Part III: 2050

Introduction

Forecasting a vision of the future is risky under the best of circumstances. However, it is not difficult to imagine that space and spaceports will affect our lives halfway into the 21st century. Using the past 50 years as a model of technology advancement, we can expect the future to be altered in ways we have not begun to imagine. Even 20 years ago, who would have imagined the impact of the digital and wireless revolutions?

In 2050, geopolitical issues will still be a global concern, and much of the world population will still be focused on the basic needs of housing, food, and family. However, because the rate of change will accelerate during the next 50 years, the world in 2050 will be less like life as we know it than the life of a half-century ago. Access to space through the use of ground-based and space-based spaceports, for example, will enable dramatic breakthroughs in health, security, transportation, energy, and many other areas critical to human well-being. These advancements in life quality will be facilitated by significant reductions in the cost of launches, thereby opening up markets for yet-to-be-discovered products.

If humankind is to progress in raising the global standard of living, new resources will be necessary to fuel the engine of growth. These resources can be found in space: tritium from the Moon for possible energy production, solar energy, and routes of commerce between Earth and Mars are only a few. Spaceports of the world will have to accommodate the growth of the markets that will develop these resources. Considerable technical capability is being developed now that will someday exploit potential new resources, but if additional resources in space are not discovered and markets developed, spaceport growth will be minimal. The following snapshots of technology development may fuel the growth of future spaceports around the globe.

Transportation. Most of the hub airports in the United States will offer affordable passenger and cargo transportation aboard a full range of aircraft and space vehicles. Depending on their destination and purpose, customers will be able to fly on conventional subsonic aircraft, supersonic Concorde-type airplanes, or space vehicles that can reach low-Earth orbit (LEO). Air and space sickness will be obsolete, enabling passengers of all ages to fly in comfort and safety.

Health. Safe, effective drugs will exist for most deadly diseases, including HIV/AIDS, cancer, degenerative neuromuscular disorders such as multiple sclerosis, and diseases caused by virulent bacterial and viral pathogens. Many of these miracle drugs will have been designed through the ethical application of genetic research and produced in the microgravity of space by a network of pharmaceutical facilities operating in LEO. New protein enhancers developed and produced in space will be a major factor in the continuing explosion in agricultural productivity and quality, ensuring bumper yields from crops, livestock, and aquaculture.

Security. From its use of space, the US military will continue to have an advantage in acquiring precise intelligence, delivering targeted weapons, and being able to quickly deploy troops and equipment at any location on the globe. Military satellites will be capable of pinpointing the smallest visible objects on Earth and, with new optics and spectrotechnology, they will be able to differentiate objects with high resolution. These advantages will help cement and enhance the strike effectiveness of the global community against pockets of terrorism and human exploitation.

Environment. Space will continue to be the chief asset in measuring and anticipating changes in the planet's vital signs. For the first time in world history, a healthy environment will be regarded as a key security issue. The global community will employ its military resources to protect the environment and minimize the effects of environmental attacks by rogue nations or environmental terrorists.

Energy. Energy efficiency and conservation will be increasingly incorporated into homes, ground vehicles, and business operations with less reliance on fossil fuel as humans transition their energy needs to other sources. Many nations will have joined France, Japan, and Lithuania in expanding the use of ground-based nuclear power. New energy sources, combined with greater reliance on space-based sources of "clean" energy, will provide limitless and much-needed power to the world population. These and other undiscovered space-based advantages would give advanced nations in 2050 unprecedented opportunities to mitigate and eradicate poverty, hunger, and disease in their own societies and in the Third World.

Exploration. The exploration of the solar system will expand to include the outer planets and the nearest star systems. The Moon will be used as a scientific outpost similar to the way Antarctica is used today. Space tourism will become a viable business sector, and commercial space transportation systems will be approaching a stage of growth and rapid maturity, similar to that experienced by the airline industry in the early 1950s. The development of nanotechnology (miniature machines based on the manipulation of atoms and molecules), "Buckytubes" (single-carbon fiber structures), and related products—along with advances in materials, new propulsion systems, direct energy conversion devices, and a worldwide support infrastructure—will make the use of space almost commonplace.

Unknown technologies will spring up to advance human knowledge and change daily life in various ways. Technology advancement can be envisioned as a funnel: the initial idea is the base of the funnel, and as time goes by and more research is conducted, the funnel becomes larger and larger as basic technology is better understood and improved. As the funnel's diameter expands to incorporate new ideas, side technologies are developed. Some of these fall by the wayside; others are developed into useful products, and occasionally, a new technology spins off in a new direction.

