.0-10	.001-.01
Total	4.0-17	.0045-.02

To reduce water requirements on long voyages, a desalinization plant may be used to purify external water or to recycle hygiene water and urine. Assume 75% of hygiene water can be recaptured and 1kg per person per day of urine. Sizing for desalinization plants can be found in Table 20.

3.4 Calculate Performance

3.4.1 Will it fit/fly/turn on?

The first calculation is to determine if the vehicle can function at all.

- **Will it fit?** The sum of the volume all of the ship systems must be less than the volume of the hull.
- **Will it fly?** The lift mechanisms of the ship (Aerolyth panels, wings, etc…) must provide more lift than the mass of the ship. Additionally, the total ship's mass can not be greater than the maximum carrying capacity of the hull.
- **Will it turn on?** The sum of the power requirements for the ship's systems must be greater than the electrical power generated by the generators or batteries.
- **Will it compute?** If a computer is used on the ship, the sum of all the systems compute requirements (IPM) must be less than the compute capacity of the computer.

If the answer to any of these is no, the designer should adjust the spring style design to compensate.

3.4.2 Motion: Velocity, Acceleration, Altitude

Maximum Velocity: The maximum velocity of the ship is computed with this equation:

$$V = 60 * \left(1.67 * \frac{P}{D}\right)^{0.333}$$

Where P is the output power of the propulsion system, D is the ship's drag, and V is the ship's velocity in meters per minute. If the ship uses wings, and the maximum velocity is less than the stall speed, the design is not viable and must be adjusted.

Acceleration: The acceleration of the ship is computed with this equation:

$$A = 0.6 * V^2 * \frac{D}{M}$$

Where V is the maximum speed in meters/second, D is drag, M is the ship's mass in kilograms, and A is the acceleration in meters per minute per minute.

Maximum Altitude: If the ship uses Aerolyth, the maximum altitude is determined by the amount of power provided to the Aerolyth panels (See Table 6). If the aircraft is lighter-than-air, the maximum altitude is 4000m. If the aircraft uses aerodynamic lift, use Table 48 or this equation:

$$Alt = 10000 * \left(1 - .8 * \left(\frac{V_{stall}}{V_{max}}\right)^3\right)$$

V_{stall} is the wing's stall speed, V_{max} is the aircraft's maximum speed, and Alt is the maximum altitude in meters. If the aircraft has a supercharged engine, multiply Alt by 1.2.

Table 48: Maximum altitude for Cayley

$V_{stall}/V_{\_max}$	Max Altitude (m)	Max Supercharger Alt(m)
0.20	9900	11900
0.25	9800	11800
0.30	9700	11700
0.35	9600	11500
0.40	9400	11300
0.45	9200	11100
0.50	9000	10800
0.55	8600	10400
0.60	8200	9900
0.65	7800	9300
0.70	7200	8700
0.75	6600	7900
0.80	5900	7000
0.85	5000	6100
0.90	4100	5000
0.95	3100	3700

Runway requirements: If the ship is a Cayley craft, it will require a runway to take off. The minimum distance of this runway is:

$$0.75 * \frac{V_{stall}^2}{A} * C$$

where V_{stall} is the wing's stall speed, A is the acceleration, and C depends on the type of landing system. For skids C=1.5, for wheels C=1.0 and for pontoons (i.e. a water take off) C=2.5.

3.4.3 Maneuverability

3.4.3.1 Maneuver Rating (Method 1)

$$\left\lceil 4.8 * V^2 * \frac{D}{M} \right\rceil$$

ceil(4.8*V^2*D/M,0)
max rating: 8

3.4.3.2 Turn Rate (Method 1)

Aerolyth: Maneuver*40
Cayley: Maneuver*150
Min: 15 max:600

3.4.3.3 Turn Rate (Method 2)

$$T = \frac{30}{\pi * \frac{M*V}{u}}$$

$$\begin{aligned} u = {} & 0.6 * V^2 * D \\ & + L * C \\ & + 1.05 * V^2 * H * W * (F + 2) \end{aligned}$$

	Maneuver		
Lift System	Low	Medium	High
Aerolyth/LTA	0.17	0.21	0.24
Aerolyth Flapper	0.26	0.29	0.33
Cayley	0.42	0.57	0.71
Pure Cayley Flapper	0.5	0.64	0.77

3.4.3.4 Maneuver Rating (Method 2)

$$a = \left(\frac{6 * L * u}{M * (L^2 + W^2)}\right)^{0.5}$$

$$b = \frac{0.6 * V^2 * D}{M}$$

$$M = ceil\left(\frac{(a^2 * b^2 * T^2)^{0.33}}{1.3}\right)$$

Aerolyth organ+1
w/o at least standard flight instruments –1

3.4.4 Space Performance calculation

Without drag forces, craft behave differently in space than in the atmosphere. Complete coverage of space dynamics and orbital mechanics is beyond the scope of this work, however a few usefule numbers to compute are **Space Acceleration,** which is how quickly a ship can change its velocity by using rockets while in space, and Delta-V (ΔV), which is the maximum amount that a ship can change its velocity before it runs out of fuel. For a more complete examination of these topics (and much more) see [***23***] [***24***] [***25***].

Space Acceleration is computed by the equation:

$$a = \frac{F}{m}$$

where a= space acceleration (in m/s/s), F is thrust (in Newtons), m is mass (in kg).

Delta-V is computed by the equation:

$$\Delta V = Isp * 9.8 * ln\left(\frac{M_0}{M_1}\right)$$

Where Isp is the specific impulse (from Table 39), M_0 is the initial full mass of the ship, and M_1 is the mass of the ship minus the mass of the rocket's fuel. Delta-V is measured in m/s. A Delta-V of at least 300m/s is required to perform high-altitude bombardments (See Section **Error! Reference source not found.**, page **Error! Bookmark not defined.**). An additional Delta-V of 30m/s using high precision rockets can improve bombing accuracy. To reach a Low Earth Orbit requires 8000m/s.

3.4.5 Iterate?

If these parameters (maneuverability, acceleration, etc…) are acceptable, the Spring Style is ready, and the design processs can advance to the next stage. If not, return to Section 3.3 and adjust the design to improve its performance.

3.5 Design the Ship

After the "Spring Style" is complete, the lead designer hands it off to the design team to complete the detailed design. This team completes the deisgn (sometimes introducing new problems or new efficiencies into the design) and calculates the cost to manufacture the finished product.

3.5.1 Design Time & Cost

The amount of effort required to design the ship is based on mass of ship, the design school, and a formula:

$$13.5 * (Mass_{NRE})^{0.6} * NRE_{School}$$

Derived from [*26*], in which $Mass_{NRE}$ is the "dry" mass of the ship in kilograms. That is, the mass without any fuel, cargo, ammo, or crew. NRE_{School} is a factor that is determined from Table 49. This formula gives you the number of man-weeks it takes to complete the design. To find the total time it takes the design team, divide the number of man-weeks by the size of the design team (Table 1, column 4) and round up.

