Transport

Figure 1: (Paul Chadeisson)

Transport technology in 2100 would appear outwardly similar to most people from the year 2000 – cars still run on the roads, airplanes and ships roam the skies and seas. But under the hood the cars would be running on nanofuels and be controlled by artificial intelligence. Long-range transport has had to deal with the risk of infection, largely disappearing in favor of local transports rather than having to deal with complex quarantine protocols.

The areas where the biggest obvious difference is visible is the resurgence of lighter than air vehicles and space travel.

Blimps

Figure 2: Prospect Shore, New York (Lindfors)

One unexpected effect of the development of ultralight, ultrastrong graphenes and the social changes across the world was the emergence of the air nomad lifestyle. Cheap, standardized solar-powered blimps that can be moved to suitable locations and leave when conditions appear bad began to appear in the 2050's in China and soon spread worldwide. For many they were just a way of moving around or escaping danger, and were normally stored folded up. The rigid core can be wheeled and used as a mobile home, while the bladder can be inflated in less than an hour. While helium is the preferred gas many desperate people use bio-produced hydrogen, gambling that the anti-fire tricks built into the construction can keep them safe.

Air nomads soon developed an impressive toolkit (or rather, seed bag) of biotech tools for supplying the blimps with spare parts and necessities.

Figure 3: Prospect Shore, New York (Lindfors)

Space Travel

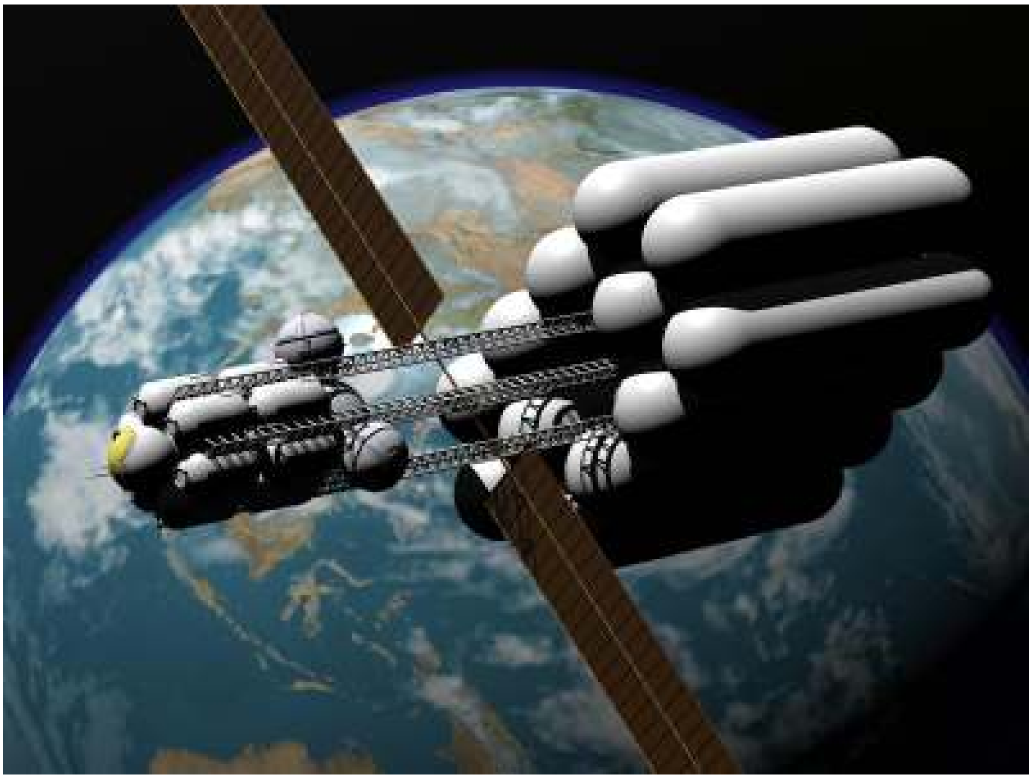


Figure 4: Phoenix Space Development's *Eurydice* shortly before launch in 2043. The ship had a small crew section housed inside the radiation-shielding water and equipment compartments at the front. The aft part of the ship consisted of hydrogen tanks surrounding the nuclear engines.

> *Space travel is* shit*.*
> *--Charles Stross, Saturn's Children*

In space the main factors affecting transport are energy, time and safety. The relative speeds of everything in space tend to be in the range of kilometers per second, faster than rifle bullets. To go anywhere vehicles need to be able to accelerate to high speed – but this requires significant amounts of energy and often extreme amounts of propellant since an internally powered vehicle needs to accelerate not just its payload but the fuel too. This has led to the popularity of beam-powered propulsion, where energy is supplied from the outside using laser arrays.