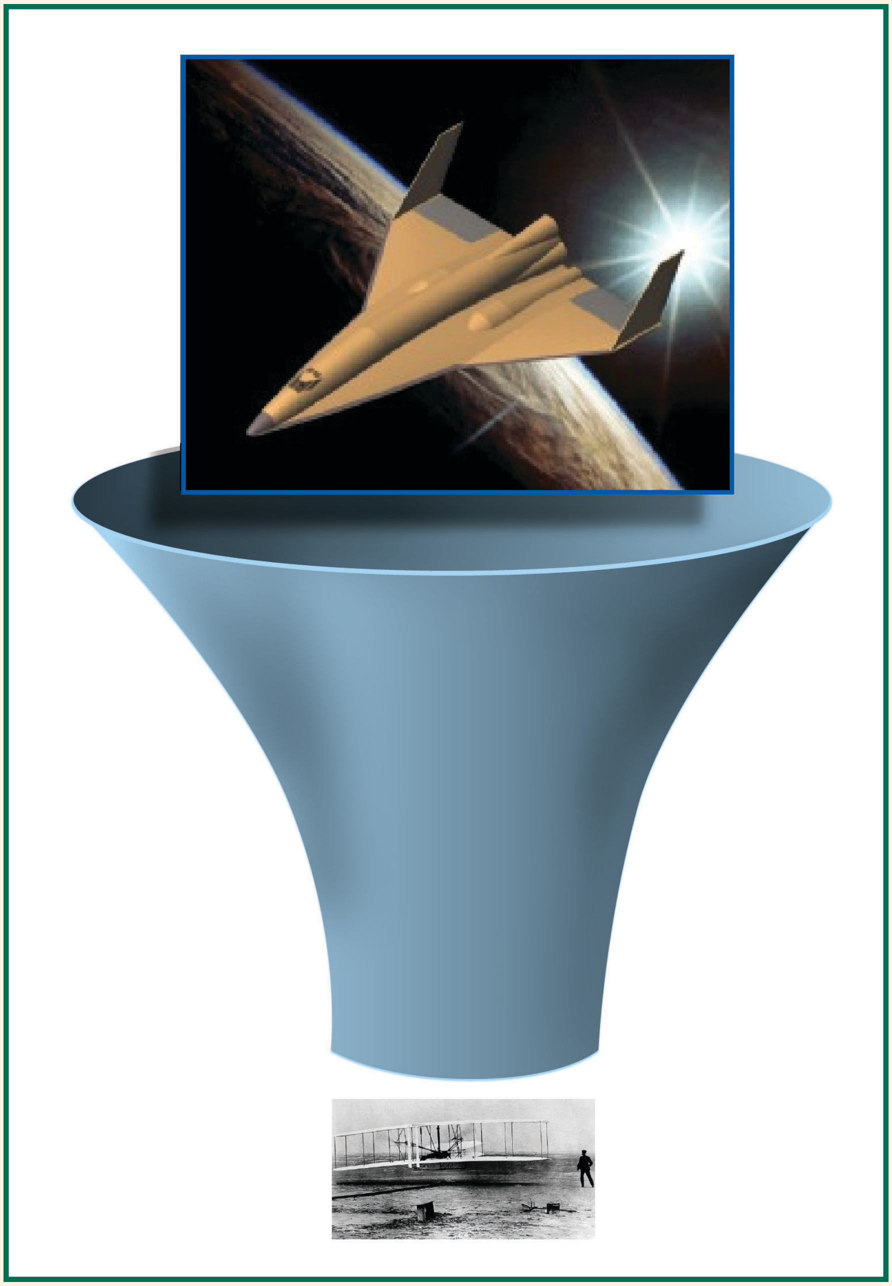


Illustration: Glennan Graphics

Figure III-1. Technology funnel

Space Technologies and Spaceports

The technologies that could aid space exploration must start with the safety of passengers and flight crew, ground and operations crews, local and global populations, the environment and ecosystem, and future generations.

This emphasis on safety in all aspects of life will lead to improved reliability and mission success. The goal will be to achieve space transportation systems and the accompanying ground support infrastructures that are as safe and reliable as, or better than, airline operations in 2002. The technologies most likely to drive advances in space flight by 2050 are as follows:

- Nanotubes, based on carbon fullerene research (Buckytubes), resulting in ultra-lightweight and ultra-strong structural materials
- Adaptive gossamer membranes, replacing precision mirrors and antennas
- Ultra-precision formation flying, replacing trusses and most structures
- Coherent cooperation of large swarms of picosats (weighing 5 pounds or less), enabling the equivalent of huge communications arrays
- Plentiful, cheap, megawatt-level space power beamed from an array or on board
- Nanotechnology to provide distributed, powerful, lightweight, cheap information storage and processing
- Energy density increases and new energy storage devices to enable high-performance propulsion systems that will support the growth of spaceborne payloads

Launch Systems

In order to fully exploit space, a reliable, efficient, and cost-effective method must be designed to deliver large amounts of payload into orbit. The cost per pound of delivered payload must be reduced to something more reasonable than the $5,000 to $10,000 cost-per-pound level of today's launch systems. The efficiency of the system will be gained by designing vehicles and ground infrastructure capable of processing and reusing any launch system within a short period of time, which in 2050 might be down to 1 or 2 days. New types of highly robotic spaceport facilities will have to be designed to achieve compressed processing schedules while maintaining acceptable levels of safety and reliability. The reliability of the system will also result from total reusability and robust propulsion systems that do not overstress launch system structures. It is unlikely that any large payload launch system will be single-stage-to-orbit (SSTO) simply because of the physics involved. In 2050, a fully reusable launch system will likely consist of a carrier aircraft using multicycle propulsion engines to reach an altitude of 20,000 feet and an orbiter vehicle to take the payload into orbit and then return at the end of mission. The launch system could be robotic, remote controlled, human-piloted, or any combination thereof.

Improvements in spaceport architecture and infrastructure will have to keep pace with advances in and types of launch vehicles and auxiliary systems. Designing robust, cost-effective, reusable space transportation systems would be futile without corresponding improvements in spaceport facilities, equipment, and processes to enable the timely and safe launch of such new systems. Among other improvements in spaceport technology, ground support systems and facilities of the future are expected to rely heavily on automation and robotics at levels of sophistication commensurate with the more complex demands imposed by future generations of launch systems.

The primary sources of technology advances in spaceport infrastructure include

- The design process for future launch vehicles and auxiliary systems, which must also consider the ground support capabilities required. The design process will define the requirements spaceports will have to meet.
- The continuing development of more sophisticated, capable automation and robotics systems. This will involve technology advances in other industries for other purposes, as well as those achieved by and for the aerospace community.

Assist systems—magnetic levitation (MAGLEV) or a rail gun—might be used to reduce the required propellants at initial takeoff. The most common form of launch assist system, in use for many years, consists of strap-on solid rocket boosters used on the Space Shuttle and on large expendable launch vehicles. A launch assist system that remains on the ground and can be refurbished has a number of advantages over strap-on rocket boosters. The use of conventional space vehicles and their assist systems will require the fewest changes in spaceport infrastructure, but they are least likely to achieve the cost reductions required for viable future commercial space transportation systems. Ground-based launch assist systems may achieve the necessary cost reductions, but would require revolutionary changes in spaceport infrastructure.

