Review of the International Space Market

Brian Brighenti, Eric Griffel, Kyle Unfus

Advised by Professor Oleg Pavlov
Department of Social Science and Policy Studies
Worcester Polytechnic Institute
Worcester, MA 01609
(508) 831-5234
opavlov@wpi.edu

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Executive Summary

This document is designed to introduce the reader to the Space Industry. Sufficient data is presented displaying the history of the industry, the technology involved, legal and market analysis. Within this document, the reader can find details on the main technological components of a spacecraft including thrusters, power generators, shielding and attitude control. The reader will also find space regulations detailing international cooperation, property rights and pertinent regulations and treaties. Moreover, this document contains information on the "Corporate Giants" such as Boeing, Lockheed Martin, and McDonald Douglas. The industry is not just composed of such giants, but its composition is changing and it now includes small private companies which will most likely change the face and direction of the space industry. Information on these companies is also included. In conclusion, this document outlines current industry trends.

History

The Cold War between the Soviet Union and the United States was a struggle for dominance and influence over the other nations of the world. This included a race for the best technology and to be the first to explore the unknown. On October 4, 1957 the Soviet Union became the first nation to put an artificial satellite around the Earth with the launch of Sputnik 1 into an elliptical orbit (Figure 1). This launch would drive the two superpowers into what has become known as the Space Race. The Soviets were again the first to put an animal into space on Sputnik 2 launched in 1957 with the dog Laika onboard. She would die in reentry but in 1960 the Soviets successfully put two dogs into orbit and retrieved them alive. The Soviet Union also put the first human into space and into orbit with the launch of Yuri Gagarin aboard Vostok 1 on April 12, 1961. The United States was not far behind, however, launching Alan Shepard into space only 23 days later. John Glenn became the first United States citizen to orbit Earth on February 20, 1962. Over the next years many flights were made by both countries in preparation to sending people to the moon[1].

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[1] http://en.wikipedia.org/wiki/Space_Race. Accessed 3/23/06.

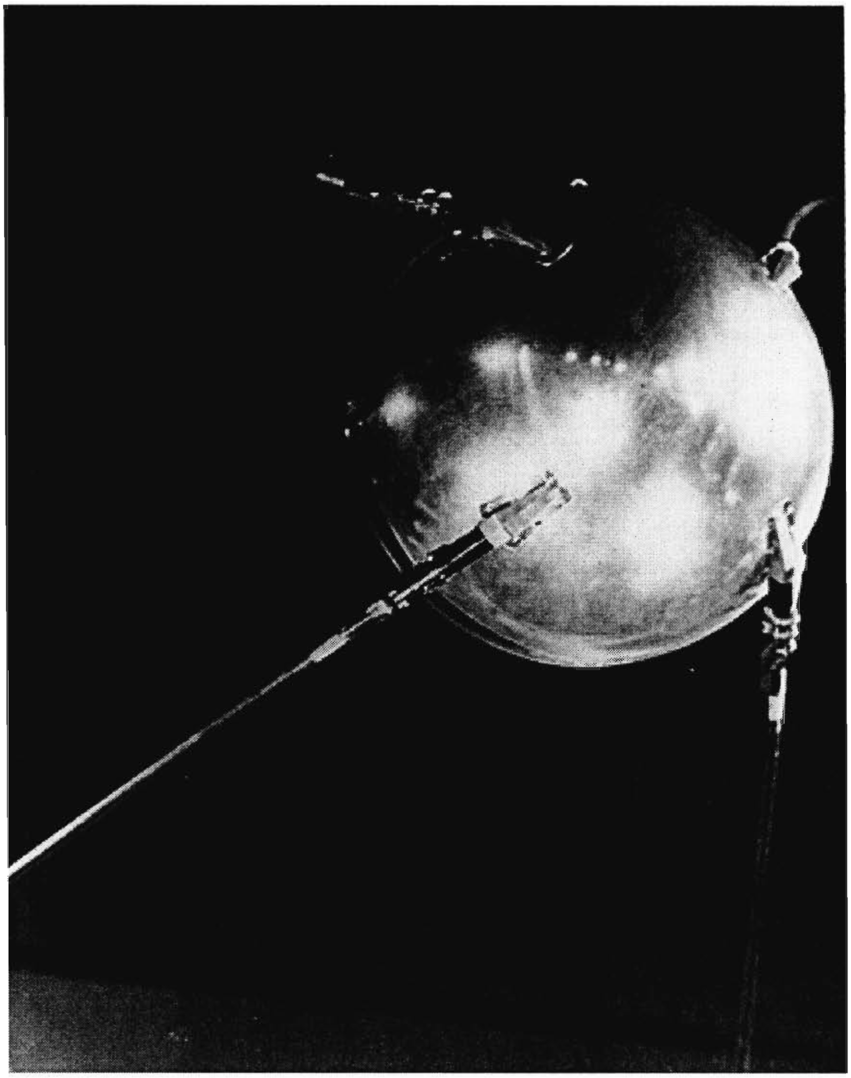

Figure 1: Sputnik 1

The Soviets were able to land a probe on the moon with the launch of Luna 1 back on January 4, 1959 but the United States was to become the first nation to put a man on the moon. In July 1969, Neil Armstrong became the first person to walk on the moon. The Soviet program that had developed a moon lander was stalled and eventually cancelled due to the failure of the rocket which was designed to launch their lunar module. The United States would make 5 more successful landings on the moon before changing its focus to other projects[2].

[2] http://en.wikipedia.org/wiki/Space_Race. Accessed 3/23/06.

After the moon landings, competition between the two nations slowed as each superpower developed their own space stations, cooperated in joint missions, and the United States built their space shuttle fleet (Figure 2). The space race between the US and USSR ended in 1991 when the Soviet Union dissolved and funding for the new Russian space industry was drastically cut. However, with the emergence of the European Space Agency (ESA), Japan, and China with their ambitious space programs it currently seems that the world may be on the verge of another space race. This race may lead to the development of a colony on the moon and even Mars in the relative future. It seems as the technology that is necessary for space flight becomes cheaper and more widely available a commercial space race may develop in the coming decades. The newly formed Space Adventures is sending tourists into space and several companies are following closely behind[3].

