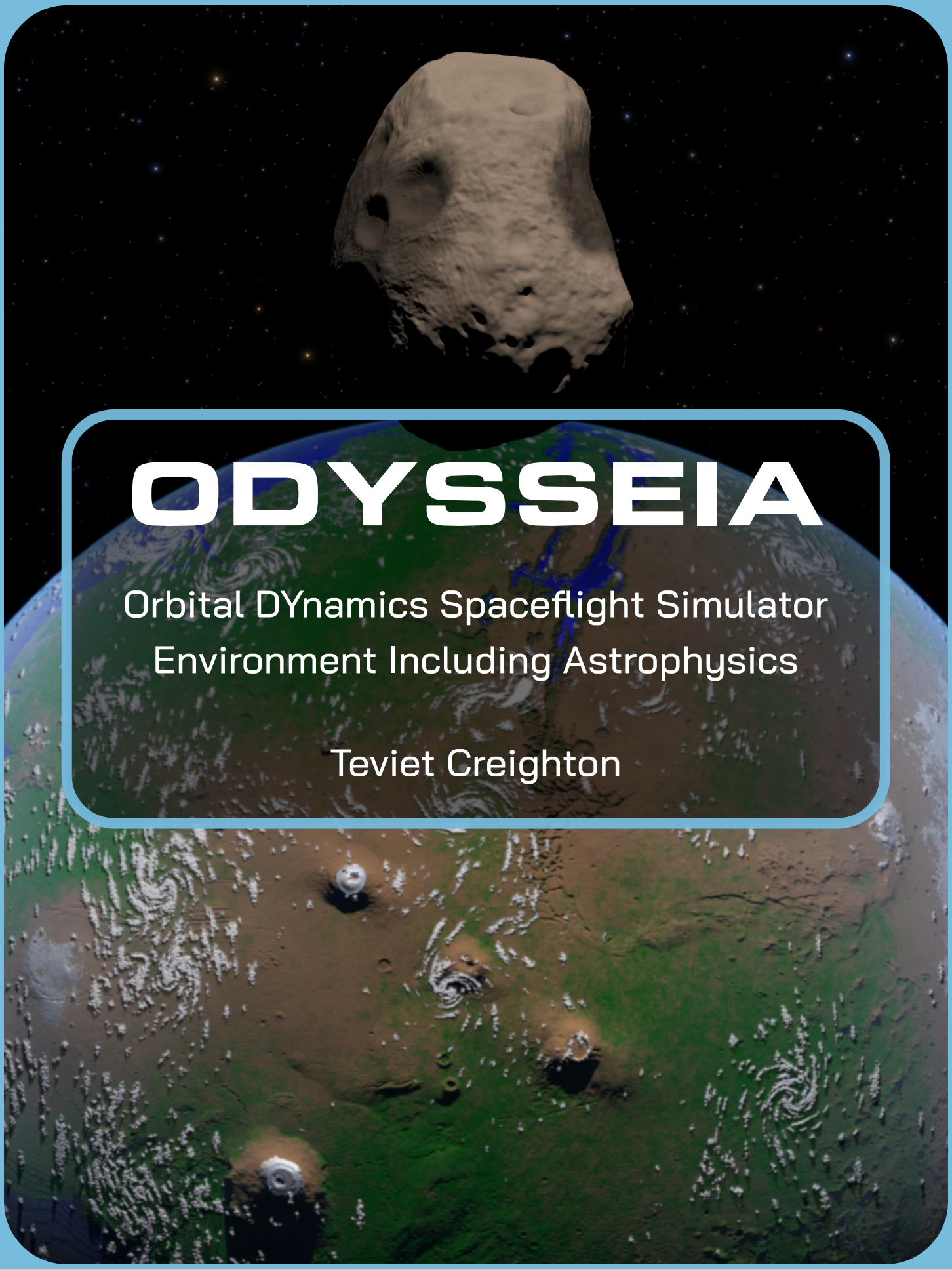


ODYSSEIA

Orbital DYnamics Spaceflight Simulator Environment Including Astrophysics

Teviet Creighton

Chapter 1
Introduction

ODYSSEIA is a proposed space exploration computer program for teaching and exploring concepts in space travel. While inspired by games such as Kerbal Space Program and Orbiter, it expands the scientific and educational content to include a relativistically accurate physics engine, realistic astrophysics, planetology, and plausible advanced spaceflight technologies.

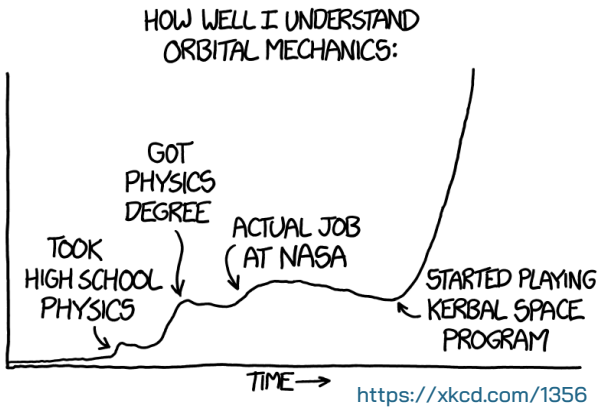
Concept and Goals

The aim of **ODYSSEIA** is to be a fun and realistic toy for space exploration in a broad sense, including not just spaceflight simulation, but also astrophysics, planetology, spaceship design, mission planning, and technological development. The concept of a *toy* (or *open world*), as opposed to a straightforward *game* or *simulator*, is to allow players to set their own objectives, increasing the program's entertainment and educational value.

The goals of playability and realism are often in conflict, and games set in space must typically make compromises between them. Kerbal Space Program uses realistic rocket technologies but unrealistic astrophysics to make spaceflight easier to achieve. Orbiter, by contrast, focuses solely on spaceflight simulation in the real-world Solar system with pre-designed spacecraft, limiting the options for play and exploration. Other space exploration games typically take artistic license with both technology and physics to produce an entertaining scenario. **ODYSSEIA** aims to achieve both playability and realism through a judicious choice of setting.

The base setting for **ODYSSEIA** is a far-future terraformed Mars, known as *Erith* to its inhabitants (the *Erithlings*). Erith has been engineered to have an Earthlike atmosphere and biosphere. Ancient disasters destroyed Terrestrial civilization, while the Erithlings underwent technological regression, and are now rediscovering spaceflight. This premise accomplishes **ODYSSEIA**'s goals in the following ways:

- Mars has 40% the surface gravity and escape velocity of Earth, making it much easier to achieve orbit with realistic starting technologies (1950s equivalent). Having low gravity and an Earthlike atmosphere also makes spaceplanes and similar flight technologies more achievable.
- Mars has two moons in close proximity: Phobos and Deimos. These are handy targets for early exploration before undertaking interplanetary missions.
- From Mars, the asteroids and giant planets are well within reach using contemporary-equivalent technology, making them appealing mid-game targets. Travel to Earth is more challenging, but opens up dramatic arcs in the mid to late game.
- The post-collapse scenario creates incentives for exploration, beyond simple curiosity or resource exploitation. Uncovering centuries-old ruins on the Martian moons or asteroids would be the basis for rapid scientific and technological development. A sample return or manned mission to Earth's surface would result in a trove of new discoveries.
- Beyond terraforming Mars, the Ancients also stellated Jupiter and terraformed its moons into habitable environments. Optionally, they could also have created stargates to other starsystems, opening up endless worlds to explore.



https://xkcd.com/1356

Chapter 2
Setting

It is the dawn of a new age for the civilization of Erith! After untold millennia of preindustrial languor, followed by recent generations of technological progress, the Erithlings now stand on the cusp of spaceflight. The lure of nearby worlds has spurred a rush of enthusiasm and industry. What adventures await?

Although it is not stated explicitly, it will be evident to players that the world of Erith is situated in our own Solar system, albeit thousands of years in the future, with the Erithlings being the descendants of Martian colonists. The fate of Earth's high-tech societies is unknown, but they have left their mark on the Solar system: terraforming new worlds to accommodate human life, creating a new star to warm them, and leaving scattered artifacts to tantalize and enlighten. This is the universe that the players will explore.

The Elian System

The major bodies of the Elian (Solar) system, and their general properties, are as follows:

Eli: Also known as the Sun, a G2 main sequence star. Tens of thousands of years have not significantly changed its properties. Unlike the present-day Sol, Eli is considered to be one star in a binary system, due to the stellarforming of Esti (Jupiter).

Taki: The in-game name for Mercury. It is difficult to reach, but has substantial metal deposits and an abundance of solar energy.

Therm: The planet we know as Venus. Therm is a "dry greenhouse" world with a crushing atmosphere of carbon dioxide and sulfuric acid, and surface temperatures that can melt lead. Beyond a desire for completeness, there is little reason to go here.

Bary: This is Earth as it is known to the civilization of **ODYSSEIA**. It is much heavier than Erith and correspondingly challenging for Erith-adapted people and technologies to operate in. Its climate is a "wet greenhouse", with a smoggy atmosphere rich in carbon dioxide and depleted in oxygen compared to contemporary Earth, and with smaller and more acidic oceans. Despite its hostile environment, there are extensive relics of past civilization that make a visit worthwhile.

Lept: Bary's natural satellite; i.e. Luna. With its lower gravity and benign, sterile environment, it is a science-rich target more accessible than Bary.

Erith: The homeworld of the **ODYSSEIA** civilization. Erith is Mars terraformed to have a breathable near-Earth-standard atmosphere, small but substantial oceans, extensive grasslands, and even forests with amazingly tall low-gravity trees. Its appearance from space is striking, with red deserts, green vegetation, blue oceans, and white clouds and ice caps: it may not be immediately recognizable as Mars.

Pete: The larger of Erith's two natural satellites (i.e. Phobos). Pete is in a relatively low orbit (below Erithostationary orbit), and has nearly negligible surface gravity, making it a useful milestone and waypoint in players' exploration program. In addition to subsurface ices and hydrated compounds, Pete has extensive surface ice deposits from volatile ejecta during the terraforming of Erith. These can be mined for fuel.