Rather than distance, speed differences matters when moving between orbits. The required velocity change (delta-v) is the main indicator of cost of a trip. Going from L4 to an asteroid requires a far smaller energy expenditure than going from LEO to L4. The cost of going from an equatorial orbit to a similar but polar orbit can be as big as going to the moon.

Orbital transfers take time and require exact timing. Launch windows shift as the planets move, and unless the vehicle has a very powerful (i.e. expensive) engine most of the trip is going to be coasting in zero gravity. Trips within the Earth-Moon system tend to take a few days, while going to NEOs, Mars or Jupiter requires many months or even years.

OTA demands high safety standards and regularly inspect space vehicles, so safety is *usually* not a problem. But the longer the trip, the higher the chance of solar flares, micrometeors or people doing stupid things out of sheer boredom.

Cost

The cost to launch a kilogram to orbit on Earth is about $100 dollars. On the moon it is 1/5 as costly.

Launching a single person requires around 1100 kg (i.e. the person, life support, vehicle etc). The cost of a HELL launch from Earth is $110,000 (real price, based on a rich nation economy in 2100, is $4,074). A shuttle from Earth is between 20-50% more expensive, depending on spaceport location. A shuttle launch from the Moon costs $22,000 (real price $814)

Going to space is a feasible holiday for many Japanese, keeping the Lunaside tourist industry going. On Earth it is still a major expense, and given the quarantines in orbit earthlings rarely travel outwards these days.

Orbital transfer cost around $12,000 per km/s delta-v (real cost $452), with extra cost of living for multi-day trips.

Prices vary by around 20% depending on market conditions, planetary positions and demand. Cut-rate prices at fly-by-night companies can be had for even less, trading comfort, safety and speed for money. While it might save money to use swing-bys, aerobraking and halo orbits it is not a pleasant way of travel.

Laser Propulsion

Figure 5: Porcelain bell approaching a transfer habitat. (Mark Maxwell and t/Space)

Laser propulsion is the most common form of propulsion in the lunar system. Orbital lasers fire on colored ice that evaporates, producing thrust. This is used for the HELL launchers on Earth, but even more for local travel between Earth, the Moon and L4/5.

The main advantage is that it is cheap. The disadvantages include that it requires ice propellant blocks, cannot accommodate all orbits and relies on external support systems. OTA inspects and guarantees safety, but occasionally a laser array goes offline and a short trip becomes much prolonged since the course corrections cannot be done as desired.

The most well-known laser propulsion craft was the “porcelain bell” developed by PSD and licenced to most other launch firms. They were an extremely simple, cheap and robust construction made from sand and biotech binders that could be manufactured almost anywhere using automated factories. They had minimal comforts and life support, but were enough for a few hours of use. The emigrants were locked into the bell, the bell attached to a column of ice, the assembly lifted above a laser array and then launched using a high energy beam. Marketers were not fond of the term "HELL" or any mentions of lasers, so they tended to call the porcelain bells "lightships". By current standards the porcelain bells were far too unsafe and uncomfortable to be acceptable vehicles, but the vast majority of mid-century emigrants came to space in a bell.

Lightsails

Lightsails are popular for slow cargo, especially when augmented by laser pushing. Many of the probes to the outer solar system and volatile transports inwards are sent using sails. They are rarely used for passenger transport. Lightsails are also used for station keeping for some installations. It is cheap, but tends to be slow and have low thrust.

Lightsail regattas are held regularly in cislunar space, with different designs competing to make the most of the sunlight (the “regular division”) or propulsion lasers (the “augmented division”, often called beamracing). Many space engineering companies participate in the regattas, and there is some prestige in winning the Eagle’s Cup (going from LEO around the moon and back). The 2099 winner, Yardstick Tech of *da Vinci*, is famously competitive and expected to put up a fierce race with Kitakami Photonics, the new favorite, this year.

Steam propulsion

Smaller orbit-orbit shuttles use thrusters that evaporate water, nitrogen, oxygen or some other volatile into steam. This is enough to change orbit, although it requires some suitable source of power.

Electromagnetic propulsion

Ion engines are used for various smaller probes, allowing them to accelerate slowly but persistently over long time. Various magsails and tethers have been tried, but have so far rarely been economical.

Electromagnetic accelerators (“railguns”, “coilguns” and “flickerguns”) are used to launch packages from surfaces in vacuum, especially the Moon. They have great acceleration and can provide significant thrust. However, using them for space vehicles without permit is banned by OTA since such accelerated reaction mass would be a great safety hazard and would break space pollution regulations.