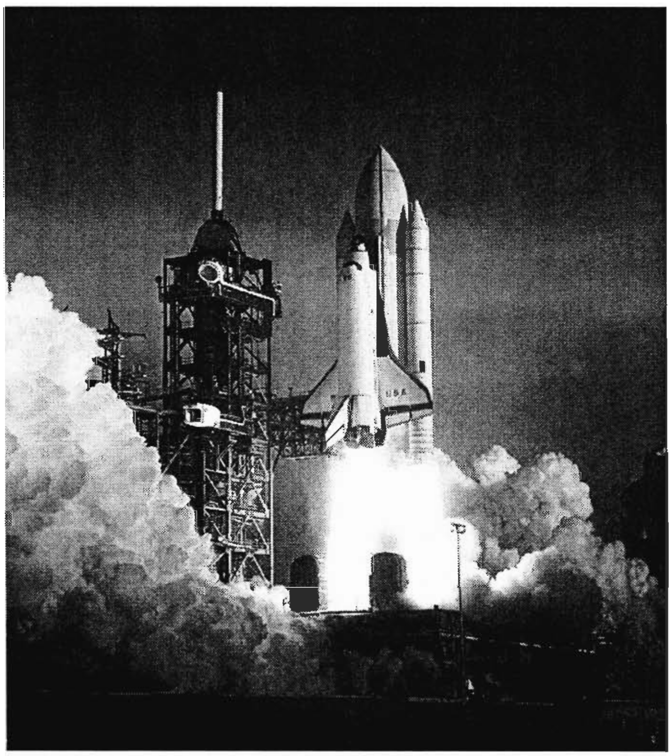

Figure 2: Space Shuttle Columbia in 1981

[3] http://en.wikipedia.org/wiki/Space_Race. Accessed 3/23/06.

Technology

Propulsion

One of the most important aspects of space flight is propulsion. Propulsion for space flight and atmospheric launches functions based upon Newton's third law of motion: for every action, there is an equal and opposite reaction[4]. Simply stated this is the law of conservation of momentum. Momentum is the mass of a body multiplied by its velocity. Momentum is conserved in a system of bodies due to inertia, which is a body's resistance to change in momentum. Space shuttles use this law to propel themselves onward by launching very small particles out the back of the rocket at very high speeds, which cause the rocket to move in the opposite direction at a smaller speed due to its significantly greater mass and inertia. An example of this concept would be a gun; the recoil by the shot is an example of the gun being flung back as the bullet of propelled forward. Larger ammunition generates greater recoil, since it possesses more mass for greater momentum.

Propulsion is not, however, a singular science for the concept of space flight. Since a rocket needs to propel itself against gravity when closer to a planet as opposed to when further away from a planet, or some other sufficiently large body of mass to generate a field of gravity, there are different measures of efficiency for the various stages of space flight. When closer to a large body, an engine which provides more thrust, or force, than an engine which consumes fewer resources per second would be more efficient. This is a result of a greater force of gravity existing when closer to a large body of mass as well as atmospheric resistance, the gasses in the atmosphere impinging the hull of the rocket generating friction, which counteracts a large portion of the force

[4] http://csep10.phys.utk.edu/astr161/lect/history/newton3laws.html. Accessed 3/26/06.

supplied by the engines. If there is too little thrust generated, then the rocket will be dragged towards the attracting body. In distant space, however, an engine which consumes less resources rather than producing more thrust would be ideal. Since the rocket does not need to fight against any other forces acting against the thrust, the engines will be able to obtain a similar velocity with much less force allowing for the potential for much greater fuel efficiency.

Since gravity and weight play a pivotal role in rocketry propulsion, engine efficiency is usually not measured in terms of thrust, as heavier engines would in turn require greater amounts of thrust to achieve similar capabilities. As a result, engine efficiency is generally measured in terms of either exhaust velocity, specific impulse, or the amount of payload that can be lifted at a given cost. The first measure is of limited use due to the same reason that thrust is ineffectual, and the third measure in large part requires the use of many components of specific impulse. As a result, the method of measure which will be discussed in detail will be specific impulse.

Specific impulse is a measure of propulsion which takes into account many factors. The central factors consist of thrust generated by the engine, mass flow rate of the exhaust as it leaves the engine and the gravitational acceleration constant[5]. The first factor, thrust, is a force applied by the engine by accelerating a propellant using a propulsion system in the engine. It is defined in this case as a relation between the mass flow rate and the equivalent velocity. The equivalent velocity of the rocket is a relation between the velocity of the exhaust leaving the engine, the pressure of the exhaust leaving the engine, the pressure of the atmosphere surrounding the engine, and the mass flow rate. The mass flow rate is a relation between the density of a gas, the velocity of the gas and the perpendicular planar area it is moving through. It is a constant value that,

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[5] http://www.grc.nasa.gov/WWW/K-12/airplane/specimp.html. Accessed 4/26/06.

along with the constant density value, shows that as the area through which a gas has to move decreases the velocity of the gas increases. Many engines will utilize this property to rapidly accelerate exhaust leaving the chamber by creating a small path for the exhaust to travel through in the nozzle, then expanding that path to exhibit a larger area for the propellant to move through[6]. Total impulse of an engine is a relation between the force being applied and the change in time in which the force is being applied. The gravitational acceleration constant is equal to 9.8 meters per second squared when near Earth, and is a measure of the acceleration an object experiences towards Earth when in free-fall. Specific impulse is finally defined as the total impulse of an engine divided by that engine's weight as well as the weight of the fuel[7].

Solid-Fuel Engines

Solid rocket engines have been used since before the 19th century, first developed for use in China. In lieu of using simple explosives, solid propellant engines utilize variations of explosives in order to obtain a steady-burning fuel, which will not instantaneously combust upon ignition but instead provide a more steady burn. This allows the engine to possess controlled and sustainable thrust for propulsion[8]. They remain simple and consequently safer, as well as being cheaper to design and implement since there are no intricate parts. The two greatest drawbacks are the lack of any ability to throttle the thrust provided[9], and an inability to stop the engine once ignited. Once a solid-fuel engine has been started, it will continue to burn until there is no remaining fuel. As a result, on the inside of a solid-fuel engine there is often a hole cut out, creating a

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[6] http://www.grc.nasa.gov/WWW/K-12/airplane/mflow.html. Accessed 4/26/06.
[7] http://www.vectorsite.net/tarokt_1.html#m1. Accessed 3/26/06.
[8] http://science.howstuffworks.com/rocket5.htm. Accessed 3/27/06.
[9] http://www.m-w.com/dictionary/throttle. Accessed 4/18/06.

shape related to a pipe on the inside, similar to the shape of an upside-down well as shown in Figure 3.

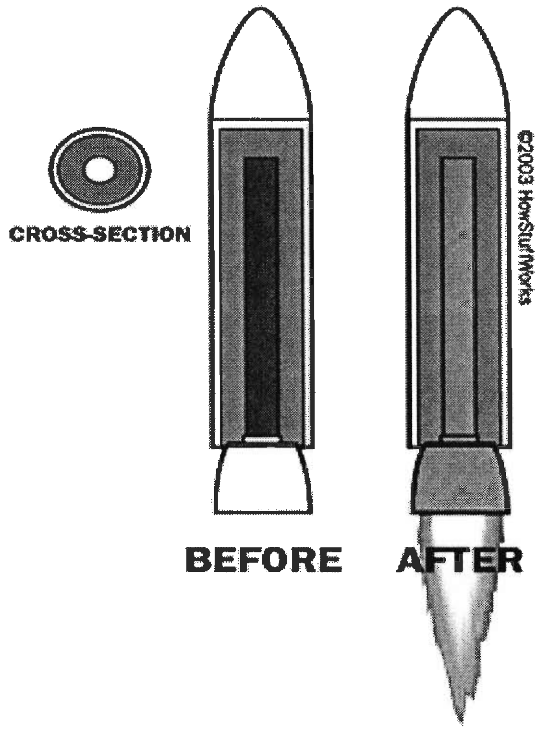

Figure 3: Cross-Section of a Solid-Fuel Rocket[10]

This opening increases the surface area of the solid fuel causing it to burn faster than it would without the cut-out section. Additionally, various shapes can be cut into the opening so that it is no longer round. Various shapes increase the surface area and change the rate that the fuel burns at various stages in the launch so that the thrust provided by the engine increases or, more commonly, decreases at later stages in a launch (Figure 4).