Example: A ship's fully loaded mass is 206600kg and its "dry" mass is 186000kg. It is designed using the Zeppelin School. Its NRE requirement is $13.5*(186000)^{0.6}*0.62 = 12146$ man-weeks. A 500 person design team would require 12146/500=25 weeks to design the ship.

Table 49: School Design & Construction Factors

School	NRE_{School}	$Prod_{School}$	Materials (£/kg)
Venusian	0.49	7.5	.03
Architectural	0.32	4.0	.003
Naval	0.44	5.0	.005
Zeppelin	0.62	5.5	.03
Cayley	0.66	6.0	.03

3.5.2 Design Effects (Optional)

The design process may affect the performance of certain systems in unforsee ways. Good design may reduce their weight or volume; poor design may increase these factors. In general, each system that must be “designed” can be affected. So stores (e.g. food, water, ammunition, fuel) do not have to make design effect roles. Additionally, Aerolyth panels do not have to make design roles as their design is so standardized. Weapons do not have to make a though their mountings do.

For each designed system:

1. Make one opposed d20 roll for each “card” the design team is rated at (Table 1, Column two). The Player’s roll is modified by the design team’s modifier (Table 1, Column three). The opposing role is modified by +35.
2. Draw one card and, for each successful roll, draw one additional card.
3. Select the highest card (with Ace being the highest). This card is used to modify the system according to Table 50. Clubs or Diamonds increase or decrease the mass or volume of the system by the specified amount. Hearts modify the functionality of the system, so, for example a 4♥ would decrease the output of an engine, by 30%, or the effectiveness of armor by 30%. Spade (♠) effects are detailed later.

Table 50: Design Card Effects

Suit…	♣	♦	♥	♠
Card	Mass	Volume	Function	Other
2	+100%	+50%	-50%	Dangerous Failure Mode
3	+50%	+25%	-40%	Poor Reliability
4	+30%	+15%	-30%	Delayed 200%
5	+20%	+10%	-20%	Delayed 50%
6	+10%	+5%	-10%	Poor Righting
7	No Effect	No Effect	No Effect	Poor Living Conditions
8	No Effect	No Effect	No Effect	Odd Noises
9	No Effect	No Effect	No Effect	Ugly Design
10	No Effect	No Effect	No Effect	?
J (11)	No Effect	No Effect	No Effect	?
Q (12)	No Effect	No Effect	No Effect	?
K (13)	-10%	-5%	+10%	Low Maintenance
A (14)	-20%	-10%	+20%	Solid

After determining any changes to the original characteristics, the ship should be reevaluated. It may no longer be viable.

Example: A sample set of design effects:

System	Card	Effect
Generator 50kw output X2	K♥	Function +10%
Gatling Gun X 2	2♣	Mass +100%
Battery	5♠	Delayed 20%
Advanced C&DH	A♠	Solid
Power regulator	A♦	Volume -10%
35 Bunks	K♥	Function +10%

3.5.3 ♠ Effects

Space cards have a variety of effects, and generally require some interpretation:

- **Dangerous Failure Mode**: under stressed conditions, the component reacts in an unpredictable or danger manner. For example, a dangerous failure mode in armor may mean that there is a possibility that the armor will damage the ship's structure if struck. A dangerous failure mode for an engine could mean it explodes when stressed or emits a thick pall of smoke.
- **Poor Reliability**: The component is unreliable and has a 1% chance of failure when used. (for components which are constantly used, such as engines, the chance of failure is per day)
- **Low Maintenance**: The component requires 10% fewer crew to operate or maintain.
- **Poor Living Conditions**: This component causes uncomfortable conditions for those around it. This may be due to poor layout (e.g. poorly spaced bunks), smell (e.g. engine fumes routed through living quarters), sound (very loud machinery), or other problems.
- **Odd Noises**: The component causes odd noises – these may not be very loud, but are just… odd… The practical effect may be that it is difficult to diagnose problems with the machinery, as odd behavior or noise may become common.
- **Ugly Design**: For some reason, no one likes the way this part looks. Maybe the interior design is bad, maybe there is a bad color scheme, maybe there is an excess of rococo design motifs.
- **Delayed**: The given component takes longer to design by some factor, F. The total design is delayed by the factor, times the mass of the component, divided by the NRE mass of the total vehicle. E.g. if the engine consumes 20% of the NRE mass of a ship, and is delayed 200% (4♠), the total ship is delayed by 40% (20%*200%=40%). If they ship would normally take 20 weeks to design, the delayed design would require 28 weeks.
- **?:** Game Master's discretion.
- **Solid**: The component is solidly built. It is 25% more resistant to damage.
- **Poor Righting**: If the ship is a Cayley, <maneuver –x>. If the ship is Aerolyth based, if it is rammed, there is a 25% chance it will tilt beyond its Aerolyth limit and lose lift.

3.5.4 Vehicle Design Sheet

The Vehicle Design Sheet (VDS) is used as a quick reference for combat. Refer to Section **Error! Reference source not found.** to construct the Vehicle Design Sheet.

3.6 Build the Ship

3.6.1 Construction Time & Cost

The total cost of a ship is based on the labor it takes to build the ship and the cost of the ship's materials and components.

Table 51: Production and Materials Costs

School	$Prod_{School}$	Materials (£/kg)
Venusian	7.5	.03

Architectural	4.0	.003
Naval	5.0	.005
Zeppelin	5.5	.03
Cayley	6.0	.03

3.6.1.1 Construction time

The formula to determine the construction time is based on [*26*]:

$$(49.7 * (Mass_{Total})^{-0.24} * Mass_{NRE} + HullFrameTime) * \left(\frac{lotSize}{2}\right)^{-0.33} * Prod_{School}$$

Prod$_{\mathbf{School}}$ is found in Table 51. **lotSize** is the number of copies which will be produced. **Mass**$_{\mathbf{Total}}$ is the total mass of the ship (in kilograms), **Mass**$_{\mathbf{NRE}}$ is the "dry" mass of the ship (See 3.5.1) in kilograms. **HullFrameTime** is found in Table 2, column 8. This formula determines the number of man-hours it takes to build each ship. Building the first ship of any new class takes additional time. If necessary, the formula to compute this is:

$$(49.7 * (Mass_{Total})^{-0.24} * Mass_{NRE} + HullFrameTime) * 1.25 * Prod_{School}$$

Ship building labor costs 0.005£/hr.

Example: A ship's fully loaded mass is 206600kg and its "dry" mass is 186000kg. It is designed using the Zeppelin School. 25 ships are being built. The Hull framing time is 13000 hours. The construction time per ship is $(60*(206600*2.2)^{-0.24}*186000+13000)*(25/2)^{-0.33}*5.5=1201200$ hours. The labor cost per ship is £6005.99.