Koko: The smaller of Erith's natural satellites (i.e. Deimos), similar to Pete but half the size. It is just outside Erithostationary orbit, making it another handy stepping-stone.

Chalik belt: This refers to the asteroids in the belt between Erith (Mars) and Esti (Jupiter). Chalik-1 (Ceres) through Chalik-25 (Aurora) correspond to actual asteroids with radii greater than 100km; additional asteroids will be procedurally generated in the game.

Esti: Formerly the planet Jupiter, Esti has been stellarformed into a brown dwarf star through a variation on the Thorne-Żytkow process. Its luminosity is about $2\times10^{-5}\ L_{\odot}$ and its surface temperature is 1200K, meaning that the Sun (Eli) remains the dominant source of *visible* light within the Esti system, even as Esti provides enough infrared heating to melt the ice on its inner moons.

Piro: The innermost of Esti's four major satellites. Formerly known as Io, this world has become even more hellish with the stellating of Esti: combining Io's tidally-driven vulcanism with Venus-like levels of heating. Piro's atmosphere is a thick toxic brew of hydrogen sulfide and hydrocarbons, blanketing a surface dominated by seas of boiling sulfur.

Cleo: The stellation of Esti has transformed icy Europa into the pleasantly tropical ocean world of Cleo. Ancient terraforming projects have also introduced specially-engineered algae into Cleo's oceans, giving it a breathable oxygen atmosphere. However, unlike the real Earth or terraformed Erith, Cleo's ocean is world-spanning and over a hundred kilometres deep. Its only solid surface structures are floating mats of biogenic matter: these shifting "archipelagos" support diverse island ecosystems.

Ermo: The largest of Esti's satellites. Within the Esti system, Ermo/Ganymede and Cleo/Europa have a similar orbital ratio as Erith/Mars and Bary/Earth. Ermo has been slightly terraformed to give it a cold but livable temperature: mostly frozen but with a large lake of liquid water at its Esti-facing pole. However, it has only microbial life and a thin unbreathable atmosphere.

Krio: The most distant of Esti's major satellites, Krio remains largely unchanged from its days as Jupiter's moon Callisto. It has an icy surface pocked with craters, and no significant atmosphere.

Kirk: This is Saturn, and still has its distinctive rings thousands of years into the future. Perhaps more than any other world, Kirk's distinctive appearance marks the Elian system as our own Solar system. Kirk has numerous moons, including 7 major moons, one of which bears special mention.

Thol: The largest of Kirk's moons, Thol has a thick atmosphere of nitrogen organic particles, and lakes of cryogenic hydrocarbons. In this setting, Thol also has an extensive biosphere of complex but slow-moving organisms, based on a hydrogen metabolism.

Hal: The gas giant formerly known as Uranus. Its most significant feature is its high axial tilt, giving interesting transfer orbits to and from its satellite system. It has faint rings and five major moons, all of which are fairly ordinary iceballs with no atmosphere.

Kian: The outermost gas giant, known today as Neptune. Kian's rings are fainter than Hal's but still significant. It has one major iceball moon.

Chione belt: This refers to Eli's Kuiper belt and other bodies beyond Kian's orbit, including several planetary-mass objects. Chione-1 through Chione-25 are known trans-Neptunian objects with radii larger than 300km, while other bodies, including comets on eccentric orbits, will be procedurally generated.

What's in a name?

World names in **ODYSSEIA** are shortened from ancient Greek roots, because why not? The resulting names sound familiar, even amusing, to a Western audience, without suggesting that Erithian civilization derives from any specific contemporary world power or space agency.

- **Eli** from ἥλιος (*hēlios*, "sun")
- **Taki** from ταχύς (*takhys*, "swift")
- **Therm** from θέρμη (*thermē*, "heat")
- **Bary** from βαρύς (*barys*, "heavy")
- **Lept** from λεπτός (*leptos*, "light")
- **Erith** from ερυθρός (*erythros*, "red")
- **Pete** from πέτρα (*petrā*, "rock")
- **Koko** from κόκκος (*kokkos*, "granule")
- **Chalik** from χάλιξ (*khalix*, "gravel")
- **Esti** from ἑστία (*hestiā*, "hearth")
- **Piro** from πύρ (*pȳr*, "fire")
- **Cleo** from χλιαρός (*khliaros*, "lukewarm")
- **Ermo** from ἐρῆμος (*erêmos*, "desert")
- **Krio** from κρύος (*kryos*, "cold")
- **Kirk** from κίρκος (*kirkos*, "ring")
- **Thol** from θολός (*tholos*, "sepia")
- **Hal** from ἁλς (*hals*, "sea")
- **Kian** from κυάνεος (*kyaneos*, "blue")
- **Chione** from χιών (*khiōn*, "snow")

For all major bodies noted above, the orbital parameters, physical properties, and large-scale topography of the body will be taken from observed data (where available), except in cases where changes to the system would render these obsolete: e.g. the inner satellites of Esti. Detailed topography and other details, such as climate and biomes, will be generated with the same procedural engine as used for interstellar worlds (below), to ensure consistency between the Elian system and other starsystems.

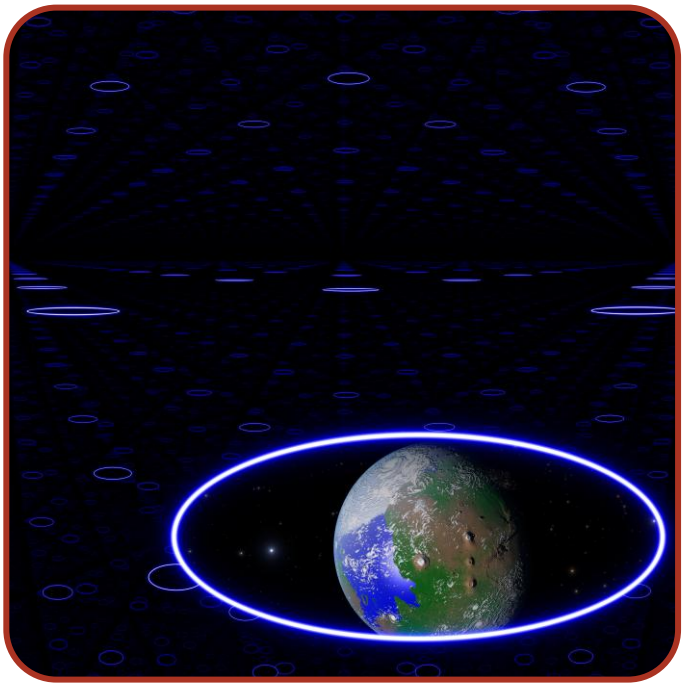
Other Starsystems

Since one of the primary goals of **ODYSSEIA** is to incorporate realistic astrophysics and geophysics into the game, it stands to reason that it should expand the setting beyond a single starsystem. There are two ways to incorporate interstellar travel into the game:

- In a "hard" science setting, at sufficiently advanced technology, *slower-than-light* missions could be sent to other starsystems. These might take anywhere decades to millennia, but could be possible with generation ships, hibernation, or fully-robotic crews.
- In a "firm" science setting, ancient civilizations may have left behind a *stargate network* (below), allowing access to an unlimited number of other starsystems on the same timescales as interplanetary travel.

Other planetary systems will be generated procedurally by a semi-empirical starsystem generator. This program abstractly represents our current understanding of planetary formation and evolution, building systems that match the observed distributions of exoplanets without requiring detailed *ab initio* numerical simulation. Individual planetary properties are similarly generated with heuristic methods that produce plausible *outcomes* of planetary geophysics, without explicitly modeling the complete process.

ODYSSEIA will faithfully reproduce the positions and spectral types of a few thousand nearest and/or brightest stars, but will make no attempt to reproduce known exoplanet systems: the state of exoplanet research is too fluid for such data to be reliable. Instead, the random system generator will be used for all other starsystems.



Stargate Network

A *traversable wormhole* is one of the few known ways to achieve faster-than-light travel without violating established laws of physics. It does, however, require the manipulation of exotic negative-energy "contramatter", the existence of which has not been demonstrated, but could be achieved by a sufficiently advanced technology. In the default **ODYSSEIA** setting, *stargates* are among the relics left behind by advanced Terrestrial civilizations before their mysterious disappearance.

The standard interstellar stargate is a ring of ultradense matter about 5 metres across with a mass of about 400 tons. Through the ring is a portal to some other region of space. There is no obvious "surface" or tunnel: looking through either side the ring, one sees whatever is on the corresponding side of the connected portal.

Passing through the ring, one emerges at a "transfer station" outside the plane of the Galaxy. The station consists of about 400 million gateways in a triangular grid, each leading to a different starsystem. The array forms a rough but not perfect hexagon, suggesting that it may be incomplete. The gates are held in position by a rigid contramatter framework that resists any attempt at bending or breaking: ramming the lattice at any significant velocity will destroy the vessel with no effect on the stargates.

Technology

Space exploration is hard, but it serves to organize and measure the best of a civilization's energies and skills. Much of the thrill of space exploration comes from seeing and experiencing the achievements of technological progress.

The default setting of **ODYSSEIA** begins at the dawn of the Erithian space age, with technology roughly equivalent to Earth of the 1940s and 1950s. However, rapid technological progress is a key part of the game, allowing modern and futuristic gadgetry to make an appearance. This can be justified within the fictional setting in two ways. First is the extraordinary interest Erithlings have in space travel, stimulated by the abundance of valuable worlds within reach. Second is the opportunity for *space archaeology*, where the discovery of ancient records and artifacts can lead to scientific breakthroughs.

Throughout this advancement, care is taken to maintain the *physical plausibility* of the technologies introduced. Every machine or instrument is constrained by the laws of physics: even in the "firm science" setting, the hyper-advanced stargates bend but do not break these laws.