Aerobraking wings

An easy way of “gaining” a delta-v is by reducing velocity and changing direction by skimming across Earth’s atmosphere. This requires some careful piloting and design, but can significantly reduce travel costs even when Earth is not the destination. Many trips from Luna, Geo or HEO make use of an aerobraking step as they approach LEO. LEO-manufactured disposable glider wings made from lightweight nanofoam are also used to make a complete landing: the wing is used during re-entry to brake, and the passenger capsule is re-used (usually by launching with HELL).

Chemical propulsion

Chemical propulsion is mainly used in space planes and some shuttles. It is expensive and polluting, but is independent of external support.

The moon is poor in volatiles, and the frugal japanese do not like to waste water on launching (or to be unduly dependent on cometary ice). Hence they have developed chemical rockets using raw materials found on the moon. The most common type is the liquid oxygen/aluminium rocket. Such chemical propulsion is relatively common Lunaside, even competing with steam propulsion.

The main producers of ground-orbit shuttles are Graumont-Heloise Aerospatial of France, CDA of Germany and Rakko Dynamics of Japan. It is somewhat of a niche market, but most of these companies also produce other air vehicles or orbit-orbit shuttles.

Nuclear propulsion

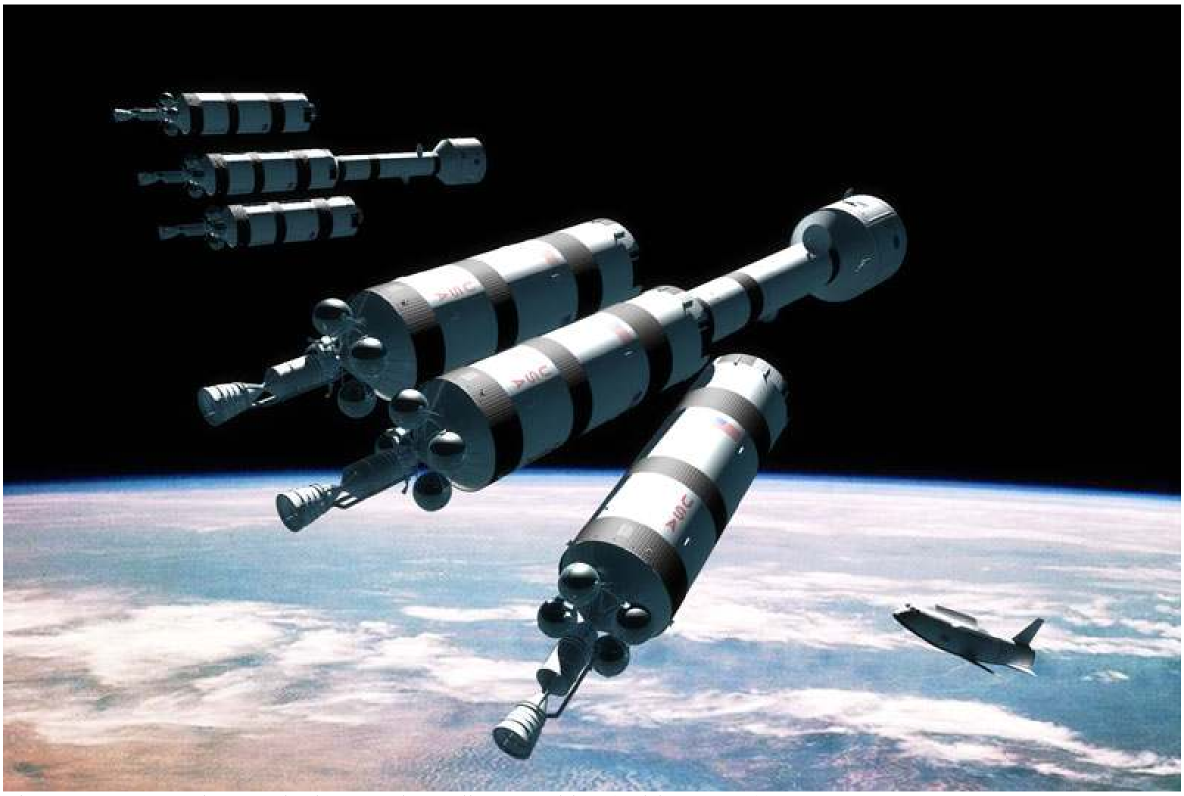


Figure 6: Nerva units attached to two long-distance ships (Adrian Mann)

Nuclear propulsion using nuclear thermal ("nerva") engines is used when high thrust is needed over long distances. This is mainly true for expeditions to NEOs, Mars and the rest of the solar system, but also for moving finished habitats. In the Earth-Moon system Nerva tugships are rented for heavy moving.