Propulsion

The primary types of propulsion available in 2050 will likely be variations of systems being researched and developed today. Ideally, by the year 2050, propulsion systems will feature high specific impulse, Isp (the number of seconds 1 pound of propellant will provide 1 pound of thrust), low propellant mass fraction (the fraction of the vehicle that is propellant), and a high thrust-to-weight ratio (engine thrust divided by engine weight). The technology funnel effect applies here: ideas being proposed now will expand the size of the funnel, eventually generating new technologies that will signal a breakthrough in propulsion systems.

The types of propulsion being explored today and their likelihood of being fully developed by 2050 are described below.

Rocket-Based Combined Cycle (RBCC). An RBCC is a small rocket engine placed in a larger tube open at both ends and operating in four modes:

1. In the **ejector mode**, the rocket engine works like the compressor stage of a jet engine. The high-velocity rocket exhaust entrains and compresses air flowing into the open front end of the system. This air burns fuel in a manner similar to the afterburner of a jet engine.
2. In the **ramjet mode**, the rocket is turned off when the vehicle reaches around Mach 2. At that point, the ram pressure is sufficient to compress the inlet air.
3. In the **scramjet mode**, the secondary fuel injection is moved forward to allow adequate time for fuel and air to mix before being burned to provide thrust.
4. The **rocket mode** begins when the vehicle escapes the lower atmosphere and the rocket reignites.

The main advantage of this type of first-stage system is weight. By initially using off-board resources (ambient air), the vehicle may be lighter and less costly to operate, and have a greater design margin for reliability and safety. Testing of this concept is underway, and it is likely to be the leading candidate for propulsion systems in 2050.

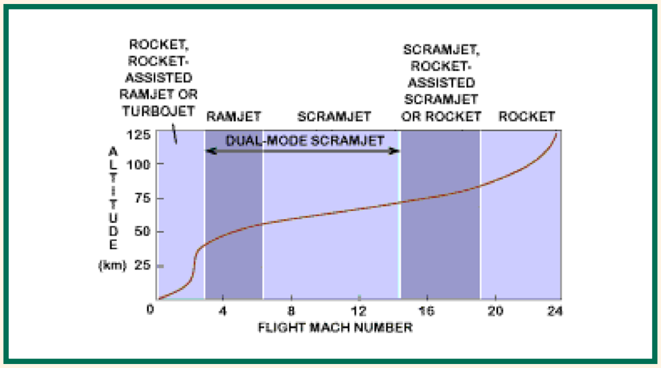
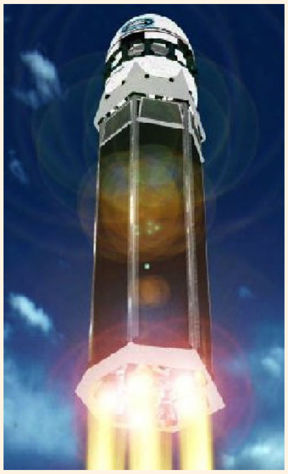


Illustration by Joann Rosario, reprinted by permission.
Source: *Scientific American*, February 1999.

Figure III-2. Flight mach number



Pulse Detonation
Rocket Engine
(Illustration: NASA)

Pulse Detonation Rocket Engine (PDRE). The PDRE is essentially a straight pipe closed at one end and open at the other. In a manner similar to what occurs in an automobile combustion chamber, a pulse of fuel and oxidizer is injected into the tube and ignited by a spark plug. The expanding gas provides pressure on the closed end and exits the open end, resulting in thrust. The cycle is then repeated.

The advantage of this first-stage system is economy. The fuel is injected at a relatively low pressure, thus requiring lighter weight and less expensive pumps. A detonation wave traveling at 10 times the speed of sound completes the combustion cycle before the gas has time to expand. This type of combustion cycle (Humphries) avoids the energy losses associated with conventional rocket engines and releases about 10 percent more energy from the propellant for thrust. The very nature of the geometry and simple components involved may yield a very low-cost system. A PDRE system may not be applicable to all vehicles because of the vibrations and frequencies inherent in the system.

Laser Beamed Energy Propulsion: The Laser Lightcraft. The laser lightcraft system uses a ground-based beam of pulsed laser light directed onto the optics of a small flight vehicle. The laser pulse is tightly focused into a vehicle reaction chamber, where it initiates a laser-supported detonation and rapidly heats air or fuel to extremely high temperatures. Hot gas expands through a nozzle to provide thrust. Air or fuel is then resupplied to the chamber to begin the cycle again. In recent free-flight tests at White Sands, New Mexico, a 30-gram spin-stabilized vehicle reached a height of 125 feet using a 10.6 micron CO_2 laser at 10kW power and 20 pulses a second.

One megawatt of laser power is estimated as the requirement for each kilogram of payload to orbit. A major concern is that atmospheric “blooming” or dispersion of the laser power may limit the ultimate payloads to only several hundred kilograms.

Research on this type of propulsion is being conducted primarily by the Rensselaer Polytechnic Institute in Troy, New York, the Air Force Research Lab, NASA Marshall Space Flight Center, and the US Army at White Sands, New Mexico.

Gun Launch to Space. A gun launch system may entail the lowest possible cost of gaining access to space by chemical or electromagnetic systems. Most of the launch equipment in a gun launch system stays on the ground, thus eliminating the costs of having to carry propellants to launch the spacecraft into orbit. Several concepts have been identified that may be able to provide the 8 kilometer-per-second velocity required. These concepts include a multistage light gas gun, a blast-wave accelerator, and a coil gun. Gun launch and similar systems impose entirely new requirements on spaceport architecture, including the development of new technologies, ground support facilities, and risk assessments for acceptable levels of safety.