The following sections present the framework for tracking technological advancements in **ODYSSEIA**, and an incomplete sampling of the *categories* of items available at each technology level. More details may be found in Chapter 4.

Technology Levels

Technological advancement is a complex interplay of scientific knowledge and industrial capability across a multitude of different fields, and is not readily expressed as a single numerical index. For game purposes, however, *technology levels* are a useful heuristic for tracking what technical abilities the Erithlings will have at any point in the game.

1. **Early space age:** Equivalent to mid-20th Century Earth. E.g. basic rockets and jet engines.
2. **Atomic Rockets:** Equivalent to late-20th Century Earth if early progress in space exploration had been maintained. E.g. nuclear-thermal rockets and air-ram engines.
3. **Modern age:** Equivalent to early-21st Century Earth. E.g. scramjets, ion drives, solar sails.
4. **Near future:** Current experimental prototypes, or foreseeable developments in the coming decades. E.g. ramjet-rockets, advanced nuclear propulsion, magnetic sails.
5. **Optimistic near future:** Sound concepts facing possible technical hurdles. E.g. fusion pulse propulsion, fusion reactors.
6. **Intermediate future:** Plausible concepts but with no clear development path, making their timing a matter of speculation. E.g. Bussard ramjets, bulk antimatter production.
7. **Far future:** Speculative ideas that do not violate physics but may or may not be possible. E.g. neutrino drives, stargates.

Rather than the "tech trees" popular among many games, technology in **ODYSSEIA** advances along *tracks* representing major fields of science and technology, listed below. Players can prioritize development along specific tracks, but there is a limit to how far any track can advance beyond the others. This emphasizes the interdependence of technology better than tech trees.

Basic Science represents fundamental physics and knowledge of the laws of nature. It cannot exceed Instrumentation by more than one level.

Chemistry represents more specific knowledge of matter and reactions. It cannot exceed Basic Science, and cannot exceed Instrumentation by more than one level.

Materials represents detailed understanding of substances and fabrication processes. It cannot exceed Chemistry, and cannot exceed Instrumentation by more than one level.

Biosystems represents biology and biochemistry. It cannot exceed Chemistry, and cannot exceed Instrumentation by more than one level.

Instrumentation represents electronics, photonics, and other applied physics. It cannot exceed Basic Science, and cannot exceed Materials by more than one level.

Power Systems represents knowledge of devices for energy storage and generation. It cannot exceed Materials or Instrumentation.

Propulsion represents knowledge of motive systems and engines. It cannot exceed Materials or Chemistry.

Any given spacecraft system will require a certain level of technology in one or more tracks. For this purpose, technology levels can be treated as continuous values, allowing differentiation between basic and advanced systems within a given level.

During play, steady technological advancement will occur due to research on Erith, requiring time and (in some story modes) monetary investment. Certain in-game activities can also push technology forward, adding "points" to one or more technology tracks, or making specific systems available in advance of the usual progression. Such activities can include: testing new or experimental components in flight (advancing their principal tech track); performing observations or collecting data in new environments (advancing Basic Science, Chemistry, or Biosystems); or uncovering records or artifacts from ancient facilities (advancing multiple tracks, or "unlocking" specific systems).

Resources

Resource management is a critical part of space mission planning, whether it's fuel to launch in the first place, or food and water for extended missions. The promise of wealth from extraterrestrial resource extraction is also one of the major motivations for space exploration.

To maintain playability and realism, **ODYSSEIA** strikes a balance between vagueness and specificity when defining different types of resource. These are presented below.

Raw Materials

These are the natural environmental conditions that serve as the *source* of other resources.

Interstellar Medium: Tenuous hydrogen gas between planets and stars. It requires magnetic scoops hundreds of kilometres across to collect significant quantities.

Atmosphere: Various volatile substances in gas form. This can include mixtures or compounds of hydrogen, carbon, nitrogen, oxygen, sulfur, or noble gases, depending on the world.

Seas: Volatile substances in liquid form. Typically compounds of hydrogen, carbon, nitrogen, oxygen, or sulfur, depending on the world. These are easy to collect, and, depending on the substance, may require only minimal processing/purification.

Ices: Volatile substances similar to Seas (above) but in solid form: somewhat more challenging to mine and collect, but abundant on outer worlds.

Rock: Solid metal oxides, silicates, and sulfides. Abundant on inner worlds, but require extensive mining and refining.

Lithophilic Ore: Rocky material enriched in rare earth elements. For simplicity, all such elements are grouped together. Ordinary rock (above) counts as low-grade lithophilic ore.

Siderophilic Ore: Material composed of or enriched in nickel, iron, and precious metals. Denser than ordinary rock or lithophilic ore, it is usually confined to planetary cores, but some asteroids are composed entirely of siderophilic ore.

Refined Resources

These are useful substances extracted, purified, or chemically processed from raw materials.

Hydrogen: Generally stored as a cryogenic liquid and used as chemical fuel or reaction mass. Obtained from various volatile substances (atmospheres, seas, ices) or interstellar medium.

Oxygen: Stored as cryogenic liquid and used as chemical fuel, reaction mass, or in life support. Obtained from various volatile substances, or, more energy-intensively, from rock.

Nitrogen: Stored as cryogenic liquid and used as reaction mass, coolant, or life support. Obtained from atmospheres, seas, and ices.

Noble Gases: Argon, xenon, and the like, usually stored as compressed gas and used as ionizable reaction mass. Obtained from atmospheres.

Cryogenic Hydrocarbons: Methane, ethane, etc. stored as cryogenic liquid and used as chemical fuel, reaction mass, or in food production. Obtained from carbon-rich volatiles.

Ammonia: Stored as cryogenic liquid and used as reaction mass or in food production. Obtained from nitrogen-rich volatiles.

Water: The most abundant and convenient storable form of hydrogen and oxygen, used as reaction mass or in life support. Obtained from most volatiles (atmospheres, seas, ices).

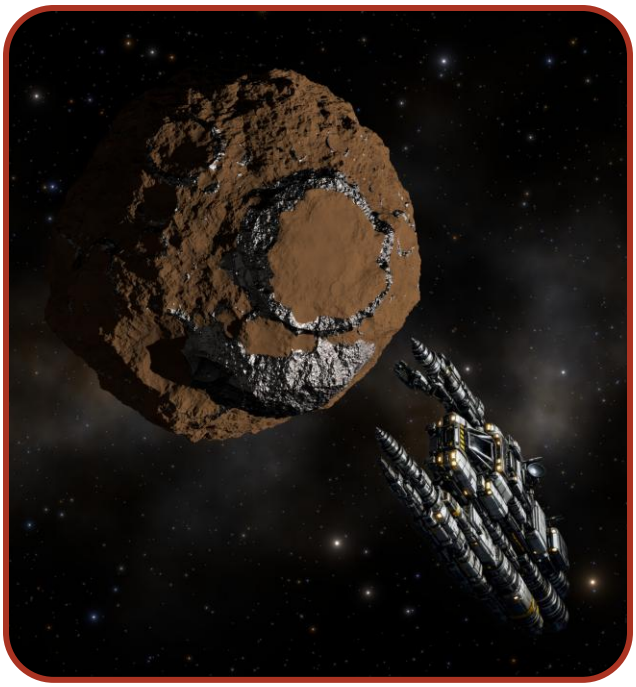
Storable Hydrocarbons: Liquids such as kerosene, gasoline, and alcohol, used as chemical fuel or in food production. Kerosene is a typical contemporary rocket fuel on Earth, whereas Erith, lacking petroleum deposits, relies more on alcohol. Obtained from carbon-rich volatiles.

Storable Oxidizer: Liquid oxidizing agents such as nitrous oxide, nitric acid, hydrazine, or hydrogen peroxide. Used primarily as an oxidizer for chemical fuels, or as monopropellant fuel. Typically obtained from nitrogen-rich volatiles.

Light Metals: Aluminum, titanium, and similar metals obtained from rock or lithophilic ores. Iron is included due to its natural abundance in ordinary rock. Used primarily for construction.

Rare Earths: Lanthanides, actinides, and similar metals obtained from lithophilic ores or (in very low concentrations) ordinary rock. This category includes fission precursors such as natural uranium and thorium. Used in industrial processes and to make fission fuel.

Heavy Metals: Gold, platinum, iridium, and other "noble" metals obtained from siderophilic ores. Nickel and cobalt are also included in this group. Used in electronics and industrial processes, or as repositories of wealth.



Manufactured Consumables

These are consumable resources requiring more specialized fabrication and handling than plain chemical synthesis and bulk storage.

Food: Edible products used for long-duration life support. Requires chemical precursors such as hydrocarbons, nitrogen, and water, as well as farms, hydroponic gardens, or, at higher tech levels, bioprocessors ("food vats").

Solid Fuel: Chemical propellant combining fuel and oxidizer in solid form. Solid fuel rockets are built with a fixed amount of fuel that is consumed completely when the rocket fires. Requires light metal and nitrogen compounds to synthesize the fuel, and shipyard facilities to build or refurbish the rocket casing.

Fission Fuel: Fissile uranium or plutonium, used to fuel fission nuclear reactors or nuclear thermal rockets. Rare earth elements (thorium and uranium) must be processed in isotope enrichers or breeder reactors to get fission fuel rods.

Fusion Fuel: Isotopes of hydrogen, helium, and lithium, used as fuel for early fusion nuclear reactors and rockets. Hydrogen or light metal (lithium), or surface material from *airless* bodies, must be processed in isotope enrichers or breeder reactors to get fusion fuel pellets.

Nuclear Bomblets: Fission and fusion fuel assembled into (small) nuclear explosive devices, used for nuclear pulse propulsion drives.

Antimatter: Produced from raw energy in antimatter distilleries, and used as fuel for antimatter reactors and rockets. Highly sophisticated containment systems are required to safely store and transport antimatter.