[10] http://science.howstuffworks.com/rocket5.htm. Accessed 3/27/06.

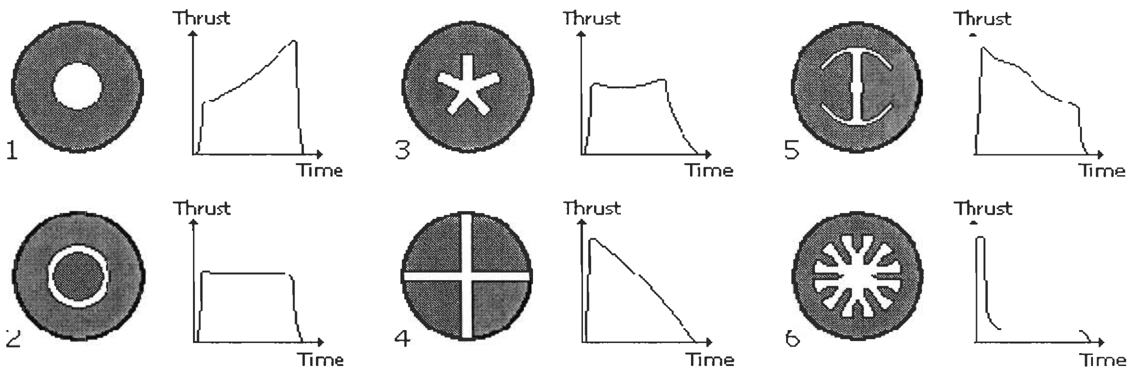

Figure 4: Varying Gemetries of a Solid Rocket Motor[11]

This variation of the geometry of the exposed surface can enable the solid-fuel engines to provide various degrees of thrust for different missions[12]. In addition to the geometry of the fuel, the composition of the fuel also plays an important role in the capabilities of the engine. Most engines contain compounds consisting of a fuel, an oxidizer, and a binding agent to maintain cohesion. In a chemical reaction, many chemicals require an oxidizing agent in order to burn. The chemicals will react with the oxygen in the oxidizer in order to break the chemical bonds of the reactant and release the energy stored in those bonds[13].

Liquid Hydrogen Fuel

Many launch vehicles currently in use utilize liquid-hydrogen as fuel and liquid-oxygen as an oxidizer. The mixture will produce water and large amounts of energy in the form of heat and thrust[14]. First used in the Saturn V and Saturn 1B rockets, as well as the Centaur upper stage, liquid hydrogen engines have been widely used in the main

[11] http://www.braeunig.us/space/propuls.htm#geometry. Accessed 3/27/06.
[12] http://www.braeunig.us/space/propuls.htm#geometry. Accessed 3/27/06.
[13] http://www.qrg.northwestern.edu/projects/vss/docs/Propulsion/2-what-is-an-oxidizer.html. Accessed 3/26/06.
[14] http://www.newton.dep.anl.gov/askasci/chem00/chem00042.htm. Accessed 4/27/06.

booster stages due to their high efficiency. Hydrogen also doubles as a coolant[15]. Specific impulse for hydrogen is roughly a third higher than for most other rocket fuels. As a result, these engines are more controllable and capable of being stopped and restarted.

The main drawback to using liquid hydrogen & liquid oxygen for propulsion is that hydrogen has a very low specific gravity, which is a measure of its density compared to that of water at a specific temperature[16]. It is far below all other gasses and liquids[17]. This is a disadvantage because it requires more space for storage and larger tanks. Since the larger tank is needed, the rocket will weigh more, requiring more thrust to be spent to lift the rocket into space. To reduce the weight of fuel, a mixture ratio other than the one which would provide the greatest total impulse is used. A typical mixture uses more oxygen than optimal for the maximum total impulse.

In addition, to reduce the amount of space needed for storage of fuel, the gasses are launched in a liquid cryogenic state[18]. The problem with doing so is that in order for hydrogen and oxygen to remain liquids, hydrogen needs to remain at a temperature below -183 degrees Celsius, while oxygen needs to remain at a temperature below -252 degrees Celsius[19]. In order to obtain the low temperature, the fuel & oxidizer are pressurized. As the fuel and the oxidizer are consumed, a portion of them evaporate to the gas state until the pressure is equalized.[20]

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[15] http://www.nasa.gov/centers/glenn/about/history/apollew.html#props. Accessed 3/26/06.
[16] http://geology.csupomona.edu/alert/mineral/gravity.htm. Accessed 3/26/06.
[17] http://www.engineeringtoolbox.com/specific-gravities-gases-d_334.html. Accessed 3/26/06.
[18] "The science of producing very low temperatures such as those required for natural gas liquefaction." http://lnglicensing.conocophillips.com/about/glossary/index.htm. Accessed 3/26/06.
[19] http://www.braeunig.us/space/propel.htm. Accessed 3/26/06.
[20] http://www.dunnspace.com/self_pressurized_rockets.htm. Accessed 3/26/06.

Engines Currently in Use

Below is information on several engines which are currently in use.

Rocketdyne Engine

Produced at Boeing Rocketdyne Propulsion and Power in Canoga Park, California, the RS-27A engine is a pump-fed single-start engine. It uses a combination of kerosene (RP-1) as a fuel and liquid oxygen as an oxidizer. The engine provides 890kN of thrust at sea level. The stage contains roughly 96,000kg of useable propellant and can burn for 260s. This engine has not yet failed during a launch.

Aerojet Engine

Aerojet's AJ10-118K liquid-propellant engine propels the Delta series rockets at the second stage of flight. It is able to achieve 43.4kN in a vacuum. Using nitrogen tetroxide as an oxidizer and Aerozine-50 as a fuel, it contains 6006kg of useable fuel and can burn for a total time of 432s. It is able to stop thrust and restart as needed.

Graphite Epoxy Motors

The Alliant Techsystems's GEM-40 motors are additional engines attached to the outside of the vehicle to add thrust. Their name comes from the casing of the motor made of a graphite epoxy. Graphite is used because it is stronger and lighter than aluminum. The engine is able to provide 446kN of thrust at sea level. These motors use hydroxyl-terminated polybutadiene (HTPB) solid as a fuel.

Thiokol Motor

The ATK Thiokol (a branch of Alliant Techsystems) Star 48 motor is a solid motor which is used in the optional third stage of the Delta series expendable launch vehicles. It is able to provide an average thrust of 67.2kN in a vacuum for 84.1 seconds.