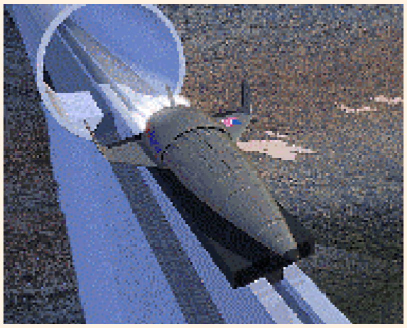
Problems in the gun launch system that need to be addressed include the following:

- Developing a method of orbit circularization to avoid reentering Earth's atmosphere
- Launch loads of 30,000 to 50,000 times the force of gravity, allowing for only the smallest and most robust payloads
- Developing concepts for rapid and low-cost turnaround.

At the present time, the US Army, Lawrence Livermore National Laboratories, and the University of Texas are investigating these concepts.

Magnetic Levitation (MAGLEV) Launch Assist. The MAGLEV launch assist system accelerates a combined sled and launch vehicle down a horizontal or gently rising track for 2 miles. A two-stage RBCC launch vehicle is released from the sled once the velocity reaches 400 mph. The track length permits contingent recovery operations of the sled and launch vehicle in the case of a launch abort. A ground-based reusable launch assist system can reduce the overall vehicle size by more than 20 percent for the same payload delivery capability.

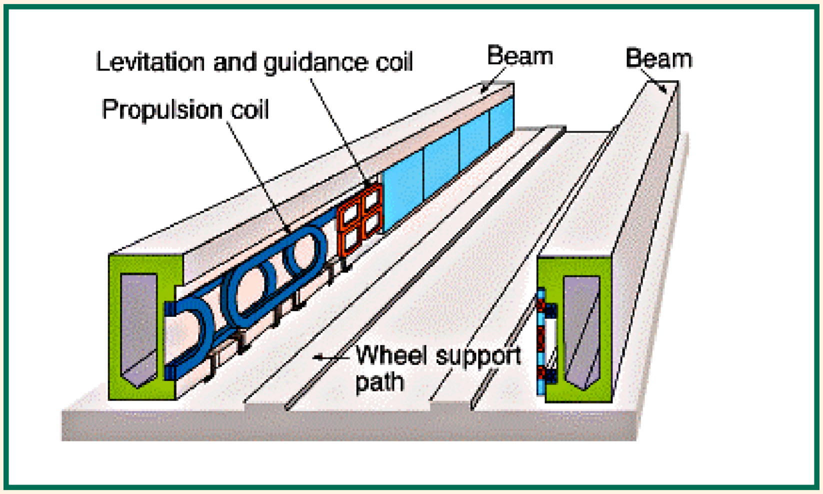
Although MAGLEV transportation was first proposed more than a century ago for use by the railroads in the late 1880s, the first



(Drawing: NASA)

Maglev vehicle leaving tube

operational use of this type of train will not debut until at least 2005. Germany and Japan are at the forefront of MAGLEV train technology, and both countries are currently testing prototypes of their MAGLEV trains. Despite US interest in MAGLEV trains and extensive testing over the past few decades, the cost of building a MAGLEV transportation system has been deemed prohibitive. The estimated costs for building a MAGLEV train system in the United States range from $10 million to $30 million per mile. To accommodate such a system, spaceports would have to devise effective ways to amortize the development, construction, and operational costs of MAGLEV facilities so they do not eradicate potential savings in launch costs. The technological challenges in using a MAGLEV launch assist system may be less daunting to commercial spaceport operators than managing the expense of building and maintaining the system.



Source: Web site "How Things Work"

Figure III-3. Magnetic levitation launch assist

This launch concept is being explored by several organizations including PRT, Inc. of Chicago; Lawrence Livermore National Laboratories (LLNL); Foster Miller, Inc. of Boston; and The Boeing Company. Two small test tracks are being operated at Marshall Space Flight Center and one at LLNL.

AJAX: A Russian Hypersonic Aircraft Concept. A magnetohydrodynamics (MHD) generator is designed to pass high-velocity ionized gases through a magnetic field and divert them in a direction perpendicular to the field. The electrons and negative ions are diverted in one direction, while the positive ions are diverted in the opposite direction. Electrodes placed to collect these charged particles can generate electrical power while decreasing the gas flow. Applying power from an external source accelerates the flow.

Russian scientists have proposed using an MHD generator to make the hypersonic flow of a scramjet look like the optimum supersonic flow conditions of a ramjet. Their concept is to place an MHD generator and flow ionizer in the engine inlet to slow down the gas flow to ideal ramjet conditions. The electrical power from the MHD generator is sent to an MHD accelerator located at the ramjet exhaust flow to increase thrust. The device as conceived is also able to virtually double the airflow into the ramjet inlet by using MHD and weakly ionized gas effects to reduce drag. Problems with this concept include the mass of the magnets, electrodes, and ionizer. NASA-Ames Research Center, Anser Corporation, and the Air Force Research Lab are studying this launch concept.