Immaterial Resources

Two commodities require special note, as they are not physical objects or materials.

Electricity: Energy produced by chemical, nuclear, solar, or other generators, stored in batteries or capacitors, and used to power other systems.

Money: Abstracted resource allocation. On economically developed worlds, resources can be traded in exchange for money, rather than processed from raw materials.

Chapter 3
Gameplay

As stated in the introduction, **ODYSSEIA** is designed as a toy rather than a plotted-out game. Story elements in the setting should be thought of as *landmarks*, rather than *milestones* towards a defined objective. Players are free to pursue their own goals within the **ODYSSEIA** setting, using the provided tools and simulation engine.

This synopsis will not go into detail about the simulator or user interface, but will discuss how the game can be played in very broad strokes.

Typical game activities include the following:

- Spaceship design and mission planning.
- Piloting and spaceflight operations.
- Exploration and discovery.
- Space construction and colonization.

Depending on the chosen *story mode* (below), some of these will take on a greater or lesser role. Details about ship design are presented separately in Chapter 4.

Story Modes

ODYSSEIA can be played in different ways, depending on how players wish to challenge themselves, and which aspects of gameplay or the setting they find most entertaining. The program allows for three distinct modes of play: *creative*, *exploration*, and *colonization*.

Creative Mode

A creative game gives players a great deal of control over the setting, allowing them to build spacecraft and perform missions according to their own goals and self-imposed restrictions. The level of technology is set by the player, and can be adjusted at will. "Teleportation" and "telekinesis" tools allow vessels and other structures to be placed directly in desired locations or orbits.

There is no limitation on funds when building spacecraft on Erith. Access to resources "in the field" follows normal resource extraction rules; however, the "teleportation" tool can be used to alleviate these restrictions. Also, off-world facilities of a sufficient size (delivered or teleported in place) can be designated as *developed* (see *Colonization Mode*, below), removing resource restrictions for construction or fueling there.

Exploration Mode

In an exploration game, players start with only early space age technology. Technology level increases as time passes or as the player achieves certain in-game objectives (testing experimental systems, performing research missions, or discovering ancient records or artifacts). In addition to any objectives that the player chooses to pursue, this mode imposes a general story arc of exploring new worlds, making scientific discoveries, and achieving technological breakthroughs.

Exploration mode removes the "teleportation" and "telekinesis" tools. Worlds with sufficient facilities can still freely be designated as "developed" (see below), but these facilities must be delivered or built using the normal in-game mechanics.

Colonization Mode

This is the most sophisticated and challenging story mode. In a colonization game, the player must pursue economic objectives alongside scientific or other goals. Construction and research on the homeworld, as well as maintaining staff and morale, costs money; while discoveries, commissioned activities, and resources extracted "in the field" provide sources of income.

As its name suggests, colonization mode adds a story element of developing autonomous off-world facilities. Players can accept contracts for missions to set up outposts with refineries, factories, and other industrial capacity, and to perform supply and trade missions. After these initial "milk run" missions have demonstrated the outpost's economic viability, it qualifies as *developed*, switching from a "subsistence" to a

"consumer" economy. The game will take over and abstractify the acquisition and distribution of resources within a sustainable economic unit, and players will interact with this economy using money. This allows colonies to serve as points of departure for launching later missions.

Mode Switching

The story modes presented above are intended as a framework, not a straitjacket. There are occasions when a player might want to switch to a different story mode: since **ODYSSEIA** is built around open play, such mode switching is allowed. For instance, players in a colonization game might use creative mode tools to skip over a particularly onerous "milk run" mission, or jump ahead to a completed colony, before resuming colonization play mode.

Timeline Branching

Players may save their game at any point, and revert to previous save points without discarding later saves, allowing them to explore different story lines (timelines). **ODYSSEIA** will employ version control tools to manage memory-efficient differential save files, and to organize and visualize branches

When switching from creative to exploration or colonization mode, the player may specify the technology level in each track (by default it will be the maximum level of any equipment currently deployed). When switching into colonization mode, the player may specify the amount of funds now available.

Game Time

By default, gameplay during missions is in real time: one real-world second per game-world second. For simplicity, **ODYSSEIA** uses the SI second as the base unit of time, along with minutes (60 seconds) and hours (60 minutes). Longer units differ from their real-world counterparts.

Martian terraforming, in particular the addition of water through cometary impacts, have shortened its day and lengthened its year. Erith's day is 88,663 seconds – less than the current Martian "sol" but still slightly longer than an Earth day. Since hours and minutes are unchanged, this means that clocks will advance to 24:37:42 before rolling over to 00:00:00 at the start of each Erith day. An Erith year is 59,360,143 seconds, or 669.503 Erith days.

Time Warp

Realistic interplanetary travel takes a long time, especially at the technology levels of a starting **ODYSSEIA** game. A probe on a typical (Hohmann) transfer orbit from Erith to Bary (Earth) takes about 17 months. Other activities, such as technology R&D and rocket construction, also occur on timescales of days, months, or years.

To make the game playable, then, **ODYSSEIA** includes a time warp function to accelerate game time, anywhere from 2× to as fast as the game engine can handle with any precision. During time warp, the physics simulation will be simplified: vessels are treated as rigid bodies with fixed mass and inertial moment, allowing simple point-mass approximation of their motion and rotation. Time warp is disabled if any important vessels are undergoing complex interactions (such as rocket thrust or aerodynamic movement), or are in imminent danger of a collision. Objects marked as "disposable" may simply be removed if they experience such interactions during warp.

Players may turn warp on and off by hand, or may specify a time or event at which to drop out of warp. Spaceships with sufficiently skilled Pilots (see p. 12) and/or equipment with sufficiently high Instrumentation technology level (p. 6) may perform *orbital prediction* for their vessel, and warp to a specified point along their predicted trajectory. Note, however, that orbital prediction uses cruder approximations than the full physics engine even under warp, so players may also specify a warp *prediction tolerance*, which will terminate the time warp if the vessel's position diverges from the predicted path.

Interstellar Travel

As described on p. 6, the presence of a stargate network allows travel to other starsystems on the same timescales as interplanetary travel. However, if the stargate option is not enabled, or the player has not found any stargates, interstel-

lar travel becomes more challenging. It is possible to launch sublight missions to nearby stars, but the timescales involved will typically be decades or centuries even with advanced propulsion technology. The best option in this case is to create a story branch that follows *only* the interstellar expedition. Once it has left the vicinity of Elian planets, it can apply extreme time warp until it arrives at its target.

Focus Elements

A game's *focus* is the element in the game world with which the player is currently interacting. In **ODYSSEIA** this may be a *vessel*, a *facility*, or an individual *Erithling*.

Vessels

The main focus element of the game will be vessels, a catch-all term including spaceships, satellites, space stations, ground bases, rovers, marine or submarine ships, etc. A vessel generally consists of a number of *components* enclosed in or attached to one or more *hulls*. Chapter 4 provides more details about these parts.

When focused on a vessel, players can select among its components and their various functions (performing measurements with a sensor, activating an engine, etc.). By default, the player will normally interact with a central control component (cockpit, computer, etc.) that provides integrated flight control.

Vessels interact with their environment or other vessels using the full physics and graphic engines. The interior of a vessel doesn't require full modeling, unless focus shifts to an interior element, i.e. an Erithling occupant (see below).

Facilities

A facility is a large structure (vessel or close grouping of vessels) with a degree of self-sufficiency and advanced capabilities. To qualify as a *developed facility*, the vessel(s) must meet certain criteria:

- Sufficient manufacturing and construction components (see Chapter 4) to allow for maintenance, repair, and expansion.
- A certain number of crew of various occupations (p. 12).
- Sufficient stockpiles of resources.
- Ability to replenish these resources, demonstrated through "milk run" missions.

Designating vessels as a developed facility allows the game to abstractify and simplify certain large-scale operations. Components can be repaired, upgraded, or built using a simplified construction interface, rather than manipulating them into place using the physics engine. Resources can be bought and sold for money, rather than performing supply missions. In most other ways, facilities are still treated as vessels.

At the start of play, **ODYSSEIA** will provide an initial set of "stock" developed facilities on Erith, for shipbuilding, research, training, and communication. Since colonization is a major theme of **ODYSSEIA**, there will be no fundamental difference between the initial stock facilities on Erith and those established later on other worlds.

Erithlings

Players may also interact with individual Erithlings inside or outside of vessels. Erithlings inside vessels can be assigned to crew stations, allowing the player to control its associated functions. They may also switch crew stations or move between habitable components through connecting accessways.

Erithlings outside of vessels may move around and manipulate their environment, including grabbing, lifting, and moving other elements. They may use certain equipment (instruments, tools, tethers) that they bring with them, depending on their occupational specialty (p. 12). In particular, Technicians may perform repairs and construction (attaching elements that have been placed close together).

When focused on an Erithling, a player can choose between a third-person or first-person perspective. A challenging exercise in realism would be to perform entire missions in Erithling-focused first-person perspective, seeing only what that individual sees, and controlling only those shipboard functions that the Erithling has access to. For any but the simplest missions, this should probably be attempted only in a multiplayer game (p. 12).

Relativistic Concerns

As part of its commitment to astrophysical realism, **ODYSSEIA** uses a relativistically-accurate physics engine. When focused on an element, what one sees, and the passage of time, are accurate for the reference frame of that element. This includes relativistic time dilation, gravitational redshift, and light propagation time.

The last is the most significant: while lightspeed lags may only be fractions of a second on and around Erith, they can be minutes or hours between distant bodies in the Elian system. Communicating with or remotely controlling a distant vessel incurs the *round-trip* light propagation delay. Interplanetary missions may have crews for local control, or advanced computer control systems. Simpler computers allow for actions or scripts to be triggered at specified events, to perform planned maneuvers, observations, etc.

Switching focus is also limited by lightspeed lag: if a player switches to a distant vessel and back, time will jump ahead by the round-trip delay. **ODYSSEIA** will provide a warning when this lag is more than a few seconds. If distant vessels require near-simultaneous control, the player must either program one of the vessel's actions in advance, or enlist another player to help (below).