It uses a solid fuel which contains HTPB as a binding and can carry up to 2025kg of the fuel.

Power Systems

When on Earth, if a large system needs additional power it can either connect to a large power station, if the system operates in a stationary location, or it can refuel at a nearby facility. In space, however, there are no stations where it is possible to draw power from, and the nearest refueling platform is a fuel-intensive trip back to Earth. Thus, it is vital that a space vehicle is able to provide all of its own fuel and power. This section reviews several types of power systems which are currently being implemented.

Radioisotope Thermoelectric Generators

This type of thermoelectric device converts heat generated during the decay of radioactive isotopes into useable electric energy through the Seebeck effect. The generators contain two dissimilar conductive metals. The two metals are joined into a circuit. When the two connections between the metals are heated and cooled so that they achieve different temperatures, a current is formed according to the difference in temperature between the two joints[21] as shown in Figure 5.

[21] http://chem.ch.huji.ac.il/~eugeniik/history/seebeck.html. Accessed 3/27/06.

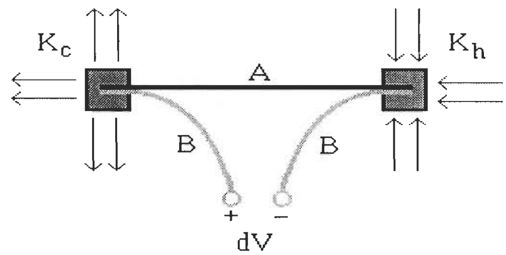

Figure 5: A Representation of the Seebeck Effect[22]

This system is very effective in spacecraft since there are no moving parts; the joints are stationary and the process generates electricity continuously without motion. Although the general design allotted a lifespan of only several years for the generators, they have all exceeded those estimations by large factors of time. The decay of the fuel for the generators has been predictable allowing for accurate estimation of future levels of power. Radioactive thermoelectric generators have proven to be very stable as well as very reliable. As of 2004, there have been no failed launches as a result of a radioactive thermoelectric generator. Although the generators provide a low output of energy they are widely used as backup generators or in satellites which require little operational energy due to their high reliability and their lack of moving parts[23].

Photovoltaic Power Generators

A photovoltaic power system is another name for a solar power generator. These devices use specific properties of semiconductors to generate energy. One difficulty with using photovoltaic generators is measuring their efficiency. Generally the generators are rated according to what power they will deliver when they are new, clean, and provided with bright, continual sunlight, which may not always be feasible. Additionally, the efficiency ratings are only taken from small groups of cells whereas larger blocks of

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[22] http://chem.ch.huji.ac.il/~eugeniik/history/seebeck.html. Accessed 3/27/06.
[23] http://www.ne.doe.gov/space/space-desc.html. Accessed 3/27/06.

photovoltaic cells would incur greater amounts of resistance due to a large number of cells being joined together[24].

Satellites

Satellites are objects which can either hold an orbit around a significantly larger body of mass or can function as probes to return data from a distant location. There are many distinct models of satellites used for a multitude of purposes[25]. The first model of satellite whose effects are most readably noticeable to observers would be communications satellites. Communications satellites are used to return communications signals sent from devices such as cell phones and pagers, and potentially amplify the signals using transponders and rebroadcast it at a new frequency. Another type of satellite used are astronomy satellites. Astronomy satellites are used to record images from space where the satellites are not hindered by atmospheric interference such as clouds or heat, which would cause interference to an infrared imager. A different model of satellite is the reconnaissance satellite, which is used to record images of the Earth for the purpose of spying on foreign countries or geological research. Whatever the purpose of the satellite, however, the systems onboard are largely similar.

Body

There are several important systems that are needed in any type of satellite. The first of these systems is the body of the satellite. This component may seem simple, but since it contains the various sensors and circuitry which constitute the purpose of the satellite, it needs to maintain those systems at a stable level of heat, radiation, and other

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[24] http://www.teicontrols.com/notes/TechCommunicationsEE333T/FinalReport-PhotovoltaicPowerGeneration.pdf. Accessed 3/27/06.
[25] http://collections.ic.gc.ca/satellites/english/index.html. Accessed 3/27/06.

externalities which will interfere with the onboard systems. The satellite body contains a hull which can protect the internal systems from small floating particles and is usually made of a sturdy yet lightweight metal. Another purpose of the body is to protect the satellite from radiation, for which the body will contain a heavy metal, such as lead, which can absorb radiation. The body will also need to provide thermal protection from the extreme temperatures that will be experienced in space, both cold temperatures as well as heat from the sun. Often Mylar is the optimal choice. Finally, there are conductors built into the body of a satellite to draw electrical build-ups away from sensitive areas.

Attitude Control System

An equally important component for a satellite, which is expected to maintain an orbit around the Earth or another significantly large body of mass, is the attitude control system. This serves the purpose of stabilizing the satellite and maintaining it in the orientation the satellite needs to hold in order to perform its function. For example, a satellite designed to analyze Earth would be ineffective if it slowly rotated to orient away from the planet. Generally, this stability is achieved through gyroscopic motion or current-filled rods. A gyroscope is a disk-like object where as much of the mass is distanced from the center as possible. When the gyroscope begins to spin at rapid speeds it generates forces which maintain it in its place, allowing it to act as a stabilizer. In the case of a satellite, the entire body can spin about the center causing the entire spacecraft to act as a gyroscope[26]. In the case of electrically charged rods, the induced currents in the rods surrounding a satellite create a magnetic field around the rods. When the satellite orbits a large body of mass with its own magnetic field, the body's magnetic field creates

[26] http://www.gyroscopes.org/behaviour.asp. Accessed 3/28/06.

a force on the satellite until the magnetic field in the satellite aligns with the body's, holding the satellite steady[27]. Finally, there can be small thrusters onboard the satellite that can be used to hold it in a proper orientation.

Transponders

A satellite transponder is a combination of a transmitter and a receiver. In satellites, they are used to receive signals from the Earth and rebroadcast the signals back to Earth, such as in use for a satellite television network. The satellite will contain a receiver which will pick up the signal, a frequency converter which will allow the satellite to convert the signal to another frequency range, and a transmitter which allows the transponder to broadcast the received signal[28].

Launch Vehicles

NASA employs many launch vehicles, each of which has a unique function. Many launch vehicles are designed and built by contracted companies, such as the Pegasus series rockets which are designed by Orbital Sciences Corporation and the Delta series rockets which are designed by The Boeing Company. There are two types of launch vehicles: expendable launch vehicles and reusable launch vehicles. An expendable launch vehicle is a means of delivering a payload into space where the payload does not need to be returned to Earth within a short period of time. Expendable launch vehicles use a design based upon Cold War and post-Cold War ballistic missiles. Generally consisting of multiple boosters called stages, each stage will propel the rocket upwards until it consumes all of its fuel. Subsequently, the stage will be discarded for the purpose of allowing the next state to become active as well as reducing the weight of the rocket.

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[27] http://collections.ic.gc.ca/satellites/english/index.html. Accessed 3/28/06.
[28] http://www.tech-faq.com/transponder.shtml. Accessed 4/3/06.