Nerva engines use a nuclear reactor to heat hydrogen or other volatile fuel, expelling it at great speed. The big advantage is the high thrust for long periods and the independence of propulsion lasers. But it also requires hydrogen fuel and has radioactivity problems.

After the disaster with the PSD Orion rocket project and the subsequent damning safety review of their nuclear scramjet program all Earth nations (and subsequently OTA) have banned nuclear detonation propulsion and nuclear scramjets on environmental and safety grounds. This largely stopped development of nuclear gas core rockets. There has been some work by NekonoSpace, the Toyohashi-MacKay network and FragmenTech on nanoparticle high impulse engines that would provide sufficient thrust for interstellar missions or very fast interplanetary travel. The downside is the significant cost and the worries about near-relativistic radioactive dust. Currently only the Japanese space navy possess prototype spacecraft, and they have stated that they will not be used near cislunar space.

OTVs

Orbital transfer vehicles (OTVs) move cargo and passengers between different orbital habitats. Small habitat-hoppers link habitats in the same constellation, doing trips of just a few minutes. They are the size of a bus and fairly Spartan. Larger OTVs, "ferries", serve trips between constellations, with accommodations not unlike airplanes and trip times on the order of a day or less. Even larger OTVs, "liners" and "cyclers", move between different orbits. Trips often take a few days up to a week.

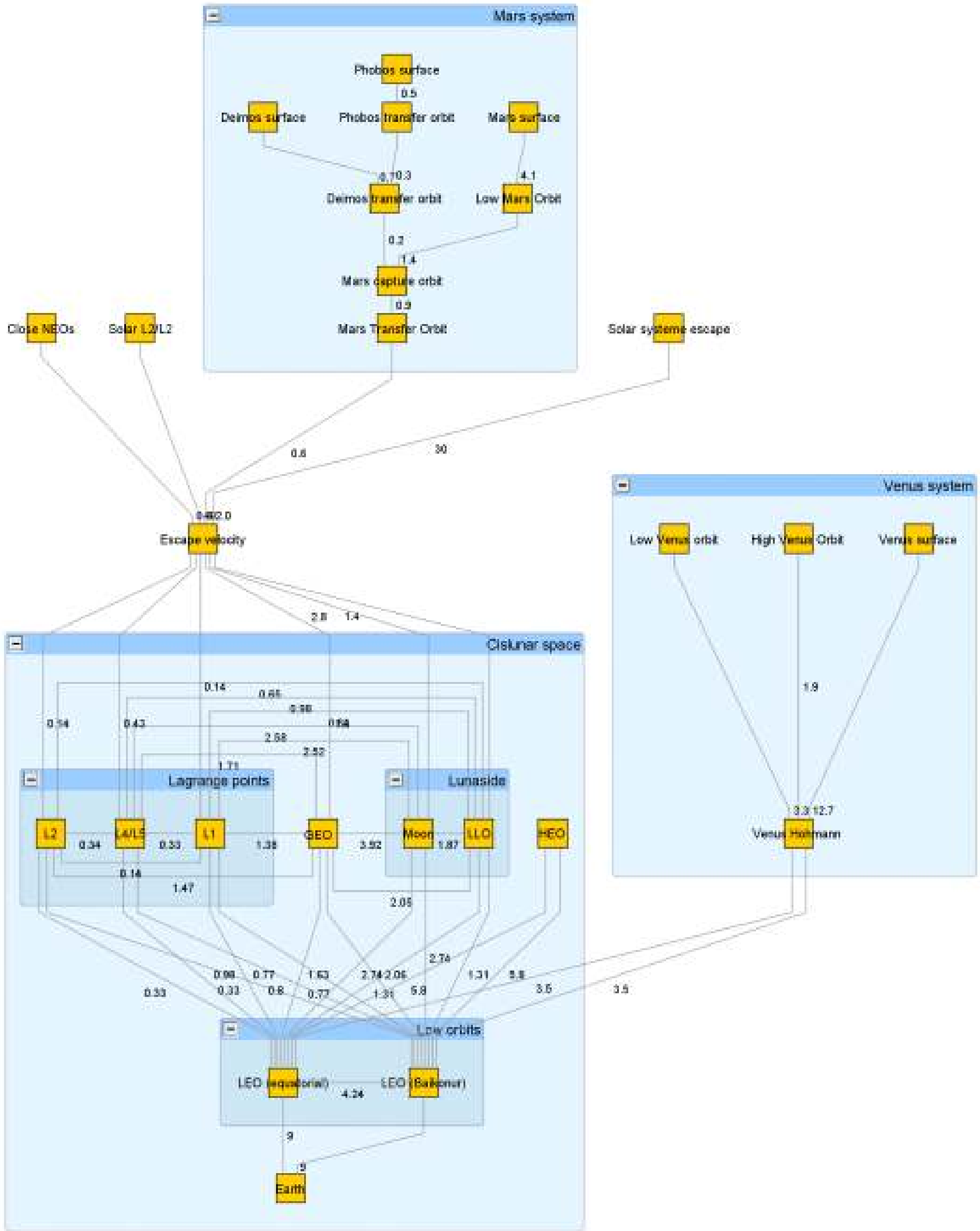
Many large transfer facilities orbit in a two-to-one resonance orbit that brings it close to the moon (allowing low energy arrival/departure) and close to the earth. As they approach cargo and passengers embark/disembark while the OTV continues on its orbit. Their trajectories act as a "railroad schedule" for inhabited space, and often set the schedules for linked habitats. For popular routes (such as LEO-GEO or Earth-Luna) cycler rosettes are used, where several cycling OTV liners are active simultaneously.