Multiplayer Games

ODYSSEIA allows for multiple players to engage with the same scenario. Cooperative play is assumed (if the players desire a competitive game, they must decide on and enforce any rules themselves). One player initiates and controls the scenario, and can invite or dismiss other players. The initial player may also assign roles to the other players, restricting their focus to specific vessels, or even specific Erithlings.

One particularly engaging (and realistic!) mode of play is for each player to be assigned to a specific crew position or Mission Control station, and attempt to complete a mission cooperatively. Parallel play is also possible, where players control separate vessels on largely independent missions within a common scenario. Note that in-game communication among players will enforce the correct lightspeed delays, so players on missions to different planets will have limited interaction. (Of course players can choose to "cheat" using out-of-game communication.)

Time warp in a multiplayer game requires specific considerations. Any player may request a time warp to a particular event or time in their own focused reference frame, and that request will be broadcast to other players instantaneously (in real time). Other players may request their own time warps. The physics engine will apply the lowest time warp factor among all active requests. Any event that interrupts the time warp will apply simultaneously to all players.

In principle, requesting or canceling warp allows a form of non-physical faster-than-light communication among players. So it goes.

Characters

ODYSSEIA is not intended to be a role-playing game, where players identify strongly with the in-game characters. Space travel is risky; the inevitable disasters and mission failures should be a source of frustration, not emotional trauma.

Nonetheless, some individualization among Erithlings is useful to the game. In particular, *occupational specializations* are important considerations in mission planning, from simple crewed missions to large-scale colonization efforts.

Occupations

Like "classes" in RPGs, Erithlings are assigned a broad occupation defining their skills and role in the mission. Unlike typical RPG classes, an individual may cross-train in multiple occupations, at the cost of increased training time. The occupations are:

Pilot: Covers shiphandling, navigation, and command duties. Basic Pilot expertise is needed to allow vessels to stabilize their orientation without drifting. Higher levels allow for precise stationkeeping, orbital prediction, automatic execution of maneuvers, etc.

Technician: Covers operation, maintenance, and repair of the ship's mechanical and electronic systems. This includes "engineers" in the vehicle operation sense. Improved Technician skill reduces the incidence of wear or failure, increases the complexity of systems that can be

repaired, and improves the efficiency of certain ship systems (such as life support, refineries, factories, etc.).

Scientist: Covers operating information-gathering instruments, performing scientific research, and technology development. This includes "engineers" in the science & technology sense. Science skill improves the scientific return of data collection tasks, and is required to operate R&D facilities.

Medic: Maintains the health of crew and passengers. This position is required for long missions. Like Technicians, Medics both prevent and heal injury or illness among the crew.

Service: A catchall category for various jobs that support the *social* needs of personnel. This includes administration, education, entertainment, hospitality, etc. Without service personnel, other crew lose efficiency (effective skill) over long missions, and paying passengers become unhappy. In a generation ship or colony, service occupations also cover caregiving and teaching of younger generations.

Passenger: Covers personnel with no assigned duties or skill requirements. Passengers may be a source of income; they may also represent colony populations that have not (yet) trained into other occupations.

Erithlings trained in multiple occupations may be assigned to crew positions requiring either occupation, or they may split their effort, at a reduction in efficiency. For instance, in maintaining the health of a vessel *and* its crew, a cross-trained Technician-Medic would not be as effective as a dedicated specialist in each role, but would be better than leaving either position unfilled.



Training

Learning is a continuous process, but in **ODYSSEIA**, as in real life, certain milestones and career junctures are recognized. The following generic career progression is used for all occupations:

Novice: This level covers a period of specialized training before the trainee is ready to assume actual duties in their occupation. It corresponds roughly to undergraduate, pre-med, or classroom technical education.

Apprentice: This level of experience consists of on-the-job training: it is the first level in which the Erithling can be assigned duties in their specialization. It corresponds roughly to graduate school, medical school (with clinical rotations), or a trade apprenticeship.

Journeyman: This level consists of further field experience, often on multiple missions or under a number of different advisors. It corresponds roughly to a postdoc, medical resident, or trade journeyman.

Master: This level represents a fully-trained specialist, equivalent to a professor, licensed medical doctor, or trade master.

Expert: This represents a specialist at the peak of their field, equivalent to a research chair, medical director, or head contractor.

Each level represents about 2 Erith years of training. Novice-level training can be classroom instruction; the others require the trainee to be assigned duties on a mission. Notable events on these missions (e.g. difficult landings, scientific discoveries, significant repairs) count as bonuses towards the next experience level.

This assumes that the trainee is working under a teacher or mentor with a higher level in that specialty; otherwise training times double. Mentors can train up to 25 Novices or 5 higher-level trainees at a time.

It is assumed that Erith has pools of potential recruits in each specialty trained to Apprentice level: further advancement requires recruits to be deployed on missions. Cross-training into a new specialty, or inducting untrained passengers or colonists into an occupation, requires going through Novice preparation. Erithlings should typically be at least 8 Erith years old before starting specialist training.

Chapter 4
Ship Design

This chapter covers the design principles for vessels in **ODYSSEIA**, which can include everything from spaceships and rovers, to stations, bases, and large developed facilities.

It is outside the scope of this synopsis to specify the user interface, give precise formulae for component costs, weights, and sizes, or even to present every component that will be available in the game. Rather, it gives basic guidance about the proposed design system, and summaries of a few major *types* of components to include.

General Principles

Broadly speaking, vessels consist of various *components* enclosed in or attached to one or more connected *hulls*. The component listings below give the technology level along a specific tract at which it first becomes available, a description of what the component does, and the adjustable features that the player can modify.

Components will generally improve with technology after their introduction, becoming stronger, lighter, or more capable. The description will take this for granted, though it may note specific improvements that have a particular impact on play. Players may also choose to install versions of a component below their current technology level, for some savings in cost.

Construction

Vessels are built in factories (p. 23). *Designing* a vessel takes place outside of normal game time. *Constructing* the vessel, however, takes game time: typically days, weeks, or months, depending on the capabilities of the factory and the size and complexity of the vessel (represented by its *price*). It will also consume resources, or cost money in an economically-developed facility.

A particular component or set of components (up to and including entire vessels) may be designated as a *mass-produced item*, paying an upfront cost but reducing the unit cost of identical copies of that item. This will also reduce the production time in line with the reduced cost. Important items may also be *stockpiled*, paying their cost in advance but reducing assembly time (paying only the cost and time for integration).

Hulls

These are components that enclose other components. The main purpose of hulls is to support their components and add structural rigidity, as well as to improve aerodynamics: the physics engine does not need to model the interaction between, or air drag on, components within a hull. Players can adjust a hull's structural strength, which affects mass and cost. Hulls are made up of the following components.

Fuselage **Materials 1**

This is a cylinder, box, or similar straight-sided hull segment. Adjustable parameters include the length and cross-section: players may specify a minimal surface enclosing a selected set of components. The fuselage will automatically have cutouts for protruding components.

Cone **Materials 1**

This is a tapered hull segment usually at the front or back of a fuselage. Adjustable parameters are the length and shape of the taper (straight or curved), and whether the apex is shifted off-axis. Truncated cones may connect fuselages of different cross-section.

Wing **Propulsion 1**

A wide and flat hull segment, typically used to provide lift or stability in aerodynamic flight. Adjustable parameters are the wingspan, length, angle of leading and trailing edges, and thickness/cross section. Short wings can also be used as *pylons* connecting other hull segments.

Door **Materials 1**

A portion of a hull segment that can open to provide access to internal components. Adjustable parameters include size, placement, single or double, and opening mechanism: sliding, hinged, iris, or (for cones) clamshell. Large doors are sometimes called "bays" and small ones "ports". Often placed next to corridors to allow crew access, or retractable components that would otherwise need to be mounted outside the hull.

Window **Materials 1**

A transparent portion of the hull, placed next to a habitable component to provide its occupants with an external view. Adjustable parameters are size, shape, position, and either flat or protruding (like a dome or bubble canopy).



Propulsion Systems

These are components that allow a vessel to move: in space, in the air, on the ground, or in and under water. Some must be connected to a power system, others provide their own power (and often some excess power to run other systems).

Solid Fuel Rocket **Propulsion 1**

The simplest form of rocket, consisting of a nozzle and a casing filled with solid fuel. Once activated, it burns fuel at a specified rate until it is all consumed: refueling counts as a major repair job. Adjustable parameters are any two of thrust, burn duration, and amount of fuel (which determines size); players then specify width or length.

Liquid Fuel Rocket **Propulsion 1**

The standard early space age rocket, controllable and steerable. Adjustable parameters are the choice of fuel and oxidizer (or monopropellant), nozzle type (atmospheric, vacuum, aerospike), gimbal range, and thrust.

Jet Engine **Propulsion 1**

Similar to a liquid fuel rocket, but uses an air intake to provide oxidizer. Adjustable parameters are fuel type, compression system (turbojet, turbofan, or ramjet; scramjet or hybrid at higher tech levels), and thrust. Must be connected to an air intake, either directly (often in an external pod) or via an air duct.

Air Intake **Propulsion 1**

An inlet to feed air to a jet engine, directly or via an air duct. One intake may feed multiple engines or vice-versa. Its adjustable parameter is its size.

Air Duct **Propulsion 1**

A component connecting an air intake to an engine in a different location. Stats depend on the size of the intake and total length of the duct.

Air Propellor **Propulsion 1**

Rotating blades that move air to provide thrust. Each component represents a single rotor system; usually they are mounted in pairs to cancel torque. Adjustable parameters are number and diameter of blades, whether blades are ducted, motor power, and type of motor: electric (requires electricity) or combustion (must be connected to a combustion engine, directly or through a drivetrain). Vertically-mounted propellors can provide lift (e.g. a helicopter or quadcopter).