3.6.1.2 Materials and Component Cost

Basic materials cost are found in Table 51 and are multiplied by the craft's dry weight (MassNRE) to determine material cost. Additionally, other components add cost, based on Table 52.

Table 52: Component Costs

Component	Cost	Notes
Steam Engine/ Spring Engine	6.3 £/kW Output	[*27*] [*28*]
Aluminum Steam Engine	25.2 £/kW Output	
Internal Combustion Engine	12.6 £/kW Output	
Generator/Electric Motor	6.0 £/kW Input	
Steel Armor or Hull	80 £/ 1000 kg	[*29*]
Aluminum Armor or Hull (pre 1882)	7050 £/ 1000 kg	[*30*]
Aluminum Armor or Hull (1882-1886)	882 £ / 1000kg	[*31*]
Aluminum Armor or Hull (post-1886)	132 £ / 1000kg	[*31*]

Component	Cost	Notes
Computers	<As Document>	
Aerolyth	50 £ / 1000kg	
Non Standard Aerolyth	250 £ / 100kg	Aerolyth with thickness > 1

Note, the total ship cost assumes a 10% profit margin, shared between the design and manufacturing groups.

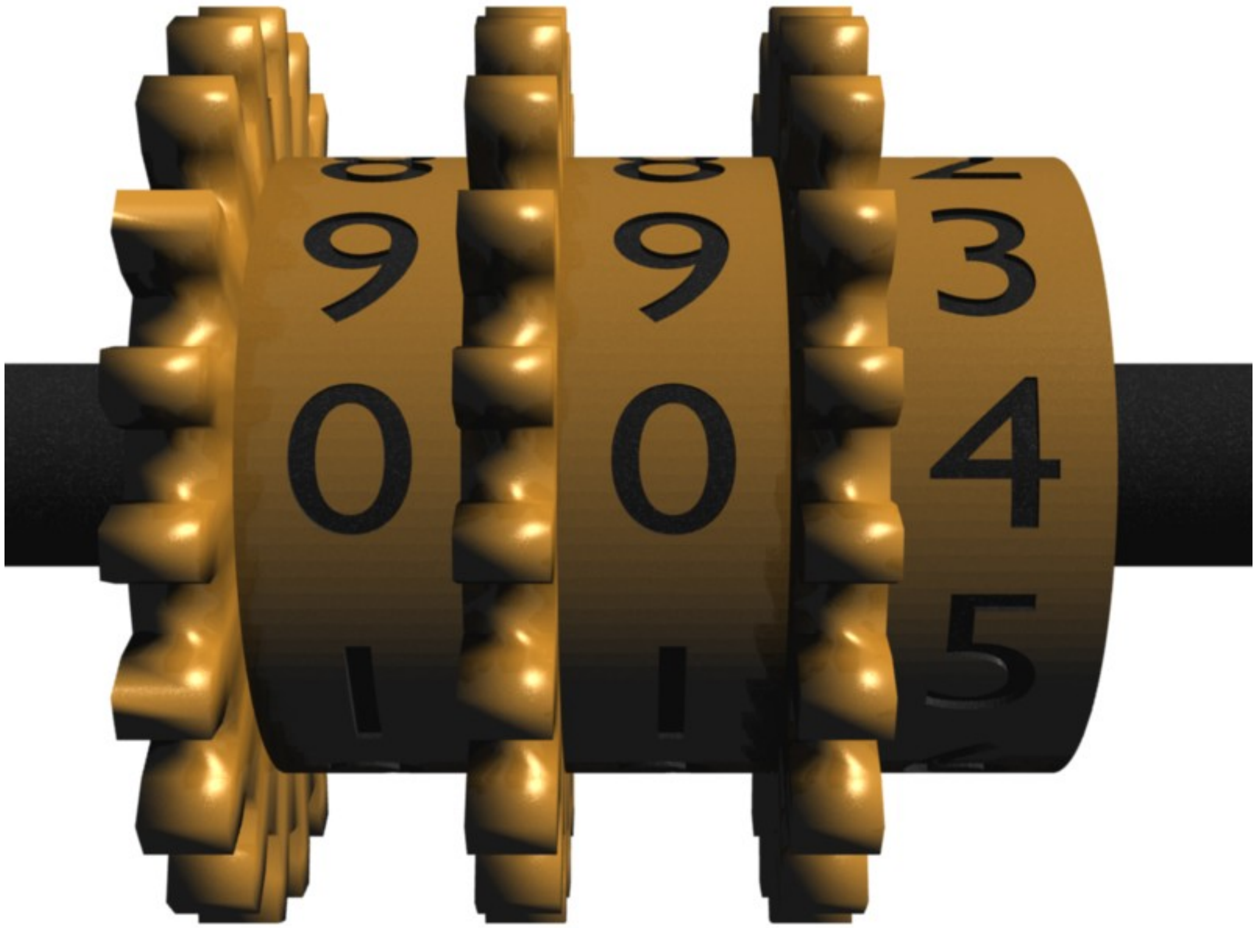
3.6.1.3 Total Cost

The total cost of a ship is the sum of the materials cost, components cost, labor costs, and the NRE cost per ship.

Example: A Zeppelin ship's fully loaded mass is 206600kg and its "dry" mass is 186000kg. The labor cost per ship is £6005.99. The total NRE cost for the batch of 25 ships is £85000.

Cost	Calculation	Cost
Materials	Mass_NRE * Materials (£/kg) = 186000 * 0.03	£5580
Component Cost	From Table 52	£40500
Labor Cost	construction time per ship * 0.005 = 1201200 * 0.005	£6005.99
NRE Cost	Total NRE / lot size = 85000 / 25	£3400
Total		£55486

4. Design Examples



4.1 Japanese MiniPlane

The Japanese MiniPlane (See Section 10.2 of *Flying Machines*) is an example of a very simple ship. Its "Spring Style" design is shown in Table 53.

The MiniPlane uses a standard hull that has been modified to be man-portable. A custom 2.58 * 1.77m high-lift monoplane wing provides 590kg of lift on Earth. An Alcohol-fuelled Internal Combustion Engine provides power, all of which goes to the propellers (i.e. it has no electrical system).