Since the various stages of the rocket are discarded during the launch, the weight of the rocket decreases incrementally and less fuel is needed overall. As a result, this form of launch vehicle is the most efficient for delivering payloads into space which will not return to Earth.

The other form of launch vehicle is the reusable launch vehicle (Figure 6). Reusable launch vehicles (RLVs) are designed to be capable of performing multiple types of missions[29]. There are various types of reusable launch vehicles, however they all propel some component of the vehicle into space and back to Earth. Various models contain booster stages which are discarded during launch, such as NASA's Space Shuttle, while others are completely contained within the launch vehicle, such as the Japanese-made Kankoh-Maru[30]. Since RLVs need to return to Earth at the end of their missions, many are designed with wings which allow the vehicles to glide in and approach Earth at a slower rate of decent, conserving the amount of fuel needed to slow the rocket upon reentry[31].

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[29] http://www.spaceandtech.com/spacedata/rlvs/rlvs.shtml. Accessed 4/27/06.
[30] http://www.spacefuture.com/archive/the_jrs_space_tourism_study_program_phase_2.shtml. Accessed 4/27/06.
[31] http://www.spacefuture.com/vehicles/designs.shtml. Accessed 4/27/06.

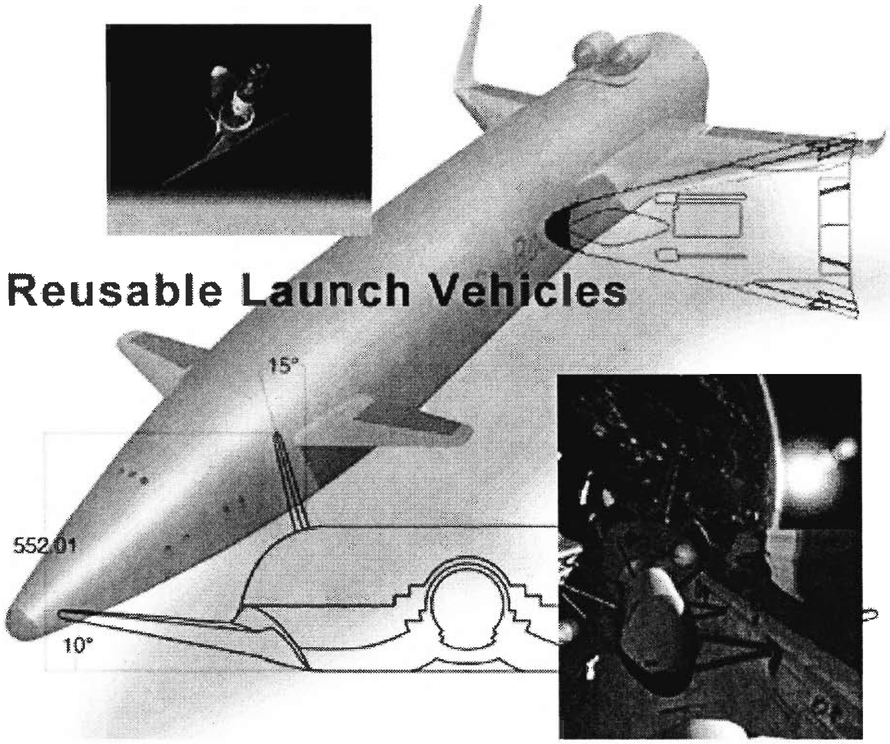

Figure 6: Model of a reusable launch vehicle[31]

Some reusable launch vehicles are designed to launch from a high-altitude flight. The RLV will achieve a high-altitude flight path using conventional jet engines, which themselves are incapable of operation in space. After achieving a desired altitude, the vehicle will launch a smaller component which will then proceed to travel into space and later return to Earth. The first successful example of this model is the combination SpaceShipOne and White Knight, which were produced by Scaled Composites for the goal of winning the Ansari X-Prize[32].

Many different launch vehicles have been used by countries and corporations with active space flight programs. The following sections will detail different launch vehicles used by the United States.

Expendable Launch Vehicles- NASA

[32] http://www.scaled.com/projects/tierone/info.htm. Accessed 4/27/06.

Delta Series

The Delta expendable launch vehicle is based upon the design of the United States Air Force's Thor intermediate-range ballistic missile. It was designed and is built by Boeing Integrated Defense Systems for use by NASA. The Delta Series has performed thirty-one launches, all of which have been successful.[33]

The Delta II is able to launch medium-light payloads into orbit. It is the primary variation of the Delta rocket. It costs between $49-$60 million (FY '94). The Delta rocket is capable of launching multiple payloads at a time using two to three stages. Its first stage consists of a Rocketdyne RS-27A engine, with additional graphite epoxy motors if needed. The second stage uses an Aerojet AJ10-118K engine. The third stage utilizes a Thiokol Star-48B solid rocket motor.

The Delta III model has not been used since August, 2000. The design of the Delta III series began as a result of a need for larger launch vehicles to move heavier satellites into space. Of the three attempted launches using a Delta III expendable launch vehicle only one succeeded. This model was replaced by the Delta IV model.

The Delta IV vehicle was designed to launch medium to heavy payloads. Utilizing the Rocketdyne RS-68 engine for the first stage and the Pratt and Whitney RL10B-2 for its second stage, as well as optional GEM-60 engines as needed, it can launch much greater weights than the Delta II counterpart, up to 12,750kg. The Delta IV Heavy variation on the model contains three common core first stage engines as opposed to the standard single core.

Atlas Series[34]

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[33] http://www.boeing.com/defense-space/space/delta/. Accessed 5/4/06.

[34] http://www.lockheedmartin.com/wms/findPage.do?dsp=fec&ci=14917&rsbci=0&fti=0&ti=0&sc=400. Accessed 3/25/06.

The Atlas launch vehicles contain light, medium, and large-class launch vehicles designed for the Unites States Defense Department and the Unites States National Reconnaissance Office by Lockheed Martin Space Systems (originally developed by General Dynamics). The original design began as an Intercontinental Ballistic Missile (ICBM) for the United States Air Force, until it began supplying the vehicles to the United States National Aeronautics and Space Administration (NASA) for development and use in space. Currently, both NASA and the International Launch Services (ILS) make use of Atlas expendable launch vehicles. Since the lifespan of the series began in 1957, there has not been one failed launch of an Atlas launch vehicle among the series' nearly 600 launches.[35]

The second expendable launch vehicle launched by NASA in 2001 was the Atlas II launched on April 23, 2001. It launched the last of the GOES Project satellites which are currently in space. The Atlas II series is a light launch vehicle, sending payloads of up to 2812kg into a low geosynchronous transfer orbit. It uses the Rocketdyne MA-5A for its stage-and-one-half propulsion system and it can take additional Castor IVA solid rocket boosters for added thrust.