Water Propellor **Propulsion 1**

Rotating screws that provide thrust in or under water. Each component represents a single screw; usually they are mounted in pairs. Adjustable parameters are screw diameter, whether screws are ducted, power, and motor type: electric (requires electricity) or combustion (must be connected to a combustion engine, directly or via a drivetrain).

Wheel **Propulsion 1**

The most common method of ground propulsion. Each wheel is a separate component; they are usually mounted in pairs (except for tricycles). Adjustable parameters include wheel size, suspension clearance, tire ruggedness, retractability, and whether the wheel is left, right, or centre mounted. *Powered* wheels must specify their maximum power, and whether they have their own electric motors (requiring electricity) or are connected to a drivetrain. Multiple (nonretractable) wheels in parallel may be joined by a *track*, rather than having their own tires.

Drivetrain **Propulsion 1**

A component connecting combustion engines to propulsion systems in need of motive power (air propellor, water propellor, or wheels). Cost and weight will depend on the power delivered and the total length of the connectors.

Lifting Gas **Propulsion 1**

A large bag filled with lighter-than-air gas. Adjustable parameters are type of lifting gas (hydrogen or hot air), volume (which determines lift), and whether it is rigid or flexible. Rigid bags can be given a player-defined streamlined shape; flexible bags can optionally be retractable. Includes the necessary heaters or pumps for inflation, but tanks for compressed hydrogen are separate. Note that helium is not readily available on Erith (on Earth it is obtained from sedimentary domes, which are uncommon on Erith), so hydrogen lifting gas is the default.

Nuclear Thermal Rocket **Propulsion 2**

A high-performance fission reactor that heats and expels reaction mass. Adjustable parameters are type of reaction mass (or multifuel at higher tech levels), nozzle type (atmospheric, vacuum, or variable at higher tech), and thrust.

Nuclear Jet **Propulsion 2**

Like a nuclear thermal rocket but using an air intake for reaction mass. Adjustable parameters are compressor type (as for jet engines) and thrust. Requires a connected air intake or duct.

Orion Drive **Propulsion 2**

Early nuclear pulse propulsion, consisting of a heavy shock-absorbing pusher plate, and a launcher that throws small shaped thermonuclear bomblets behind it. In this simplified model, the only adjustable parameter is the thrust.

Ion Drive **Propulsion 3**

An electric rocket that accelerates ionizable reaction mass to extreme speeds using electrostatic fields: this is fuel efficient but very low thrust. The adjustable parameters are thrust and exhaust speed (their product determines the drive's power requirements).

Solar Sail **Propulsion 3**

A large, lightweight deployable mirror that generates thrust via photon pressure from the Sun. Adjustable parameters are the size and shape.

Magnetic Sail **Propulsion 4**

A large deployable loop of superconducting wire: when energized with electric current, it creates a magnetic bubble that produces thrust by deflecting stellar winds. Adjustable parameters are the nominal thrust at Erith (which determines the loop's "typical" diameter), and the loop's maximum diameter (which determines its thrust in low-wind environments).

Medusa Drive **Propulsion 4**

A combination Orion drive and magnetic sail, where the nuclear bomblets have a much longer standoff distance, and apply force to the sail rather than a pusher plate. Build this as a magnetic sail (which can operate independently of the medusa drive), then add the medusa drive component, which includes the bomblet launcher, radiation shielding, and shock-absorbing sail tethers. The adjustable parameter is the medusa drive thrust (constrained by the magnetic sail size).

Airbreathing Rocket **Propulsion 4**

A combination jet engine and liquid fuel rocket, or nuclear jet and nuclear thermal rocket. Build this as a regular jet engine or nuclear jet, then select a "closed-cycle" option to allow it to switch to internal oxygen or reaction mass. No additional adjustable parameters.

Plasma Rocket **Propulsion 4**

An electrothermal rocket that uses electromagnetic fields to heat ionizable reaction mass to a plasma before expelling it. This produces higher thrust than an ion drive (though not as much as a nuclear thermal rocket), and can dynamically adjust its exhaust velocity, trading fuel efficiency for higher thrust. Adjustable parameters are maximum thrust and exhaust velocity range.

Robot Leg **Propulsion 4**

An articulated motorized leg for all-terrain ground movement. Each component is a single leg; normally mounted in pairs. Adjustable parameters are length, power, and left or right.

Fusion Pulse Propulsion **Propulsion 5**

A rocket that ejects small pellets of nuclear fusion fuel, and then detonates them with focused lasers or particle beams. The adjustable parameter is the rocket thrust.

Fusion Drive **Propulsion 5**

A "leaky" magnetic-confinement fusion reactor that expels reaction products at extreme velocity (up to a few percent of lightspeed). It has less thrust but higher fuel efficiency than pulse rockets. Adjustable parameters are exhaust velocity and thrust; the product determines reactor power. Higher-tech systems can adaptively increase thrust while reducing exhaust velocity.

Bussard Ramjet **Propulsion 6**

A fusion drive with a magnetic scoop capable of collecting fusion fuel from the interstellar medium. Adjustable parameters are the nominal drive thrust and the (huge!) collecting area. The ramjet requires a minimum speed to operate, so vessels should carry enough fusion fuel to accelerate to this speed. When not operating its fusion drive, the scoop can act as a magnetic sail.

Antimatter Drive **Propulsion 6**

A rocket that combines antimatter with matter to produce highly-energetic plasma, directed backwards by magnetic fields. Adjustable parameters are thrust, and matter-antimatter ratio, which determines exhaust speed: in the 1:1 limit, the exhaust is pions traveling at near-lightspeed.

Neutrino Rocket **Propulsion 7**

A rocket that converts ordinary matter (of any type) entirely into neutrinos aimed in a particular direction. This does not violate fundamental conservation laws, but current theoretical physics provides no known mechanism for transforming ordinary (baryonic) matter into neutrinos. A neutrino rocket is an "effectively reactionless" drive, since its exhaust is almost completely intangible. The adjustable parameter is its maximum thrust.

Contragravity Drive **Propulsion 7**

This system generates negative-energy contramatter to cancel the inertia of the rest of the vessel. At this point, internal forces between contramatter and the vessel produce acceleration, with no energy consumed, and no matter or energy expelled (a *true* reactionless drive). Adjustable parameters are the maximum vessel mass and the maximum acceleration: these must be considered separately, since if the vessel exceeds the drive's rated mass, then it will not work *at all*.

Power Systems

These systems provide power to other components, usually in the form of electricity, though some can be connected directly to a motive system or drivetrain.

Battery **Power Systems 1**

Stores and releases electrical energy. Adjustable parameters are capacity, and type: electrochemical cells (whose maximum power output is limited by capacity) or capacitors (lower storage density but can discharge instantaneously).

Photovoltaic Cell **Power Systems 1**

Generates electrical energy from sunlight. Adjustable parameters are the size and shape of the panel, whether it is fixed or mobile, and whether it is deployable and/or retractable.

Fuel Cell **Power Systems 1**

Generates electrical energy from the reaction between hydrogen and oxygen. Adjustable parameters are the cycle type (open or closed, one-way or reversible). Open-cycle cells require an air intake; closed-cycle an oxygen supply.

Combustion Engine **Power Systems 1**

Generates power by burning chemical fuel. Adjustable parameters are fuel type, cycle type (open, closed, or hybrid), mechanism (external combustion, internal combustion, gas turbine), power output, and whether it is an electric generator or will be connected to a drivetrain or motive component. Open-cycle engines require an air intake; closed-cycle requires a specified oxidizer; hybrid requires both.

Wind Generator **Power Systems 1**

Like an air propellor (p. 15) running in reverse, producing electricity from air movement. Adjustable parameters are as for air propellors.

Solar Heat Engine **Power Systems 2**

A large mirror that concentrates sunlight on a closed-cycle heat engine. Adjustable parameters are the size and shape of the mirror, maximum power generated, whether it has an electric generator or will be connected to a drivetrain, and whether the mirror is fixed, movable, deployable, and/or retractable.

Radiothermal Generator **Power Systems 2**

A thermoelectric generator heated by the decay of a radioactive isotope (e.g. plutonium, whose power output halves every 14 years). Adjustable parameters are the (initial) power output; at higher tech levels, players can select isotopes with different power densities and half-lives.

Fission Reactor **Power Systems 2**

A compact high-performance reactor that generates electricity from controlled nuclear fission. The adjustable parameter is the power output.

Fusion Reactor **Power Systems 4**

A reactor powered by controlled nuclear fusion. Typically less compact than a fission reactor, but much easier to fuel. The adjustable parameter is the power output.

Antimatter Reactor **Power Systems 6**

A reactor powered by the annihilation of antimatter with any type of matter. Power densities can be quite large, but antimatter is expensive to synthesize and difficult to store. The adjustable parameter is the power output.

Conversion Reactor **Power Systems 7**

A reactor powered by the total conversion of ordinary matter into energy. This does not violate any fundamental conservation laws, but current physics provides no feasible mechanism for accomplishing this. The adjustable parameter is the power output.

Contramatter Reactor **Power Systems 7**

A reactor powered by free energy released in the synthesis of contramatter. No fuel is required; the reaction *produces* contramatter. Its adjustable parameter is the power output.

Fuel and Storage Systems

These are systems for storing and handling fuel and other resources.

Fuel Tank **Materials 1**

A storage tank for fuel or other resources. Adjustable parameters are size, shape (usually spherical, oblong, or cylindrical), and resource stored. Early systems must specify the resource; later systems are more flexible, specifying only the *type* of resource (liquid, cryogenic liquid, compressed gas, solid hopper). Players may also select contiguous empty regions inside a hull (e.g. a wing) and build a fuel tank to fit.

Fuel Line **Materials 1**

A component connecting a fuel tank to a power or propulsion system, if they are not in contact to begin with. Cost and weight depend on fuel type, consumption rate, and total length of line.