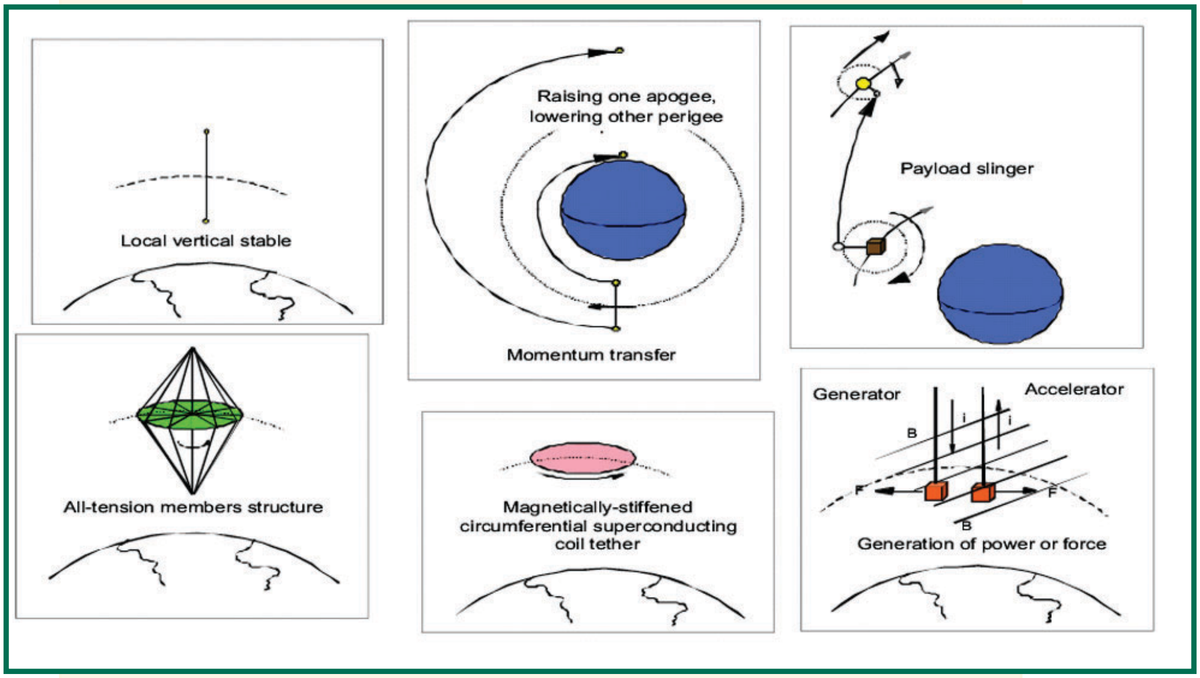
Other Electromagnetic Propulsion Concepts

Microwave Beamed Energy Propulsion. The microwave lightcraft is a lenticular-shaped helium balloon pushed into space using an intense ground-based microwave beam. The spaceport operator must provide or arrange for ground-based microwave facilities that may or may not be located on the launch site. Since microwave pressure alone is insufficient to launch the craft, microwave energy must be either converted into electricity to deliver power as an electric propulsion system or focused to provide air detonation similar to what occurs in the laser lightcraft.

Magnetoplasmadynamic (MPD) Thruster. The MPD thruster is one example of a high-power electric engine that may dramatically reduce travel times for missions beyond lunar orbit. The MPD thruster creates a very high magnetic field by striking an electric arc between coaxial electrodes. This magnetic field pushes the arc and a small amount of ionized propellant to high velocity and out the open end of the engine. Isp greater than 5,000 seconds can be achieved. Although the concept offers high Isp and low weight, it has the drawback of severe electrode erosion.

Plasma Rocket. The second example of a high-power electric engine is the plasma rocket, which uses microwave energy to heat plasma to extremely high temperatures in a magnetic bottle with mirror magnets at each end. The most energetic ions located near the axis will leak through the mirrors, producing thrust with Isp greater than 5,000 seconds. Even greater Isp numbers can be achieved by reducing the thrust levels. This concept tends to require greater weight because of the current state of magnet technology.

Tethers. Examples of tethers in space are shown below.



Source: Bekey Designs, Inc.

Figure III-4. Examples of tethers

Electrodynamic Tethers. This concept is based on the physics that a long-conducting tether passing through the Earth's magnetic field will generate an electric potential between the ends of the tether. Plasma contactors allow current to flow to and from the ends of the tether. The energy generated by the current flow decreases the orbital altitude. Energy obtained from solar arrays can reverse this process and raise the orbital altitude. Space-deployed tethers of limited length have been tested on Shuttle missions with varying degrees of success. Additional testing and design would be needed to develop space tethers of sufficient length and reliability to achieve the necessary energy flow.

Earth–Moon Tethers. Lunar payloads could be delivered using a system of three tethers. A tether in low-Earth orbit picks up a payload launched from Earth. This tether moves in a cartwheel motion to hand off the payload to another cartwheeling tether in higher Earth orbit. The second tether catapults the payload toward the Moon, where it is picked up by another tether in lunar orbit. The third cartwheeling tether then deposits the payload onto the Moon's surface.

Sails. The sail concept uses photon pressure from the Sun or a laser on a large area of ultra-lightweight film. The photon pressure produces a small but significant acceleration on the film. The angle of the sail with respect to the energy source can either add energy to the orbit or reduce it. One concept has the system moving closer to the Sun after escaping Earth orbit and then departing using the increased acceleration.

Nuclear Propulsion

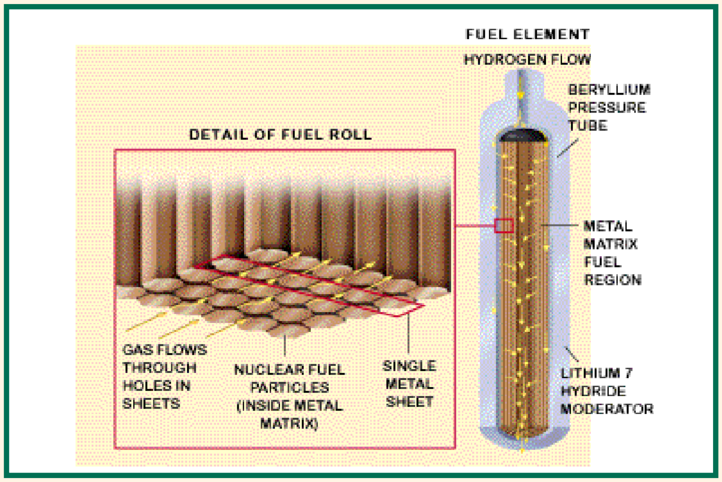


Illustration by Laurie Grace, reprinted with permission.
Source: *Scientific American,* February 1999.