Reusable Launch Vehicles

Space Shuttle- NASA

The United States' Space Shuttle is a reusable launch vehicle designed to be capable of returning to Earth. It is also capable of launching heavy payloads into space. Other roles the Shuttle fulfills are providing a lab for scientific research in space, performing repair operations in space, and returning payloads to Earth[36]. The shuttle

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[35] http://www.ilslaunch.com/atlas/. Accessed 3/25/06.
[36] http://www.hq.nasa.gov/osf/shuttle/overview/index.html. Accessed 4/3/06.

contains an external tank, two solid rocket boosters which are later jettisoned during launch, and an orbiter vehicle which reaches space[37].

The main engines, called the COBRA propulsion system[38], are produced by the Rocketdyne Division of Pratt & Whitney, which was formerly a division of Rockwell International[39] and later a division of Boeing International[40]. This production is accomplished with assistance provided by Aerojet Propulsion Associates. The Space Shuttle Main Engines (SSME) have never failed, and there are upgrades in place since 1998. These upgrades nearly doubled the reliability of the SSMEs by incorporating a system, which cools the engines and reduces the pressure inside the engine chambers. Using a mixture between the fuel, liquid hydrogen (LH_2), and its oxidizer, liquid oxygen (LO_2), the main engines are capable of producing up to 4,450kN of force in a vacuum with a specific impulse of roughly 455s.

The engines operate as a combination of four parts: the pumps, the turbine, a combustion chamber, and a nozzle. The fuel and the oxidizer are driven by two turbopumps, which are also produced under contract with Pratt & Whitney. The turbopumps operate at roughly 20,000kW for the oxidizer pump, while the fuel pump operates at just under 56,700kW of power[41]. The turbopumps drive the oxidizer into the combustion chamber, while forcing the fuel into the nozzle to run up towards the combustion chamber through the engine walls. Since the fuel is stored at extremely low temperatures, and the fuel requires an oxidizer, such as liquid oxygen, the fuel will not ignite in the engine walls and will act as a coolant. This prevents the nozzle of the engine from melting due to the heat generated by the exhaust. The temperature of the exhaust is

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[37] http://www.nasm.si.edu/research/dsh/artifacts/HS-Enterprise.htm. Accessed 4/3/06.
[38] http://www.pratt-whitney.com/prod_space_cobra.asp. Accessed 4/3/06.
[39] http://en.wikipedia.org/wiki/Rockwell_International. Accessed 4/3/06.
[40] http://www.boeing.com/defense-space/space/propul/SSME.html. Accessed 4/3/06.
[41] http://www.pratt-whitney.com/prod_space_turbopumps.asp. Accessed 4/3/06.

high enough to evaporate iron into a gaseous state[42]. After the fuel is routed through the coolant passages, it is redirected to the turbine, which causes the turbines to spin and creates the power required to operate the turbopumps. Following this, the fuel is routed into the combustion chamber where it is ignited along with the oxidizer to create a super-heated high-pressure gas that is then forced out the nozzle[43].

The Reaction Control System (RCS) onboard the space shuttle is a system designed to provide thrust for maneuverability[44]. RCS contains thrusters, valves, fuel, oxidizer, and helium tanks. It is activated through a series of control valves or through a collection of electronic logic gates. The thrusters, usually in four sets of four engines each, are placed at equidistant locations around the perimeter of the spacecraft (Figure 7). Each thruster will activate as a pair with another thruster on the opposite side of the ship to provide stable rotation and movement.

[42] http://www.boeing.com/defense-space/space/propul/SSMEamaz.html. Accessed 4/3/06.
[43] http://www.pratt-whitney.com/how.htm. Accessed 4/3/06.
[44] http://www.ksl.stanford.edu/htw/dme/rcs.html. Accessed 4/6/06.

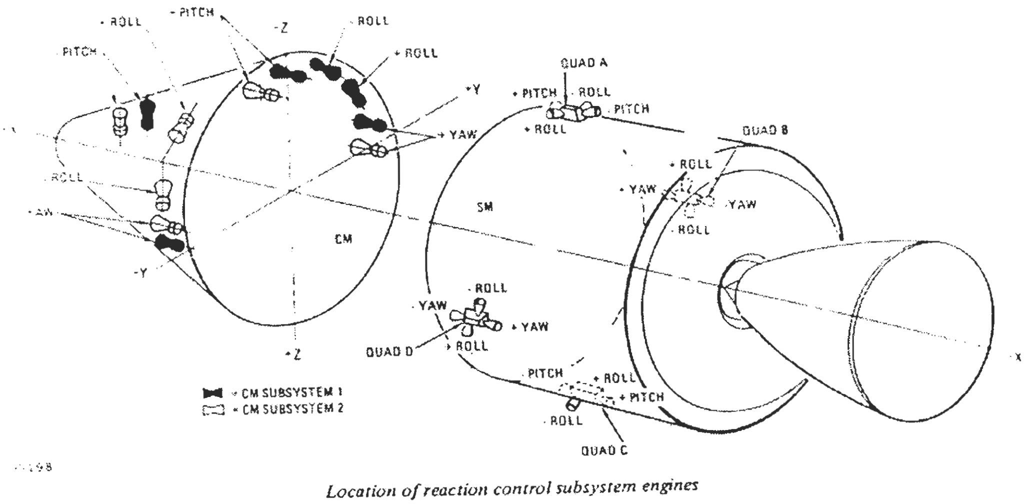

Figure 7: Location of thrusters for the RCS[45]

The thrust from the engines cause the spacecraft to roll, pitch, and yaw. Roll is rotation along the axis piercing the length of the spacecraft. Pitch and yaw allow for rotation of the nose cone away from the axis reaching through the center of the spacecraft (Figure 8).

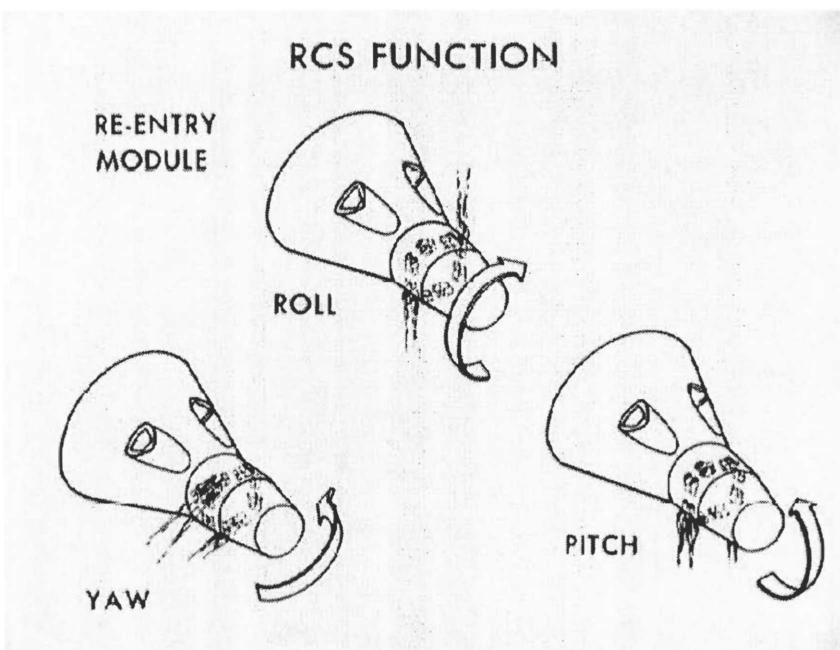

Figure 8: Diagram of RCS response [46]

[45] http://www.apollosaturn.com/asnr/p147a.gif. Accessed 4/11/06.
[46] http://www.apolloexplorer.co.uk/photo/html/gem_ov/10073842.htm. Accessed 4/11/06.