Table 53: Japanese MiniPlane Spring Style

System Name	Mass (kg)	Volume (m^3)	Power (W)	Notes
Hull Frame	100.44	-3.0475		Cayley Steel 2.65*1.15*1. Drag: 0.092. See Table 2.
Lightweight Aircraft Fabric	1.5			13.695 m^2.
Modularity: Man Portable	15.06			See Table 3
Custom Wing	69			Drag: 0.316, Lift: 590 kg. See Section 5.1.4.
Skids	5.9	0		Drag: 0.03. See Table 11.
3cyl 3L ICE Engine	60.5	0.1815	-17500	See Table 12
Alcohol Fuel	47.823	0.0605		See Table 16
Overhead	4.783			
Propeller (post-1885)	12.25	0.0175	17500	See Table 17
Maxim Gun	27.2	0.77		See Table 27
Fixed External Mount		-0.1925		See Table 28
Rounds	10	0.0025		1000 Rounds
Medium Maneuver	15.05			See Table 30
Crew station	15	1.5		See Table 44
Crew & Supplies	95			See Table 45
Cargo	110	0.68		
Total	589.51	-0.028	0	

The total weight of the systems in this ship is less than the lift, so it can fly. The volume of the systems is also less than that of the hull, so everything fits. The only draw on the engines is the propulsion system, which consumes all of the engine power. There are three sources of drag, the body (0.092), the wings (0.316), and the skids (0.03), so the total drag is 0.438.

4.2 Carro Armato

The Carro Armato (See Section 12.4 of *Flying Machines*) is a small Aerolyth-based aircraft. It uses an Eight Cylinder 10.3L water-cooled, internal combustion engine to produce 90.5kW of power. 62.3kW are directed to the propellers, which produce a little under 48kW of effective propulsion. The rest of the engine's power goes to the two 20kW generators. These generators have 5kW of overhead each, but turn the rest of the power into usable electricity.

Table 54: Carro Armato Spring Style

System Name	Mass (kg)	Volume (m^3)	Power (W)	Notes
Hull Frame	534.1	-23.8144		Cayley steel; 4.88*2*2.44 Drag:0.39
Armor Top & Front	1581			16.79m^3. 1cm Steel + 2cm Elm
Armor Bottom & Sides	6288			36.30m^3. 2cm Steel + 2cm Elm
Aerolyth panels	1623.2	0.564	16000	4 panels.19964.0 kg Lift
Retractable Skids	299.5	0.5		
8cyl 10.3L WC ICE	183.5	0.55	-90500	
Fuel (Gas)	244	0.325		
Fuel Overhead	24.4			
Propeller (1870-1885)	49.84	0.0623	62300	Output: 47971W
20kW generator (1895)	146	0.106	10000	Note: Power draw is generator overhead
Gatling Gun	1080	2.8		4 Guns
Gatling Ammo	240	0.06		8000 rounds
Gatling Turret	540	2.8	1080	
6 inch Rocket Launcher	68	0.2	0	
Ammo	408	1.02		6 Rockets
Rocket Launcher Turret	34	0.2	68	
Medium maneuver System	146.15			
High Res. Flight Instruments.	250	0.4	50	
Power Distribution System	207.25	0.17		
Battery	130.9	0.02		
Small CD&H	14	0.05	20	
Heated Pressure Suits	200		800	8 Suits
Medium Altitude Air Compressor	11.6	0.008	152	
Crew Space	160	12		
Crew & Supplies	760	0.04		

System Name	Mass (kg)	Volume (m^3)	Power (W)	Notes
Cargo	4500	1.1		
Total	19724.1	-0.835	-30	

The ship's total mass is only a little less than the Aerolyth's maximum lifting capacity, but it will fly. There are about 800 liters of spare room and an extra 30 Watts of electrical power.
The ship's body and turrets create about 0.74 units of drag. When combined with the 48kW of effective motive power, the top speed is 47.6 m/s.

Table 55: Carro Armato NRE Costs

Total Mass	19725 kg
Dry mass	13981 kg
NRE	2735.5 hours
Design time (150 men)	19 weeks
NRE cost	£19000
Lot size	30 ships
NRE per Ship	£633.33

Table 56: Carro Armato Costs

Item	Cost
Labor per Ship	£661.5
ICE engine	£1140.3
Steel	£607.74
Generators	£109.2
Aerolyth	£81.16
Materials	£70
NRE/ship	£633.33
Total	3303.140255

5.Custom Systems

5.1 Hull and Lift Systems

5.1.1 Frames: Materials and Design School

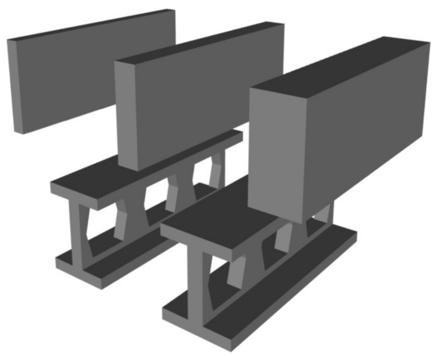


Figure 2: Different Beam Designs

The ship's frame is the internal structure that supports the ship's components and resists external forces. For simplicity of design, all frames are represented by the same generic structure. This is an oversimplification of a real design, but has the virtue of simplicity and repeatability. The frame's mass is dependent on two factors: The mass required to make the structure stable to external forces and the mass required for internal supports (e.g. floors, fittings).

When designing a frame, the primary differences between the design schools are in the materials they use and the beam and column shapes they work with (Figure 2). For example, the progressive Zeppelin School uses the most advanced materials (steel and Aluminum) and the complex (but weight efficient) open web I-beams. The more conservative Naval School uses wood, Iron, and (later) steel construction and less complicated solid beams. Though the more complicated beam offers a much higher strength to weight ration, it also requires much more labor to produce.

To design the frame, determine the maximum **carried mass (W,** in kg**)** for the ship, the **length (l,** in m**)**, the **height (h,** in m**)**, **width (w,** in m**)** of the frame, the **design school**, and the **main structural material**. Look up the appropriate coefficients for the design school and structural materials in Table 57 and Table 58

Table 57: Design School Hull Coefficients

Design School	x	y	z	c_1	c_{drag}	c_{ds}
Venusian	0.1	0.4	12	0.2	0.8	2
Arch	0.25	0.4	12	0.2	1.05	1
Naval	0.5	0.4	12	0.2	0.6	1
Zepp	0.7	0.22	14	0.05	0.12	3
Cayley	0.8	0.22	14	0.05	0.08	3.33

Table 58: Material Hull Coefficients

Material	p	E	c_2	c_{mat}
Wood (fir)	530	13	1	0.5
Concrete	2400	30	0.148	0.75
Al	2700	70	2.466666667	2.9
Steel	7900	200	2.822222222	1.7
Wootz Steel*	7800	227	3.0	2.0
Steel Reinforced Concrete	2680	50	0.415422222	1.25
iron	7870	200	1.495777778	1

*= Wootz Steel is extremely rare and available to only a few manufacturing companies.