Cargo Bay **Materials 1**

An area set up to store and secure miscellaneous items. Adjustable parameters are size and shape; players may also designate contiguous empty regions inside a hull as cargo bays. There should be a door or access point to the outside; items can only be stored if they fit through the door.

Pantry **Biosystems 1**

An area for safely storing and preserving food. Adjustable parameters are size and shape; it should be connected to a habitable component.

Bomblet Dispenser **Propulsion 2**

A racking system for feeding nuclear bomblets into an Orion or Medusa drive system. Adjustable parameters are the bomblet capacity and shape. This should be connected directly to the drive component, or chained with another bomblet dispenser.

Antimatter Trap **Materials 6**

A containment system for antimatter. It should be connected directly to an antimatter drive or reactor. Adjustable parameters are its capacity and shape.

Control and Navigation Systems

These are systems used for attitude control, fine maneuvering, and stationkeeping, as well as electronics and sensors for navigation.

Control Surfaces **Propulsion 1**

Actuated rudders, flaps, and winglets used for maneuvering in air and water. Adjustable parameters are the size and shape of the surface, and whether its attachment to the hull is hinged (like a flap or rudder) or rotating (like a canard).

Reaction Control Thrusters **Propulsion 1**

These are small liquid fuel rockets (p. 15) conveniently arranged in blocks with nozzles in different directions, used for attitude control and fine maneuvers. Design them as liquid fuel rockets (usually monopropellant), then select from standard block configurations (2 to 5 nozzles).

Navigation Sensors **Instrumentation 1**

A suite of passive sensors for location and attitude sensing. Specific sensors and capabilities depend on Instrumentation tech level: from an octant and gyro horizon (early space age) to inertial navigation systems, star-trackers, satellite navigation systems, etc. at higher levels. Its adjustable parameter is a choice of selecting "basic", "advanced", or "state-of-the-art".

Active Sensors **Instrumentation 1**

A radar, lidar, and/or sonar system (depending on technology level), providing accurate altitude measurements, range, bearing, and speed of nearby objects, and collision warning. Adjustable parameters are the type (radar, lidar, sonar) and power of the system, which affects range and precision.

Reaction Wheels **Instrumentation 2**

Multi-axis flywheels used for attitude control. External torques to the vessel will build up angular momentum in the wheels, eventually requiring an off-axis thruster to "desaturate" the wheels. Adjustable parameters are the number of axes, maximum torque, and maximum stored angular momentum.

Autopilot **Instrumentation 2**

An onboard computer that performs some or all of the functions of a pilot. Its adjustable parameter is its effective pilot skill level, which determines what actions can be automated. It also comes with a simple scripting language for preplanned instructions. Capabilities are *highly* dependent on Instrumentation tech level; at Instrumentation 4+ it can add other AI crew functions.

Crew Systems

These are components that are occupied by crew or passengers: to perform their duties, or to travel and live in comfort. They should have one or more doors connecting to the outside, and are typically connected internally as well. When placed within a hull, the shapes of these systems will adjust (to some extent) to conform with the hull surface.

A vessel must be assigned a *life support level:* none, climate controlled, pressurized (for environments with thin but breathable air), or full (providing its own supply of air). This will affect the size and expense of *all* crew systems in the vessel. Life support level can also be adjusted on a hull-by-hull basis.

Life Support System — **Biosystems 1**

This represents the equipment needed to maintain life support for a vessel. One component is needed for each hull, or set of hulls with connected habitable areas with the same life support level. Adjustable parameters are the capacity (number of people supported) and the level of support (*climate-controlled*, *pressurized*, or *full*); for full life support, also specify whether used air is *vented* or *recycled*.

Control Room — **Instrumentation 1**

A cockpit, bridge, or similar room with one or more crew stations, each assigned to a particular crew occupation (p. 12). It is primarily intended for Pilots: on larger vessels, other occupations will usually have their own specialized rooms (below). Adjustable parameters are the number of crew stations and their assignments.

Lab — **Basic Science 1**

A room with equipment for performing scientific research or technology development. Its adjustable parameter is the number of researchers it can accommodate, which determines its size and other capabilities. Optionally a lab can be *specialized* for a particular technology track (10× as effective for research in that specialty, 1/10 as effective for other specialties): its capabilities will depend on the rated technology level of the lab *in that track*. A major research facility will have labs for dozens of researchers in each specialty.

Workshop — **Instrumentation 1, Materials 1, Propulsion 1, Power Systems 1**

A room with equipment for maintaining and repairing the ship's systems. A workshop is rated for its technology level in every track, though most ship's systems will depend on Instrumentation, Materials, Propulsion, and Power Systems, and a few will depend on Biosystems. Its adjustable parameter is the number of Technicians who can work there, which, in combination with its tech level, determines its capabilities. Note that the fraction of Technicians in a ship's complement will typically be anywhere from 1 in 50 (for passenger vessels) to 1 in 5 (for working vessels in dangerous environments): but for long missions, only a third will be on duty at any time.

Sickbay — **Biosystems 1**

A medical facility staffed by one or more Medics. Its adjustable parameter is the number of beds, i.e. the number of admitted patients it can accommodate at a time; it also includes one Medic workstation per bed. For a large vessel (or colony), 1 hospital bed per 400 people is typical; in hazardous environments it could rise to 1 per 100.

Galley — **Biosystems 1**

An area where Service personnel can prepare food for other crew and passengers. Adjustable parameters are the number of Service crew (cooks) that can work there, and a quality level (*minimal*, *standard*, or *luxury*). One cook per 50 other personnel is typical for large vessels, only a third of whom will be on shift at a time.

Seating Area — **Biosystems 1**

A room filled with seats. This can represent passenger seating for short-duration missions (typically no more than a day), but, with the addition of a *stage*, could be used as a theatre, classroom, or other entertainment or educational facility. Adjustable parameters are the seating capacity, density (*crowded*, *normal*, or *spacious*), and the presence or absence of a stage.

Cabin — **Biosystems 1**

Long-term accommodation for passengers or crew. Adjustable parameters are density and quality: density can be *crowded* (4 beds per room), *normal* (one bed per room), or *spacious* (a suite with a bedroom and a living room); quality can be *minimal*, *standard*, or *luxury*.

Corridor — **Materials 1**

A component that connects non-adjacent habitable areas. Stats depend on the width of the corridor (single, double, or wider), and total length.

Airlock — **Materials 1**

A component that connects two areas with different levels of life support (e.g. the exterior of the vessel, which has a life support level of *none*). Its adjustable parameter is the number of people it can hold at once.

Ladder — Materials 1

A set of rails and rungs used to assist movement vertically or in free fall, added to corridors or the outside of a hull. Adjustable parameters are length and whether it is retractable.

Elevator — Materials 1

A small room set on rails for vertical *or horizontal* movement. Internal elevators are placed in dedicated corridors (shafts). Adjustable parameters are rail length and the occupancy of the cab.

Plaza — Biosystems 1

An open space for gatherings and recreation, found in large vessels or colonies. Adjustable parameters are area, height, and landscaping (designers can place pavement, lawns, trees, and other decorative elements). A large plaza can even have areas designated as farmland.

Garden — Biosystems 1

A hydroponic farm growing plants for food. Its adjustable parameter is its yield (the number of people it can support). Large gardens can *reduce* the capacity requirement of life support systems (p. 20), by providing natural air scrubbing and oxygen recycling.

Spin Hub — Materials 2

A connector to a section of a vessel with spin gravity. To design such a vessel, build the stationary and rotating hulls, then join them with the spin hub component. The hub provides connections for electricity, comms, and a *single* axial corridor. No other resources can be transferred between the segments. Thus, each segment will need its own life support system to recycle water, waste, etc. Adjustable parameters are the rotation rate and the diameter of the connector (which determines its structural strength). Most vessels with spin gravity will have counterrotating segments of similar inertial moment; this requires anywhere from 2 to 4 spin hub components (depending on whether there are non-spinning segments on one or both sides of, or between, the counterrotating segments). As an alternative to spin hubs, ships on long cruises can produce gravity by rotating the entire vessel.

Bioprocessor — Biosystems 4

A "food fabricator" that produces a wide variety of foodstuffs from raw organic chemicals and recycled waste products, through a combination of biochemical reactors and cell cultures in growth media. Like a low-tech garden, it is rated for its yield (number of people supported).

Robot Crew — Instrumentation 4

This is not a crew component *per se*. Rather, some or all of a vessel's crew can be replaced with machines, reducing life support requirements. Pilot and Scientist roles can largely be filled with unembodied AIs, Technicians and Medics with specialized robots, and Service with humanoid robots. Robot crew are rated for their occupational specialty and experience level.

Hibernation Pod — Biosystems 5

A capsule that preserves one person indefinitely in suspended animation with no life support.

Communication and Sensing Systems

These are instruments used for communication between vessels (or facilities), and for scientific observations and data collection.

Radio — Instrumentation 1

An antenna and transmitter/receiver for radio communication or astronomy. Adjustable parameters are antenna type (spike, dish, or phased array), size, transmit power, and whether the antenna is deployable and/or retractable. A radio can also be receive-only (common for radio telescopes). Phased arrays are spread over the hull.

Radome — Materials 1

A hull option that makes it radio-transparent, allowing a radio antenna to be placed inside.

Telescope — Instrumentation 1

An astronomical telescope for gathering data about stars and planets. Adjustable parameters are collecting area and wavelength (one or more of *gamma*, *xray*, *ultraviolet*, *visible*, and *infrared,* depending on technology level). At Instrumentation 4+ a telescope has the option of being an *optical phased array* incorporated into the hull.

Environmental Suite **Instrumentation 1**

A collection of sensors to gather data about the physical and chemical environment, including temperature, pressure, radiation, magnetic fields, gravity, and chemistry. This is presented as a single generic component so that players don't have to constantly choose from a laundry list of individual sensors. Its adjustable parameter is its sophistication (*basic*, *standard*, or *deluxe*).