Over the years, the engines have used different fuels and oxidizers. Such examples are monomethyl hydrazine (MMH) and nitrogen textroxide (N_2O_4), as well as a liquid hydrogen-liquid oxygen combination. The helium creates pressure in the tanks which are held closed using valves. When used, a fuel valve is opened 0.002 seconds prior to the oxidizer valve for ignition. The valves are designed to provide the proper ratio of fuel to oxidizer[47]. If the engines become too cold, injector coils must be activated to prevent the oxidizer from freezing.

[47] http://www.apollosaturn.com/asnr/p147-158.htm. Accessed 4/11/06.

International Legal Environment

Overview of Major International Treaties

During the competition of the Cold War, leaders from both the United States and the Soviet Union knew that there would have to be rules about conduct in space so that no situation would escalate into war between the two great superpowers. To help prevent this outcome, the first space treaty was adopted by the UN on the twenty seventh of January 1967.

The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, more commonly known as The Outer Space Treaty, entered into force on October 10, 1967. As of January 1, 2005, ninety eight countries have ratified the treaty and another twenty seven have signed it. This treaty laid the framework for all the other space treaties that have been made. The Outer Space Treaty states that the exploration of space should benefit all mankind, space can not be claimed by any nation nor occupied by one, no weapons of mass destruction should be located in space, astronauts will be treated as ambassadors of mankind, nations are responsible for the activities of their people whether governmental or commercial, and nations will avoid contaminating space. However, as the times begin to change and commercial entities are poised to enter space and governments are planning bases on the moon this treaty is being called into question[48].

Later, additional space treaties were developed and put into effect by the United Nations. The treaty The Agreement on the Rescue of Astronauts, the Return of

[48] http://www.oosa.unvienna.org/SpaceLaw/treaties.html. Accessed 3/23/06.

Astronauts and the Return of Objects Launched into Outer Space, which entered into force on December 3, 1968, was developed to ensure the safe return of astronauts to their country of origin and to prevent a standoff between the two superpowers should an astronaut or cosmonaut land in the opposing county. This agreement gives governments and the commercial space industry the comforting knowledge that in the event of a catastrophe all other nations will help in the rescue of the people and equipment involved. Entering into force on September 1, 1972, the Convention on International Liability for Damage Caused by Space Objects guarantees the reimbursement of losses to a company or government caused by space debris from another government or commercial entity. This eases investors' fears of loosing millions of dollars due to random collision with another's trash. The treaty The Convention on Registration of Objects Launched into Outer Space, put into effect on September 15, 1976, states that all space launches must be registered by the nation that the launch is from. This ensures that all parties, whether commercial or governmental, can obtain information of what is orbiting around our planet and what those orbits are. This helps prevent any accidental collisions that might take place between satellites and space vehicles[49].

The Agreement Governing the Activities of States on the Moon and Other Celestial Bodies entered force in July 1984 when Australia became the fifth nation to ratify the agreement. More commonly known as The Moon Agreement, only eleven nations have ratified and only five nations have signed the document as of January 5 2005. However, the two major space faring nations, the Untied States and the Soviet Union (Russia), have not signed the agreement. The Moon Agreement states that all military force is prohibited on the Moon or any celestial body, the resources of the Moon are the inheritance of all mankind, people should not purposely contaminate celestial

[49] http://www.oosa.unvienna.org/SpaceLaw/treaties.html. Accessed 3/23/06.

bodies, and an international body shall be set up to decide the exploitation of resources on the moon. This agreement has profound affects on the budding commercial space business. As with The Outer Space Treaty, the Moon Agreement outlaws the claiming of property and it claims the resources of space to belong to all mankind. This agreement might discourage future companies from considering operations in space. Fortunately for any country or business planning on attempting to retrieve resources from the Moon or any other body, this agreement has very little power due to the lack of countries that have ratified the agreement[50].

Property Rights

There are many organizations working toward building a base on another celestial body beyond Earth. Whether a company or a government, the people in charge of the base are going to want to use the resources nearby and claim them as their own. Claiming territory directly violates The Outer Space Law. Due to this fact many people view this law as obsolete and in need of revision. Without access to resources it would be difficult for a colony to be self-sufficient and nearly impossible to make it profitable. Without the possibility of profits many commercial entities would not venture into space because it would be a large risk to take. It is clear that before any commercial entity can enter space for profit there needs to be an overhaul of The Outer Space Treaty.

The only place on Earth which could compare to the property rights problem that we are having in space is Antarctica. Due to its remote location and its harsh climate, Antarctica has never been colonized by a nation. As more nations began to explore the continent these nations decided it would be prudent to make a treaty so that no scientific

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[50] http://www.oosa.unvienna.org/SpaceLaw/treaties.html. Accessed 3/23/06.

progress or exploration would be hindered. The Antarctic Treaty was put into force in 1961 and it states, among other things, that no nation may make any territorial claims on the continent. However, there is nothing mentioned in the treaty about private property. As people develop new techniques of gathering minerals from remote areas and in harsh climates, it is plausible that soon in the future people may be able to extract resources from under the many meters of ice that cover Antarctica. When this occurs there will be a need to revamp the current property laws as companies and nations will want to harvest these resources. Any changing of these laws in Antarctica could lead to similar changes in property laws in space[51].

Some believe that like the railroad, telephone, and airplane booms, the space industry needs large commercial involvement supported by the government before it can become profitable and available to many. Solutions to this problem include amending The Outer Space Treaty or even withdrawing from it. However, the political fallout from withdrawing from the treaty would weaken the international standing of a nation and it is unclear how other countries would react to an amendment proposal. Economist Sam Dinkin believes that the United States can use the loophole of "pseudo" property rights to enable companies to extract resources in the same way the United States regulated cell phones today. A "pseudo" property right would be issued to an individual or company by the government of the United States of America, and would guarantee that no other company or individual under the authority of the United States may use the property that is claimed by that right. However these "pseudo" property rights would only apply to the United States and no other nation or company based beyond the United States' borders would be obliged to abide by these rights. However, if multiple nations cooperate to give these rights to companies, these companies may be able to operate without too great a

[51] http://www.antarctica.ac.uk/About_Antarctica/Treaty/treaty.html#Article4. Accessed 3/27/06.

degree of opposition[52]. However nothing like this has been set up in the US or in any other country and the political fallout from setting up a system such as this remains to be seen[53].