To calculate the mass of a hull frame (M_{total}), use the following equations:

$$M_{internal} = 15 * Max(2, Floor(\frac{h}{2}) + 1) * l * w$$

$$M_{frame} = Max(\frac{c_1 * W * l}{c_2 * w * h^2}, y * p * x * l^2 * (\frac{W * z}{(0.768 * E * 10^9 * x)})^{0.5})$$

$$M_{total} = M_{internal} + M_{frame}$$

Hulls require additional labor to construct based on the design school and material. The equation to compute this labor, in man-hours, is:

$$Labor = c_{ds} * c_{mat} * M_{total}$$

The base drag of a hull is computed by:

$$Drag = c_{drag} * w * h$$

5.1.2 Pressure Hulls

Optionally, hulls can be made pressure sealed. This is useful for comfort at altitudes above 8,000 ft, and necessary for altitudes above 26,000 ft. To pressure seal a vehicle requires extra mass. The mass required is:

$$M_{pressure} = c_p * w * S/c_2$$

which uses c_p from Table 59 and c_2 from Table 58. S is the surface area of the ship, which can be computed from Table 5.

Table 59: Altitude Coefficient c_p

Altitude	c_p
0	0
12	0.65
45	1.34
600	1.46

5.1.3 Lift Systems: Aerolyth

The standard Aerolyth panel is the optimal thickness for efficiency. If panels are thinner, they produce less lift per mass at the same power, and if they are thicker they require exponentially more power. All panels have the same altitude levels (2, 12, 45, and 600 thousand feed on Earth) and reaching each additional level requires twice the power as the level below. Non-standard Aerolyth panel arrays are only available after 1885.

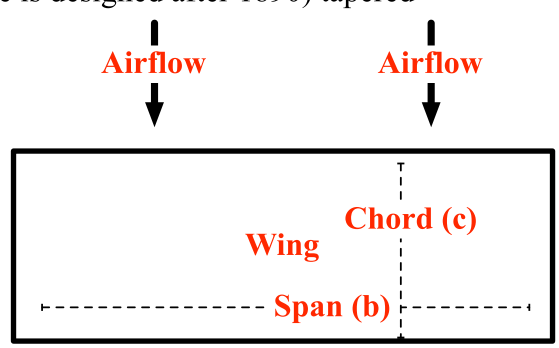
Thickness	Mass kg	Volume m^3	Power kW (level 1)	Lift/panel (N/g)
T < 1.0	405.8 T	0.141 T	1.0 T	48912 T^2
Standard (T=1.0)	405.8	0.141	1.0	48912
T > 1.0	405.8 T	0.141 T	1.0 T^2	48912 T
T = Thickness Ratio compared to Standard panel (47.5mm)				

Example: a 60mm thick panel (T=1.26) would mass 512.6kg, consume 0.128 m3, require 1.6kW to reach level 1 altitude, and produce 61784 N of lift.

5.1.4 Lift Systems: Cayley (Aerodynamic)

To design a custom aerodynamic lift system (i.e. wings), decide the following:

- •**Number of wings (N)**: monoplane (N=1), biplane (N=2), triplane (N=3), quadruplane (N=4), or quintplane (N=5)
- •**Wing shape:** rectangular, or (if the vehicle is designed after 1890) tapered
- •**Span (b)**: in meters.
- •**Chord (c)**: in meters
- •**Material**: Aluminum or wood/fabric.
- •**Maximum carried weight (TOW):** This is the maximum weight that the wing will have to lift.
- •**Wing Type**: Select from Table 60.



Next, compute the following:

- •**Lifting Surface area (S):** For rectangular wings, the surface area is S=b*c*N.

For elliptical wings, the surface area is S=0.75*b*c*N.
•**Aspect Ratio (A):** AR =
•**Wing Lift Coefficient (C_l):** Using the value for c_l from Table 60, column 3 and u from Table 61, column 2, the Wing lift coefficient is $C_l = c_l * (A/(A+2)) * u$.
•**Wing Drag Coefficient (C_d)**: Using the value for c_{d0} from Table 60, column 4, the Wing Drag Coefficient is $C_d = c_{d0} + (C_l^2 / (pi*A))$
•**Wing Mass (W)**: Using w_c from Table 61, column 3 and t from Table 60, column 5, the wing weight in kilograms is $W = 27.2S + ((0.0000164 * b^3 * TOW * w_c)/(t*S))$ for aluminum wings, and $15.3S + ((0.0000360* b^3 * TOW * w_c)/(t*S))$ for wood/fabric wings.
•**Total Surface Area**: The total surface area (useful if armoring the wings) is 2*S
•**Stall Speed:** The stall speed, in m/s, is $((TOW*2)/(p*S*C_l))$^0.5
•Drag: The wing drag is $C_d * S$

Table 60: Cayley Wing Types

Year	Type	c_l	c_{d0}	t
1895	Low Drag	0.6	0.007	0.06
1890	High Lift	1	0.01	0.06
1885	Low Drag	0.9163	0.008	0.09
1880	High Lift	1.2495	0.01	0.09
1875	Low Drag	0.25	0.0125	0.07
1870	High Lift	0.4	0.022	0.07
Note: Wing data is based off the Bleriot IX, Gottingen 398, and NACA 64-212 wing sections for an angle of attack of 4° (Low Drag) or 8° (High Lift). Data from [***32***] [***33***,***34***].				

Table 61: Lift and Weight Corrections for Wing Shape and Taper

Wing	Lift Correction (u)	Weight Correction (w_c)
Monoplane	1.00	1.00
Monoplane Tapered	1.04	0.87
Biplane	0.85	1.50
Biplane Tapered	0.89	1.31
Triplane	0.75	2.25
Triplane Tapered	0.78	1.96
Quadruplane	0.7	3.00
Quadruplane Tapered	0.73	2.61
Quintplane	0.64	3.75
Quintplane Tapered	0.67	3.27
Derived from [***35***] Further reading: Weights [***5***], Other [***36***]		

5.2 The Engine(s)

5.2.1 IC engines

To design a custom internal combustion engine, first determine:

- Year designed (Y)
- Number of Cylinders (C)
- Cooling method (W) : 1 if water cooled, 0 if air cooled
- Supercharger (S): 0 if uncharged, 1 if supercharger, 2 if supercharger and aftercooling
- Engine Displacement (D): in Liters

Then determine the following:

- Base Volumetric Efficiency (VE_base): 7.066*1.035^(Y-1883.5) (units: kW/L)
- Adjusted Volumetric Efficiency (VE_adj): VE_adj = VE_base * (1+ 0.05*W) * (1+0.25*S)
- Output (O): VE_adj * D (units: kW)
- Time Adjusted Output per Cylinder (O_tc) = (O/C)/1.047^(Y-1883.5)
- Mass per cylinder (M_cyl): (units: kg/cyl)
    - If O_tc <= 20, M_cyl = 7.1 + 1.9*O_tc
    - If O_tc > 20, M_cyl = 14.4 * 1.05^O_tc
- Engine mass (M): M_cyl * C
- Volume (in m^3): M*3/1000
- Crewing factor (Cf): (167.7+.011 O) / (1.5*((1+0.5*W)*(1+.33*S)+(C/2))^.5)
- Crew (Cr): Cr = O/Cf
- Fuel Efficiency (E_f): 77/(.057*(1-S*0.1)) (units: g/kWH)
- Fuel Consumption (F): E_f*O/1000 (unit: kg/hr)

The Key outputs are:

- Output: O (kW)
- Cruising output: 0.8 * O (kW)
- Mass: M (kg)
- Volume : M*3/1000 (m^3)
- Crew: Cr
- Fuel Consumption (standard): F (units: kg/hr)
- Cruise Fuel Consumption: 0.64 * F

Further Reading: [***37***] [***38***]

5.3 Command & Data Handling

C&DH systems are used to coordinate the crew on a ship. Each C&DH system is comprised of two parts – stations, and connection. A ship must have one C&DH station for every 20 crew members (round down) plus one additional station. Ships with less than 20 crew do not require a C&DH system. The length of C&DH connection is determined by the topology of that connection, as computed in Table 62, where d_1 is the longest dimension of the craft (in meters), d_2 is the shortest dimensions (in meters), and S is the number of stations.
Select from cables and stations from Table 63.