Figure III-5. Nuclear propulsion

The two most common types of nuclear propulsion are nuclear thermal and nuclear electric. Nuclear thermal rockets (NTRs) typically flow hydrogen gas through a reactor core to heat the gas, which provides thrust by expansion through a nozzle. An Isp greater than 800 seconds is achievable. Nuclear electric propulsion (NEP) uses a nuclear reactor to generate electric power, which in turn is used to drive an electric propulsion system. With low thrust levels, this concept can deliver an Isp much greater than 5,000 seconds.

Nuclear propulsion is a viable alternative to existing systems because chemical propulsion systems have been enhanced and improved to within a few percentage points of maximum effectiveness. Nuclear propulsion allows for a new growth path with a factor of 10^6 improvement in specific energy and a factor of 10^{100} in Isp.

The biggest obstacle to the use of nuclear propulsion is the public concern for safety, which would be present from the testing stage through development and operation. Commercial spaceports employing nuclear propulsion systems would have to design extremely rigorous levels of safety and reliability into the processing, test, storage, and other ground support facilities. While these spaceports would not be located near high-population centers or in areas where launch trajectories would traverse such centers, they still would be subjected to greater government regulation, inspection, and scrutiny than spaceports using non-nuclear launch systems. General awareness of the advantages and disadvantages of nuclear propulsion must be provided through public education and full disclosure of the safety approaches being used. If safety cannot be assured, then these systems are not feasible.

Advanced Nuclear Propulsion Concepts

High Temperature Nuclear Fuels. Solid-core nuclear reactor performance is limited by the melting point of the nuclear fuel. Exotic alloys, sometimes known as ribbon fuels, may allow Isp increases from 800 seconds to greater than 1,000 seconds.

LOX Augmented NTR. One method proposed to assist in escaping from Earth's gravity is the injection of liquid oxygen (LOX) into the NTR nozzle at the expense of Isp. As a result of the expansion of the gases in the nozzle and the temperature falling below the molecular dissociation point, the oxygen chemically combines with the hydrogen to maintain pressure for a little while longer.

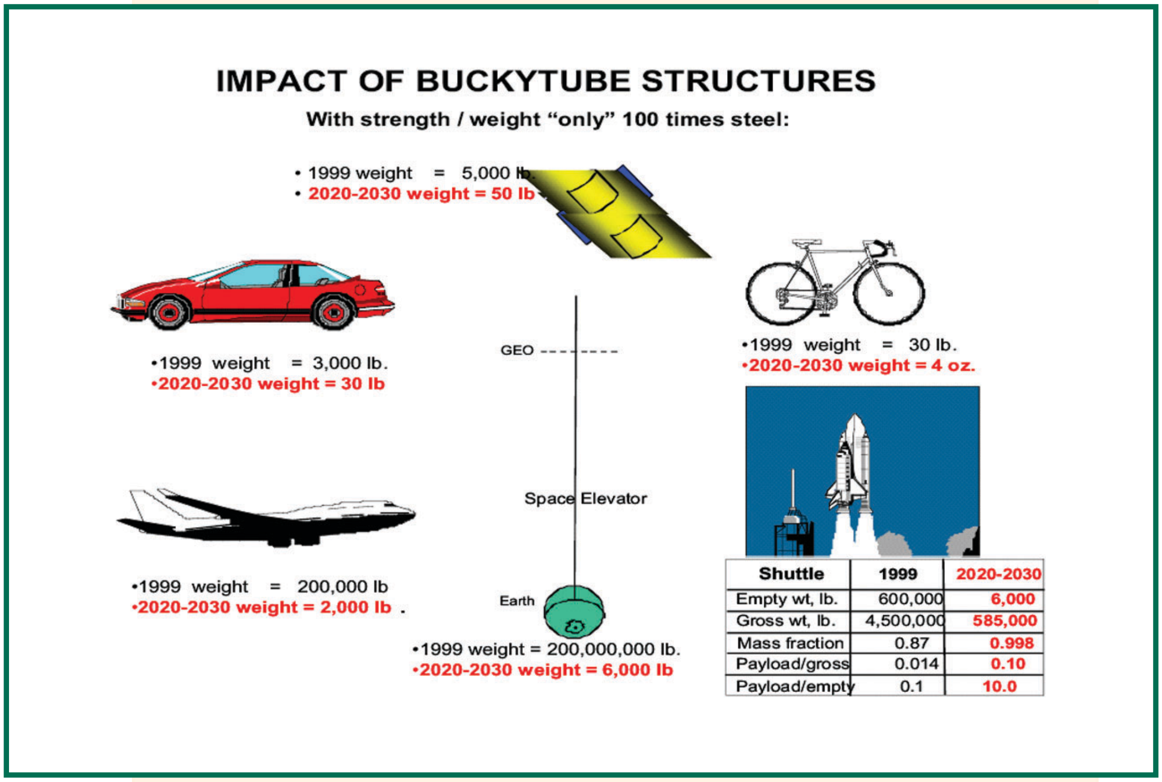
Gas Core NTR. Hydrogen gas that is heated to very high temperatures may provide Isp greater than 3,000 seconds. Los Alamos National Laboratory and Brooklyn Polytechnic Institute have mathematically simulated confinement flow patterns that retain the uranium fuel while releasing the high-pressure hydrogen through the nozzle.

Extremely Advanced Concepts

Fusion/Antimatter Propulsion. When fusion energy production is finally achieved, it promises Isp greater than 100,000 seconds, enabling human missions anywhere in the solar system. Fusion propulsion concepts tend to require very heavy, very large systems.

Space Elevators. Using Buckytube structures with a strength and weight ratio 100 times that of steel, a tether to GEO in the form of a "space elevator" is a possibility. With current technology, the tether would weigh 200,000 pounds. With ultralight Buckytube materials, this system would weigh only 6,000 pounds, with a corresponding cost reduction of 1,000 to 1.

Materials. Advancements in materials have been major technology drivers for society in general and for the space industry in particular. Lightweight materials with increased strength and enhanced elastic properties will have been developed by the year 2050. These materials will be used in everyday applications and will be essential to the increased uses of space transportation and permanent human habitation modules in orbit. Some of the potential materials are Bucky systems, adaptive materials, gossamers, and space-based manufactured matrices and metals.