Lasercomm **Instrumentation 3**

A laser communication system. Adjustable parameters are optic size and laser power. Can be placed inside a hull behind a window. At higher technology levels, the laser may be a phased array, integrated into the hull surface and covering much larger areas.

Neutrino Comm **Instrumentation 7**

A communication system that sends and receives neutrinos. These particles can travel freely through matter, allowing uninterruptable communication. Current neutrino detectors are gigantic and far too insensitive to be used for communication, but hypothetical advances in particle physics might make this device possible. Adjustable parameters are transmission power and receiver volume (determining sensitivity).

Thermal and Radiation Management Systems

These systems regulate the temperature or radiation exposure of the vessel, allowing it to operate in extreme environments or resist the heat of atmospheric reentry. In the vacuum of space, ordinary ship systems are usually more than enough to heat it; the challenge is to shed excess heat. In cold environments, a life support system will be enough to keep the crew warm.

Heatshield **Materials 1**

A component applied to the outside of some or all of the hull, allowing it to resist compressive heating from air hitting the vessel at extreme speeds (usually during reentry). Placement of the shield determines the area protected; other adjustable parameters are thickness (determining the heat it can resist), whether it is ablative, whether it can extend (increasing thickness and dissipative area), and subsequently retract. Non-ablative heatshields still require maintenance.

Radiator **Materials 1**

A fin with circulating fluid to carry away heat into the vacuum of space. Adjustable parameters are the area (which determines its heat flux), shape, and whether it is fixed, deployable, or retractable.

Heat Pump **Materials 2**

A set of heat exchangers and coolant pipes extending throughout a hull, thermally connecting it to a radiator: without a heat pump, a radiator will only cool components in its immediate vicinity. A heat pump is rated for the volume of the hull it serves and its maximum heat flux.

Radiation Shield **Materials 2**

Extra mass added to hulls or other components to block incoming or outgoing ionizing radiation. Adjustable parameters are the area covered and the amount of absorption.

Resource Acquisition and Fabrication Systems

These are systems to obtain raw materials from the environment and turn them into usable resources or finished products.

Pump **Materials 1**

A component that moves liquid between the exterior of a vessel (if it is in or under a sea) and a liquid fuel tank. Its adjustable parameter is the flow rate. This can be used by submarines to control buoyancy.

Air Compressor **Materials 1**

Gathers air from an air intake or air duct (p. 15) and feeds it to a compressed-gas tank. Adjustable parameters are the compression mechanism (turbine, ram, or hybrid), and maximum flow rate.

Drill Excavator **Materials 1**

An extendable drill that penetrates the ground under, extracting and storing material in a hopper tank. Its adjustable parameter is the drill power.

Refinery **Chemistry 1**

A chemical reactor that processes raw materials into refined resources (p. 7). This is a large facility typically requiring a staff of dozens of Technician specialists – but see the Converter system, below. A refinery is rated for its resource processing rate.

Factory **Materials 1**

A manufacturing plant capable of turning refined resources into finished products. This is a large facility typically requiring a staff of dozens of workers (Technicians) – but see the Robofac system, below. A factory is rated for the maximum size of the products it can make, and its rate of production (in monetary units per day).

Breeder Reactor **Power Systems 2**

A specialized fission reactor (p. 18) that irradiates certain rare earth elements (thorium, natural uranium) to produce fission fuel (fissile uranium, plutonium), or light elements (natural hydrogen and lithium) to produce fusion fuel. It is rated for its output rate.

Isotope Enricher **Power Systems 2**

A system that extracts the trace amounts of fissile uranium from natural uranium, or deuterium from hydrogen, producing fission or fusion fuel. Unlike a chemical refinery, this requires physical separation (e.g. centrifuges), using slight difference in isotope masses. It is rated for its purification rate.

Converter **Instrumentation 4 Chemistry 3**

An automated refinery that can be made small enough to fit on an unmanned probe. Initially, each converter processes a specific input material to a specific resource. At higher Chemistry technology levels, it is possible to perform multiple conversions in a single converter, taking advantage of common chemical reactor components. Adjustable parameters are the conversion(s) it performs and the rate of conversion.

Robofac **Instrumentation 4**

An automated mini-factory capable of producing a variety of goods for which it has design plans and requisite materials, using additive and subtractive manufacturing and robot assembly. Adjustable parameters are the maximum size of any product it can make, and its rate of production (in monetary units per day).

Magscoop **Propulsion 5**

A large magnetic field many kilometres across, that collects interstellar medium (or stellar winds) and stores it as compressed hydrogen gas. Its adjustable parameter is its collecting area: it can also function as a magnetic sail of similar size. A magscoop-fueled fusion drive differs from a Bussard ramjet (p. 17) in two important ways: first, magscoop-collected hydrogen must be processed in a breeder reactor before it can be used as fusion fuel, whereas a Bussard ramjet can fuse natural hydrogen; second, a Bussard ramjet does not have to *stop* the hydrogen stream but burns it as it flows through, which reduces drag.

Antimatter Distillery **Power Systems 6**

A specialized particle accelerator that produces antimatter from raw energy and stores it in an antimatter trap (p. 19). Its adjustable parameter is its production rate. Creating antimatter requires more energy than is released by annihilating it, but there are systems that rely on antimatter's high power density.

Attachment, Support, and Other Systems

These are systems that allow a vessel to attach to or manipulate another, plus a few structural support and other components that don't fit into previous categories.

Parachute **Materials 1**

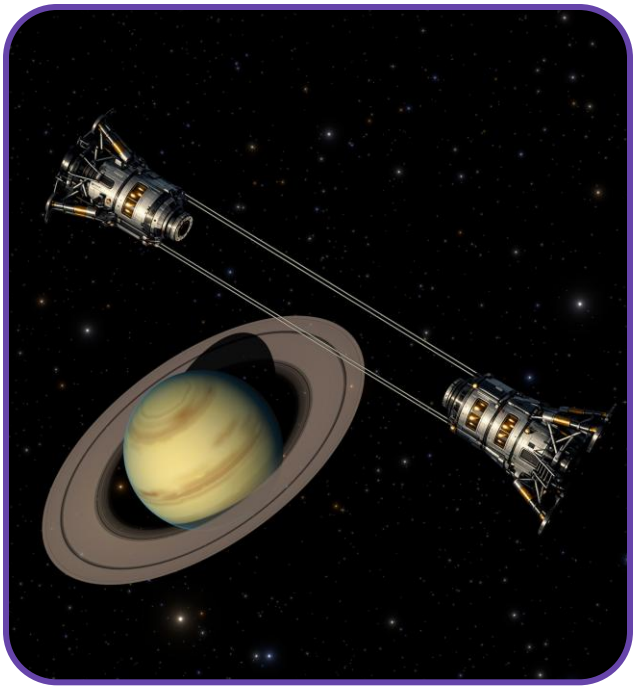
Deployable fabric chute to slow a vessel's descent through air. Adjustable parameters are fabric and line strength, chute area, and offset angle from vertical.

Parafoil **Materials 1**

Deployable fabric airfoil to both slow a vessel's descent and allow it to maneuver in a controlled glide. Adjustable parameters are strength, foil area, and aspect ratio.

Tether **Materials 1**

A simple flexible cable joining two vessels, rated for its strength and length. Both vessels must have a tether attachment (p. 24).



Tether Attachment — Materials 1

A hook or loop to attach a tether, rated for its strength. The maximum force a tether can exert is the least of the strengths of the tether and the two attachments. Optionally, either or both attachments may have a *winch* to lengthen, shorten, or retract and store the tether: the winch is also rated for its retraction speed. The attachment can freely *detach* a tether, but *reattaching* requires a person, or a robot grabber with the *hand* option (below).

Connector — Materials 1

A component on the surface of a hull that rigidly but *temporarily* attaches two hulls together. Adjustable parameters are its size (which determines the attachment strength), shape (usually round or rectangular), and whether it can detach only or reattach. Both hulls must have identical connectors. A connector with a corridor or fuel line behind it can be designated a *docking port*, allowing crew or fuel to pass through.

Strut — Materials 1

A narrow but rigid rod stretching between two connected hulls, to hold them more rigidly in place. Stats depend on the strut's length and (assigned) strength. Struts will automatically detach if the two hulls disconnect; reattaching requires a repair.

Leg — Materials 1

A retractable strut with shock absorbers and a weight-spreading "foot" at the end. Unlike a robot leg (p. 17), this is not articulated for walking, but is intended to provide ground stability and absorb the impact of landing. Adjustable parameters are the maximum load and the length.

Crane — Materials 1

A rigid extendable boom attached by a hinge to a rotating base, with a winch and tether on the end; the tether is often attached to a *grabber* (below). Used for lifting and moving vessels on a planet's surface. Adjustable parameters are the maximum length and strength of the boom and tether, and whether and how far the boom can retract.

Light — Instrumentation 1

A running light, spotlight, searchlight, floodlight, etc. Adjustable parameters are the luminosity, colour, light spread angle, and gimbal angle. This is an external light; internal lighting is included with habitable components.

Light Panel — Instrumentation 1

A wider and more diffuse light. Adjustable parameters are the luminosity, size, shape (circular, or rectangular with aspect ratio), and colour.

Grabber — Instrumentation 2

A mechanism for gripping other hulls, whether or not they have compatible connectors. Often attached to the end of a crane (above) or robot arm (below). When first introduced, the grabber can be either a simple *clamp*, *claw*, or *electromagnet*; at higher tech levels it can be a more versatile *robot hand*, or *gecko adhesive* (sticky, reusable, works in vacuum, and can detach on command). Adjustable parameters are the type of grabber (as listed above), and its strength.

Robot Arm — Instrumentation 3

Similar to a crane but more advanced, with multiple articulated segments. Adjustable parameters are the number of segments, arm strength (which applies to both the structural strength and joint torque), and whether and how much each segment can extend. The end of the arm is usually attached to a grabber (above).