Table 62: C&DH Connection Lengths

Topology	Length Required	Notes
Broadcast	$d_1 + S * d_2$	-3 on Command Rolls

All-to-All	$(d_1 + d_2) / 2 * S^2$	+3 on Command Rolls
Switched	$(d_1 + d_2) / 2 * S$	

Table 63: C&DH Systems

Name	Mass (kg)	Volume (m^3)	Crew	Power (W)	Notes
Basic C&DH					
Speaking Tube Station	0.1	.01	0	0	Uses Tube Connections
Telephone Station	4	.01	.05	10	Uses wire.
Mechanical Semaphore Station	2	.02	.01	0	Uses wire. -1 on Command Rolls
Wiring Connections	.1/m	.001/m	0	0	
Tube Connections	1.5/m	.007/m	0	0	

5.4 Computing, Communication, & Sensors

5.4.1 Custom Rangefinders

Custom rangefinders can be developed. Choose the length, in meters, of the range finder. To compute mass, use this equation:

$$\text{Crf mass} = 256*(x/2.7)^2+45*(x/2.7)$$

And to compute volume:

$$\text{Crf vol} = x/10 + 0.4$$

Where **x** is the rangefinder length.

5.4.2 Computing

Table 35 lists only the characteristics of "standard" shock resistant computers. It is also possible to produce machines with specialized capabilities, though at a greater cost and increased production time. Generally, a machine built with options will require 4-16 extra weeks to be produced. If computers are used for mission-critical automation tasks (i.e. engines or maneuvering) it is common to have one or more backup computers installed in case the primary computer is down for maintenance. Military computer systems often use the **Through-Hardened Steel, Redundancy, Shock Resistance,** and **Field Replaceable System** options. Note that if **Shock Resistance** is not used, the MTBF is reduced by 80%.

Available computing options:

- **Embedded**: An engine designed with a single function in mind (e.g. a fire control computer for a single type of weapon, a ship's navigation computer) can have its program coded directly into its machinery. It is impossible to use this computer to execute a different program unless it is physically rebuilt. **Effects**: *Mass & Volume reduced 50%; Cost Reduced 33% + £1000 startup cost; Power Reduced 40%; IPM increased 50%;*

- **Through-Hardened Steel**: Machines are made from a variety of materials, depending on the era. In the 1850s and 60s, pewter was the metal of choice due to its precision. In the 1870s and 80s brass was used due to its greater durability. By the 1890s, case hardened steel was the material of choice. It is possible to harden steel completely (i.e. not just the surface), though it takes exponentially more energy to do so. **Effects**: *Increase cost by 15%; Increase MTFB by 10%* **Note**: Only Available after 1890.
- **Enclosed system**: Machines can be completely enclosed and hermetically sealed. **Effects**: *Increase MTBF by 25%; Increase repair time by 50%; Increase cost by 5%*
- **Field Replaceable System**: A system can be constructed with maintenance in mind by breaking it into modular, easily replaceable units. **Effects**: *Increase cost by 5%; Increase volume by 20%; Decrease repair time by 25%*
- **Filtered Lubrication:** Starting in 1890, magnetic filters can be added to the lubrication system to remove pieces of metal that have been abraded from the gears. **Effects**: *Increase MTBF by 10%; increase cost by 5%.* **Note**: Only Available after 1890.
- **Not Shock Resistant**: Babbage machines are generally designed to work in stable conditions. If one is to be deployed in a difficult environment (i.e. a vehicle) it generally needs to be built to resist shocks and vibration. **Effects**: *Table __ lists costs, weight, etc… for shock resistant computers. If a computer is built to be non-shock resistant computer and is placed in a difficult environment, its MTBF is decreased by 80%. Shock resistance keeps the MTBF at the regular level. Mass & Volume of a non-shock resistant machine is decreased by 20%; cost is decreased by 50%.*
- **Redundancy**: Many internal components can be replicated so that computation can continue even in the presence of failure. Several types of redundancy can be used, from adding additional gears to each Store column (Level 1) to replicating every component in triplicate and having them "vote" on each computation (Level 4) **Effects**: See Table 64

Table 64: Effects of Redundancy

Level	Mass & Vol.	Power	Cost	MTBF
1	+5%	+1%	+8%	+10%
2	+16%	+25%	+50%	+15%
3	+110%	+110%	+125%	+25%
4	+240%	+210%	+250%	+75%

- **Princeton Architecture**: A classical Babbage machine stores its program in read-only punched cards and the data it operates on in the mechanical Store. Another option is to store the program itself in the mechanical Store. This allows faster access to the program instructions and bypasses the oft-unreliable printer mechanism. Effects: Increases MTBF by 30%; increases IPM by 10%; decreases memory by 50%. **Note**: Only Available after 1880.
- **Mass Storage**: A massive array of punched cards, machine readable and fetched. A must have for any large organization or respectable nation-state. The standard array contains One Million Standard Records of 200 words each. Characteristics are shown in Table 65.

Table 65: Characteristics of a Million Record storage device

Year	1850	1860	1870	1880	1890	1900
kg	168971	129826	103192	79286	60511	43625
m^3	80	55	47	39	32	24
cost	£8,072	£7,178	£6,657	£6,211	£5,882	£5,616

5.4.3 Advanced Radio Design

After 1897, custom radios can be designed, based on the output power. Note, that radios do not work when in close proximity to active Aerolyth panels. Table 66 explains the design process.