IMPACT OF BUCKYTUBE STRUCTURES

With strength / weight “only” 100 times steel:

- 1999 weight = 5,000 lb.
- 2020-2030 weight = 50 lb

•1999 weight = 3,000 lb.
•2020-2030 weight = 30 lb

•1999 weight = 30 lb.
•2020-2030 weight = 4 oz.

•1999 weight = 200,000 lb
•2020-2030 weight = 2,000 lb .

•1999 weight = 200,000,000 lb.
•2020-2030 weight = 6,000 lb

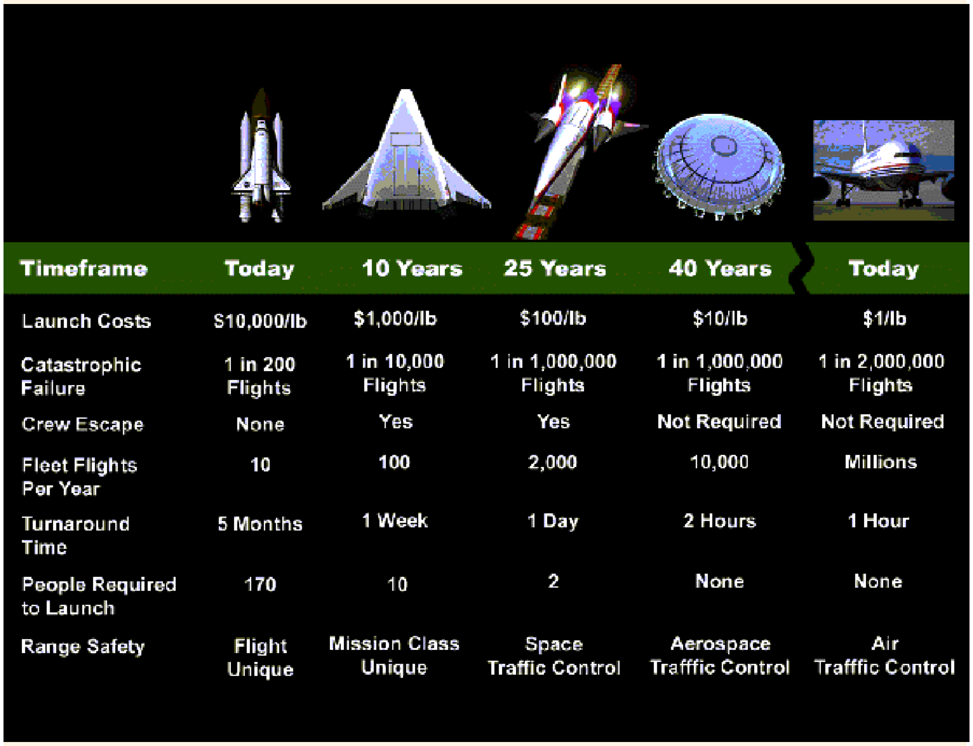
Shuttle	1999	2020-2030
Empty wt, lb.	600,000	6,000
Gross wt, lb.	4,500,000	585,000
Mass fraction	0.87	0.998
Payload/gross	0.014	0.10
Payload/empty	0.1	10.0

Source: Bekey Designs, Inc.

Figure III-6. Impact of Buckytube structures

Nanotechnology. A nanometer is 1/100,000 the width of a human hair. Because of the limitations of today’s manufacturing processes, much of the work in nanotechnology is in the realm of future electronic systems. Today, a typical satellite weighs more than 1,000 kilograms. Microsats weigh between 10 kg and 100 kg, nanosats weigh between 1 kg and 10 kg, and picosats weigh less than 1 kg. By 2050, nanosats and picosats may be commonplace. Their ability to be launched on virtually any type of launch vehicle may significantly impact the number and design of future spaceports. For example, spaceports that launch microsats, nanosats, and picosats will require laboratory-like processing and testing facilities featuring advanced microelectronics and rigorous clean-room class standards. These much smaller payloads will facilitate weight-to-orbit cost reductions, and ground facilities will have to meet exacting standards to prevent contamination or other problems that could impair on-orbit performance.

Implications for Spaceports and Space Operations. In many ways, future Earth-based spaceports will be similar to those in existence today. They will support expendable launch systems and put commercial payloads into orbit. Some spaceports also will be used to launch humans into space aboard reusable launch vehicles toward space stations or possibly vacation “resorts” in orbit around the Earth or the Moon. Some changes at Earth-based spaceports will come about in the systems used to overcome the effects of gravity through the use of nuclear rockets or ground assist systems. Other changes will result from the types of payloads launched, such as extremely small satellites, extremely large orbital components, and public space travelers. In addition, some types of space-based spaceports are expected to be operational by 2050.



Timeframe	Today	10 Years	25 Years	40 Years	Today
Launch Costs	$10,000/lb	$1,000/lb	$100/lb	$10/lb	$1/lb
Catastrophic Failure	1 in 200 Flights	1 in 10,000 Flights	1 in 1,000,000 Flights	1 in 1,000,000 Flights	1 in 2,000,000 Flights
Crew Escape	None	Yes	Yes	Not Required	Not Required
Fleet Flights Per Year	10	100	2,000	10,000	Millions
Turnaround Time	5 Months	1 Week	1 Day	2 Hours	1 Hour
People Required to Launch	170	10	2	None	None
Range Safety	Flight Unique	Mission Class Unique	Space Traffic Control	Aerospace Trafffic Control	Air Trafffic Control

Source: NASA

Figure III-7. Time frame

Conclusion

By 2050, the world will be quite different than now. Instant communication will be commonplace; face-to-face interactions will occur infrequently. Society will be global and multinational, representing a multitude of cultures and beliefs. Earth's population will continue to grow at a rate that threatens to overwhelm the resources capable of sustaining human life. "Owning" or controlling diminishing land and water resources will provoke more future wars than political or religious differences. Space will beckon, with its potential to unite the world with a common purpose of discovery and exploration. Commercial spaceports will play a vital role in this quest by providing the infrastructure to enable future launch systems. Once technology overcomes the engineering and physical limitations of routine space transportation, the ways in which we use space and its assets may well determine the direction our emerging global society takes.