Delta-V Budgets

delta-v budgets
Earth - LEO ~9 km/s
LEO - Earth ~5 km/s
http://en.wikipedia.org/wiki/Delta-v_budget

L1 transfers to Earth takes 2-3 days 0.92 kms
L2 4-6 days 1.2 km/s
L3 3-4, 1kms
L4 3-4 1kms

http://en.wikipedia.org/wiki/Delta-v_budget



Although orbits at the same height have the same speed and potential energy, changing the inclination requires a sizeable delta-v. The locations of launch sites have affected which orbits major transit stations in LEO are located and essentially produced “national orbits” – the Baikonur 51.6 degree orbit and the Japanese 36 degree orbit are the most well-known.

Inclination changes
http://en.wikipedia.org/wiki/Orbital_inclination_change

Since delta-V is expensive, it is common to take “shortcuts” by using slow or chaotic orbits, the Oberth effect and aertobraking. Direct trajectories are often more expensive than slow and roundabout orbits (e.g. the classic Hohmann transfer is simple, but can usually be improved on by using a bi-elliptic transfer). For slow trips (especially heavy cargo and outside cislunar space) it is common to put it on a loosely looping trajectory close to the Lagrange points. This allows the exploitation of the “Interplanetary Transport Network” of unstable trajectories linking the points across the solar system: slow but efficient. Oberth acceleration exploits that a thruster burn produces a larger eventual velocity change if done when traveling at a higher speed close to a planet than in free space. Vehicles on Oberth trajectories sweep down towards Earth, Luna or the Sun and accelerate near periapsis. This is common for missions to the outer system. Conversely, aerobraking against the Earth’s (or Mars’ or Jupiter’s) atmosphere is a convenient way of shedding energy without having to pay for the delta-V. While OK for smaller craft, Earth authorities generally tend to raise a stink in OTA over aerobraking moving habitats.

Spaceports and cosmodromes

Numerous spaceports appeared mid-century, as well as the occasional sea launch venture.

Baikonur, in the breakaway Baikonur Republic, is the most well known spaceport. This was where PSD developed its launchers and initiated their colonization program. Over time it grew to a massive installation launching hundreds of capsules each day. The "sky railroad" through Russia to Baikonur became a cultural symbol of bravely migrating to the adventure and possible refuge in space. Emigrees stayed in Korolevgrad near the launch sites, undergoing orientation, training and checkups before launching on the laser arrays. Today Korolevgrad has been scaled back enormously. Most of the laser arrays and infrastructure is quietly rusting away, the colonist training centers empty.

Japan initially launched colonists via Baikonur and the Tanegashima spaceport, but as the program got into full swing numerous launch sites were built across the Home Islands. The massive Japanese launch sites were used not just by the population but also by foreigners migrating to space. While a few launch sites were built in the US, most migrants flew to Japan for their launch. At their height the 30 launch sites were launching one capsule every minute, containing on average 10 people. That produced a transit flow of 432,000 people per day, placing enormous strains on the transit habitats and cycler rosettes.

Australia’s Woomera Transit Station never became a major spaceport, but it is still active.

Hammaguira in Algeria and Guyana Space Center are used by France for some launches and ground-based lasers. However, most shuttles simply take off from de Gaulle Spaceport.

Alcantara in Brazil remains an open, if minor spaceport. It has a convenient equatorial position and keeps some traffic with GEO. Especially German launches are done from here.

In North America the main spaceports are Vandenberg (CA), Dugway (UT) and Dodge (KA).