Table 66: Custom Radio Design

Value	Determined…	Example
Output Power (P)	Input Parameter, in Watts	1200
Efficiency (n)	n = 0.01*log(P)	n = 0.01*log(1200) = 0.0308
Input Power (I)	I = P/n, in Watts	I = 1200/0.0307 = 38961 W
Mass (m)	m = I*0.204, in kg	m =38961 * 0.204 = 7948 kg
Volume (v)	v = m * 0.00233	v = .00233*7984 = 18.6 m3
Max Range (r)	r = (408000*P)^0.5*0.05, in km	r = (408000*1200)^0.5*0.05 = 1106 km
Crew (c)	c = ceiling(I/10000)	c = ceiling(38961/10000) = 4

Further Reading: [***39***] [***40***]

Bibliography

[1] Terry N Sofian, *Stars of Empire: A Scientific Romance Set During the Victorian Conquest of Space*. USA: CreateSpace, 2010.

[2] Arun Rodrigues and Terry Sofian, *Flying Machines of the Worlds 1902*.: Createspace, 2012, http://www.amazon.com/Flying-Machines-Worlds-1902-Universe/dp/1480035815.

[3] Donald E Carlucci and Sidney S Jacobson, *Ballistics: Theory and Design of Guns and Ammunition*. Boca Ratio, FT, USA: CRC Press, 2008.

[4] J. C. Hunsaker, "Wilbur Wright Memorial Lecture to the Royal Aeronautical Society (Applications of Normand's Equation)," *The Aeronautical Jouranal*, July 1920.

[5] Ilan Kroo. Component Weights. [Online]. http://adg.stanford.edu/aa241/structures/componentweight.html

[6] A N Brooks, P B MacCready, P.B.S. Lissaman, and W R Morgan, "Development of a Wing-Flapping Flying Replica of the Largest Pterosaur," *AIAA/SAE/ASME/ASEE 21st Joint Propulsion Conference*, vol. AIAA-85-1446, July 1985.

[7] German Marine Insuruers. (2010) Container Handbook. [Online]. http://www.containerhandbuch.de/chb_e/wild/index.html?/chb_e/wild/wild_08_01_02.html

[8] Allen Boyer McDaniel, *Excavating machinery*. Madison, WI, USA: McGraw-Hill Book Company, 1913.

[9] Loemi. (2010) [Online]. www.loemi.com/download/LOEMI__Vacuum_Distillation_Units.pdf

[10] Robert E Ball, *The Fundamentals of Aircraft Combat Survivability Analysis and Design*, 1st ed., j s Przemieniecki, Ed. Washington, DC, USA: AIAA, 1985.

[11] David Evans, *Building The Steam Navy*.: US Naval Institute Press, 2004.

[12] John A Shepard, *The Crimean doctors: a history of the British medical services in the Crimean War*. Liverpool, UK: Liverpool University Press, 1991.

[13] Nathan Okun. (1998, June) Imperial Japanese Navy Page. [Online]. http://www.combinedfleet.com/formula.htm

[14] Tony DiGiulian. (2006, Dec) NavWeaps. [Online]. http://www.navweaps.com/Weapons/WNRussian_37mm_Hotchkiss.htm

[15] Forsyth Meigs John and Rodney Ingersoll Royal, *Text-book or ordnance and gunnery: naval b.l.r. guns*. Baltimore, MD: Isacc Friedenwald, 1887.

[16] Naval History and Heritage Command. (2008, June) Howell Torpdeo. [Online]. http://www.history.navy.mil/museums/keyport/html/howell_torpedo.htm

[17] SICE Pesaro. Benvenuto in SICE. [Online]. http://www.sicesrl.com/images/stories/datasheet/Fog%20horn_DATA.pdf

[18] Ralph Kelly, "The Searchlight in the U. S. Navy," *Transactions of the American Institute of Electrical Engineers*, vol. 38, no. 2, pp. 1605 - 1634 , July 1919.

[19] Norman Friedman, *Naval Firepower: Battleship Guns and Gunnery in the Dreadnought Era*. Annapolis, Maryland, USA: Naval Institute Press, 2008.

[20] Beardslee Telegraph Machine. [Online]. http://www.beardsleetelegraph.org/insulatedwire.html

[21] Delft University of Technoogy. (2012, Jan) TU Delft: Cold Gas systems. [Online]. http://lr.tudelft.nl/index.php?id=26227&L=1

[22] Wikipedia. (2010, July) Time of useful consciousness. [Online]. http://en.wikipedia.org/wiki/Time_of_useful_consciousness

[23] Wiley J Larson and James R Wertz, *Space Mission Analysis and Design*, 3rd ed. USA: Microcosm, 1999.

[24] Ronald Humble, *Space Propulsion Analysis and Design*, 1st ed.: Learning Solutions, 1995.

[25] Roger R Bate, Jerry E White, and Donald D Mueller, *Fundamentals of Astrodynamics*, 1st ed. USA: Dover Publications, 1971.

[26] Obaid Younossi, Michael Kennedy, and John C Graser, "Military Airframe Costs: The Effects of Advanced Materials and Manufacturing Processes," Project Airforce, Rand Corporation, 2001.

[27] William H White, *A Manual of Naal Architecture*. London, UK: William Clows And Sons, 1877.

[28] David K Brown, *Warrior To Dreadnought: Warship Design and Development 1860-1905*. Barnsley, UK: Seaforth Publishing, 1997.

[29] David Evans, *Building the Steam Navy*. London, UK: Conway Maritime Press, 2004.

[30] George J. Binczewski, "The Point of a Monument: A History of the Aluminum Cap of the Washington Monument," *Journal of Metals*, vol. 47, no. 11, pp. 20-25, 1995, http://www.tms.org/pubs/journals/JOM/9511/Binczewski-9511.html.

[31] Steven s Zumdahl, *Chemical principles*, 6th ed.: Cengage Learning, 2007.

[32] Ira Abbot and Albert E Von Doenhoff, *Theory of Wing Sections*. New York: Dover Publications, 1959.

[33] Lawrence Loftin, "Report 903: Theoretical and Experiemental Data for a Number of NACA 6A-Series Airfoil sections," NACA (NASA),.

[34] Raymond F. Anderson, "No. 397: The aerodynamic Charactersitics of Six Commonly Used Airfoils Over A Large Range of Postive and Negative Angles of Attach," NACA (NASA), 1931.

[35] *Elementary Principles of Aeroplane Design*. New York: James Selwyn and Co, LTD, 1919.

[36] Lawrence K Loftin, *Quest for Performance: The Evolution of Modern Aircraft*.: United States Government Printing, 1985, vol. 1.

[37] Wikipedia. [Online]. http://en.wikipedia.org/wiki/Superchargers#Aircraft

[38] J. Gordon Leishman. A History of Helicopter Flight. [Online]. http://terpconnect.umd.edu/~leishman/Aero/history.html

[39] John S. Belrose. (1995, September) Fessenden and Marconi: Their Differing Technologies and Transatlantic Experiments During the First Decade of this Century. [Online]. http://www.ieee.ca/millennium/radio/radio_differences.html

[40] Fred J Dietrich and Richard S Davies, "Communications Architecture," in *Space Mission Analysis And Design*, Third Edition ed. El Segundo, CA, USA: Microcosm Press, 1999, pp. 533-586.