The "Space Industrial Revolution" in the Next 20 - 40 Years

- Drivers will primarily be decreasing costs.
  - Launch costs reduced by three orders of magnitude
  - Spacecraft costs reduced by two orders of magnitude while capabilities blossom

- Commercial uses of space will proliferate explosively.
  - Expanded personal communications, navigation, observation, data services
  - Public space travel, recreation, hotels, sports pavilions
  - Business parks, advertising, film and television studios, manufacturing
  - Provision of night illumination and energy relay
  - Large-scale generation and transmission of energy-to-Earth power grids
  - Beginning of commercial activities on the Moon

- Advances will be driven by the entrepreneurial spirit and profit motives.

- The net result will be unprecedented creation of wealth and millions of ordinary citizens benefiting from space in their daily lives.

- The private sector will lead this expansion into space.

- Government will benefit from this second Industrial Revolution because only then will budgets increase and programs proliferate.

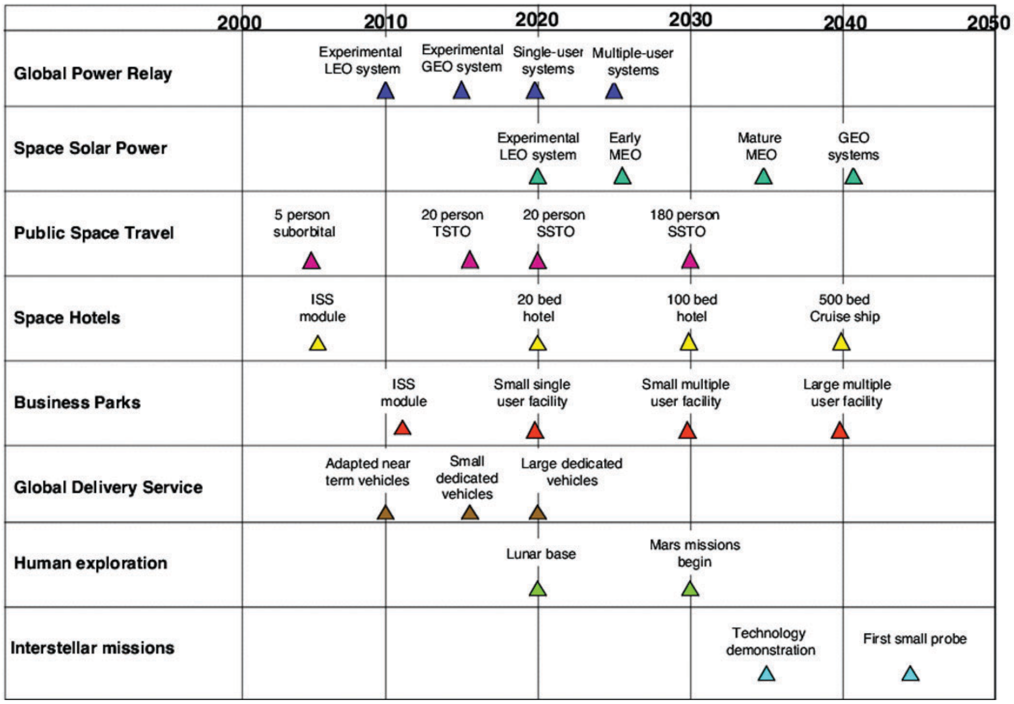
Space Features: 2050

- Adaptive gossamer materials will create 1 km antennas and 100 m telescopes.
- Coherently cooperating picosat swarms will enable huge sparse arrays.
  - >100,000 km-diameter RF antennas and >100 km-diameter telescopes
- Buckytube materials will reduce the weight of *everything* by a factor of >100.
  - Extremely lightweight materials and very low cost
- Launch to LEO or GEO will cost no more than $1 to 10/lb (airline-like costs).
- A permanent transportation infrastructure will exist in Earth and Cislunar space.
  - Propellant-less, reusable, and requiring almost no energy
- Many space functions will migrate to GEO and GSO for large coverage at low cost.
- Launch vehicles will be primarily electrically and magnetically powered.
  - Chemical propulsion outmoded
- Many sensing and active functions done from aircraft will be shifted to space.
- Spacecraft will be routinely serviced and upgraded, in orbit and on the ground.
- Brassboards and many spares will be routinely orbited.
- Megawatt power levels will be inexpensive and widely available in space.
- Powerful information processing will be available and will meet all demands.
- Huge numbers of very small as well as very large lightweight spacecraft will exist.
- Fleets of autonomous robots will fabricate and assemble enormous spacecraft.
- Macrostructures and macroengineering in space will become common.

Resulting Space Vision: 2050

- One million people will visit space each year for tours, vacations, and business.
- There will be 20-40 hotels with 100-200 beds in each Earth orbit and on the Moon.
- Space sports pavilions will have 30 million Earth TV audience “gates”.
- Many clusters of industrial business parks will exist
  - Products and services for consumption will furnish 80 percent of the world’s electrical power
- Night illumination and energy relay via space will be commonplace.
- Non-communications commercial activities will dominate space even though communications applications will continue to expand.
- Manned and robotic planetary exploration will be routine.
- The first robotic interstellar mission will be on its way.
- There will be 5,000 to 10,000 launches a year worldwide.
- NASA and DoD space will become principally R&D agencies
  - Most space operations will be commercial or commercially operated.

Applications and Time Lines



Source: Bekey Designs, Inc.

Figure III-8. Applications and time lines

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