[41] Thaveephone Douangaphaivong, "LITTORAL COMBAT SHIP (LCS) MANPOWER REQUIREMENTS ANALYSIS ," Naval Post Graduate School, Thesis 2004.

[42] B. Kent Joosten, "Preliminary Assessment of Artificial Gravity Impacts to Deep-Space Vehicle Design ," NASA, JSC-63743 , 2007.

[43] Larry V. Brom, *The Sword and the Flame*. New Orleans, LA, USA: Sergeants 3 (www.seargents3.com), 2008.

[44] Thomas Reagan Beall, "THE DEVELOPMENT OF A NAVAL BATTLE MODEL AND ITS VALIDATION USING HISTORICAL DATA," Naval Postgraduate School, Monterey, Thesis 1990.

[45] John C. Schulte, "AN ANALYSIS OF THE IflSTORICAL EFFECTIVENESS OF ANTI-SHIP CRUISE MISSILES IN LrITORAL WARFARE," Naval Postgraduate School, Monterey, Thesis 1994.

[46] Trevor N Dupuy, John R Brinkerhoff, C Curtiss Johnson, and Peter J Clark, *HANDBOOK ON GROUND. FORCES ATTRITION IN MODERN WARFARE*. Fairfax, VA, USA: Historical Evaluation& Research Organization, 1986.

[47] Trevor N Dupuy, *Numbers, Predictions, & War*. Fairfax, VA, USA: HERO Books, 1985.

[48] Ilan Kroo. (2006) Aircraft Design, Synthesis, and Analysis. [Online]. http://adg.stanford.edu/aa241/AircraftDesign.html

[49] Trevor N Dupuy, *Attrition: Forcasting Battle Casulties and Equipment Losses in Modern War*. Falls Church, VA, USA: NOVA Publications, 1995.

[50] Wayne P Hughes, *Fleet Tactics and Coastal Combat*, 2nd ed. Annapolis, MD, USA: Naval Institute Press, 2010.

[51] Allan Jeffery Danelek, *The Great Airship of 1897: A Provocative Look at the Most Mysterious Aviation Event in History*.: Adventures Unlimited Press, 2011.

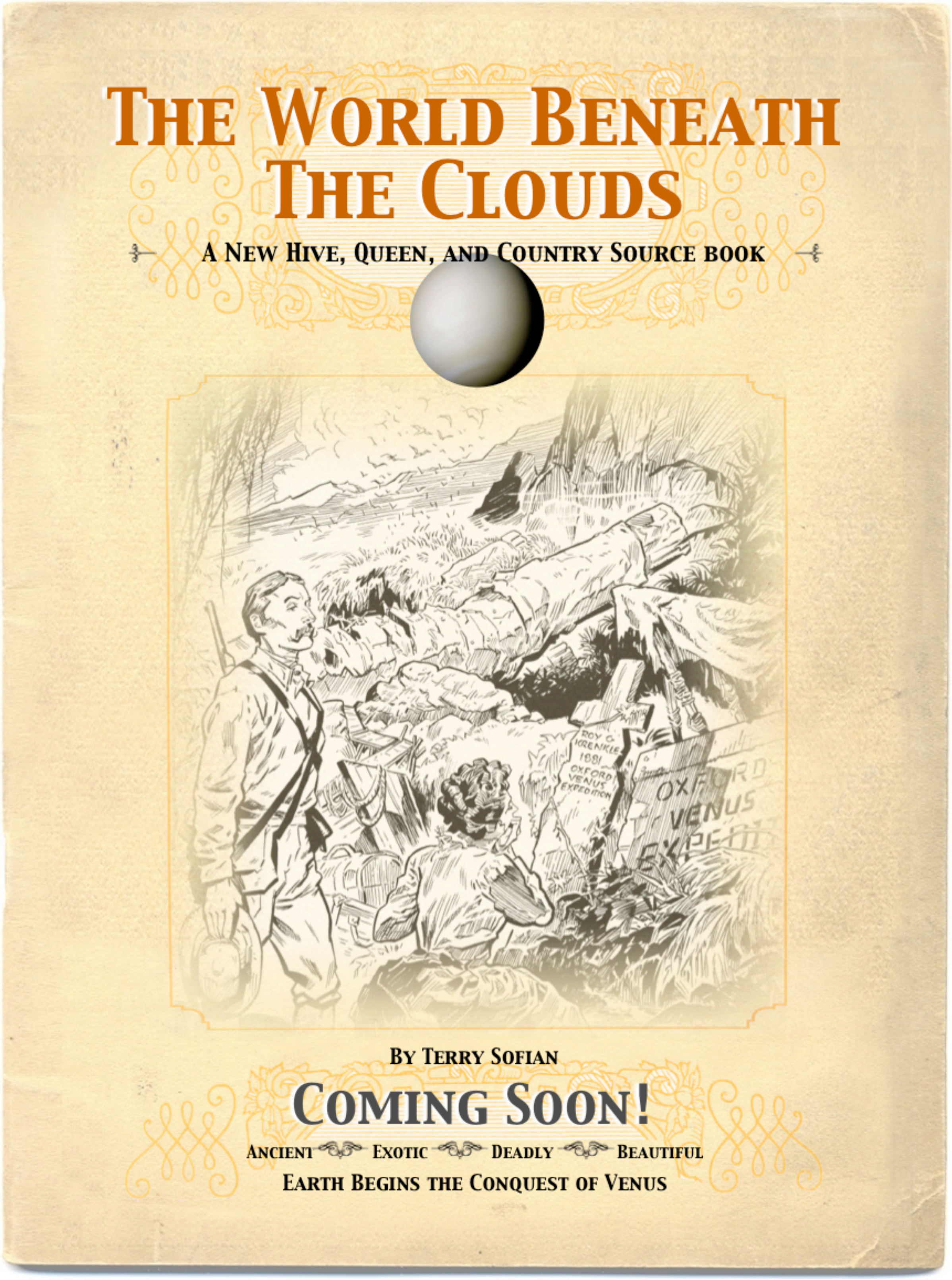
Stars of Empire
A New RPG by Terry Sofian

The Victorian Powers have discovered space flight and are striking out across the vast darkness of interplanetary space. As they explore frontiers on Earth, Luna, Mars, and Venus they encounter transplanted populations of humans, ancient and terrible alien races and ferocious exotic beasts. In 1892 The Hive broke free in Devon and put the very existence of mankind at stake.

Join the Fight,

For Hive, Queen, and Country!

www.hivequeenandcountry.com


THE WORLD BENEATH THE CLOUDS
A NEW HIVE, QUEEN, AND COUNTRY SOURCE BOOK
BY TERRY SOFIAN
COMING SOON!
ANCIENT EXOTIC DEADLY BEAUTIFUL
EARTH BEGINS THE CONQUEST OF VENUS