Other Influential Space Treaties

In addition to the larger treaties and agreements, the United Nations made a number of principals further defining and reaffirming the aforementioned articles. The Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space, simply put, restates who is responsible for what spacecraft and that any damage caused will be compensated by the nation responsible for the object that caused the damage.

The Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting states that all nations have equal rights to be able to use the broadcasting bands and nations should cooperate so that there is no unwanted interference.

The Principles Relating to Remote Sensing of the Earth from Outer Space states that all nations should seek to cooperate with each other and any sensing of a country should comply with international law.

The Principles Relevant to the Use of Nuclear Power Sources in Outer Space has much relevance to future missions as nuclear power sources become smaller and more reliable. This principal regulates how nuclear powered satellites can operate around the Earth and procedures for reentry of nuclear powered satellites. It also states that any

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[52] Dinkin, Sam. Property Rights and Space Commercialization. May 10th, 2004. Availible at: http://www.thespacereview.com/article/141/1. Accessed 3/23/06.
[53] Listner, Michael J. It's Time to Rethink International Space Law. May 31st, 2000. available at: http://www.thespacereview.com/article/381/1. Accessed 3/23/06.

nuclear plant in space or on a celestial body shall be constructed with enough safety precautions as to limit the risk of a reactor going critical. This again reaffirms that the launching party is to be held responsible should an accident happen.

The final principal is The Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of all States, Taking into Particular Account the Needs of Developing Countries. This declaration only states that nations should strive to help less developed nations obtain access to space. This declaration has no real influence on the space industry.[54]

Many of these treaties greatly influence the space industry and will continue to affect the industry far into the future. These documents ensure order and responsibility by nations and companies because all will be liable should their equipment cause damage or injury to others. The treaties involving resources and property rights will be a problem for the future space industry when people have the technology to harvest resources. There will more than likely be competition between companies and nations when building bases on the moon and other bodies. There is no doubt that revisions in space law are need to avoid confrontation in the future.

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[54] http://www.oosa.unvienna.org/SpaceLaw/treaties.html. Accessed 3/23/06.

Space Regulations

Commercial Launch Regulations

The commercial launch industry is well developed in many parts of the world. Because so many counries and companies want their own satelites in space the commercial launch industry is healthy and growing. To help make sure that these non-government owned launch sites and vehicles will be safe regulations have been imposed by different nations on launches that happen on their territory.

In the United States the regulation of commercial launches falls under the jurisdiction of a subsection of the Federal Aviation Administraton. The Associate Administrator for Commercial Space Transportation, (AST), issues licenses to permitting launches to those who have met their requirements. In order to receive a license to launch, the AST has a long list of criteria that needs to be met. When someone applies for a license the AST makes sure all of the paperwork for the license is in order before checking the rest of the criteria. The AST has to make sure that the launch is in no way conflicting with policy of the United States. They must be sure that the launch will not affect the security of the United States or cause any problems internationally.

The Associate Administrator for Commercial Space Transportation will also conduct a safety review of the entire mission plan. The launch vehicle and its payload must be built with every safety precaution taken to ensure a safe successful launch. The licensee also has to show that none of the public would be hurt or their property damaged in the event of a failure in the launch. In addition the AST checks to confirm that the launch vehicle and payload comply with environmental regulations and make sure there are no unnecessary risks to the environment.

Before the rocket can be launched, the AST will check to make sure that the payload has the required licenses and permits. Without these the AST will not allow the launch of this equipment. The AST will also determine the financial liability of the licensee and any parties involved in the launch. They must be able to prove to the AST that they have the financial means necessary to reimburse any damage that may be caused in the event of a failure of the launch.

After the AST has checked and approved all of the above criteria they will issue a license enabling the launch. While the license is active the AST needs to ensure that these regulations are enforced. The AST assigns monitors that will watch over the program until the vehicle has been launched.[55]

The United Kingdom's licensing program is very similar to that of the United States. The British National Space Centre (BNSC) is the government agency that has been set up to regulate launches within the United Kingdom. The BNSC, like its American counterpart, issues licenses to companies so that they may launch rockets. The Centre ensures that the launch is safe and complies with the international obligations of Great Britain.

In order to obtain a license from the BNSC the applicant must be able to show that the launch will not jeopardize the safety of the people, property and environment. This is ensured by inspections, audits, and testing of equipment by personnel of the BNSC. The licensee must also show the British National Space Centre that he/she is insured against third party claims. This ensures that any damage caused by the launch will be properly reimbursed. The BNSC must also verify that this launch does not breach any international laws or harm the national security of Great Britain. If the applicant

[55] http://ast.faa.gov/. Accessed 4/11/06.

meets these criteria the BNSC will issue a license enabling the applicant to launch their rocket.[56]

Commercial Manned Space Flight Regulations

The commercial manned space flight industry is still in its infant stage. However it may not be all that long until the first company brings tourists into space. The leading space tourism company at the moment, Virgin Galactic, is hoping to begin launches of their new space ship in 2008 or 2009. To keep these passengers and the passengers of any other company safe the FAA is looking into regulations that would help ensure some standard of safety. In 2004 President Bush signed legislation that would make the Federal Aviation Administration (FAA) take a phased approach to the regulation of commercial manned space flight. This phased approach was put in place to help the industry grow fast without too much interference from the federal government. On December 29th, 2005 the FAA released over 120 pages of proposed regulations that would affect manned space flight companies. These regulations focus on requirements for the crew and the passengers of any future space flight.[57]

In these regulations the Federal Aviation Administration puts guidelines on the pilots and the rest of the crew of space ship. The FAA wants the pilot of the future space ships to be required to have a commercial pilot's license. If these requirements are put into effect people with student or sport pilot licenses would not be able to pilot one of these vessels. In addition to the commercial pilots license the pilot would need an instrument flight rating and be able to prove that he or she is capable of understanding

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[56] http://www.bnsc.gov.uk/content.aspx?nid=5974. Accessed 4/12/06.
[57] Irene Mona Klotz. US Export Rules Frustrate Virgin. May 2nd, 2005 http://news.bbc.co.uk/2/hi/technology/4506133.stm. Accessed 3/27/06.

and using the instruments aboard the spacecraft. As for ground controllers the FAA has not decided whether or not they should be required to have a pilot's license. In the relapsed documents the FAA asks for comments on whether or not to mandate pilot licenses for these controllers[58].

In addition to pilot experience the FAA also plans on setting crew health standards. The regulations state that any crewman or remote operator would be required to have a second class medical certificate. A second class certificate lasts for 12 months and is the standard that is required for commercial airline flight crews. However the document also states that the Federal Aviation Administration realizes that it can not predict the stresses that different space ships will inflict on the body and that it will deal with additional health issues on a one-by-one basis by issuing licenses. While undoubtedly costing time and money this license procedure would help ensure that the space vehicle does not apply too much stress on the human body.

The document also states that the crew of the vehicle would have to be trained in a number of safety procedures. This training would include lessons to make sure that the vehicle will not be a threat to the general public. All crew members would also have to be trained in how to react in emergency situations. These trainings would be done using a number of simulations, flight testing, and any other FAA approved training. Pilots would get additional training on how the aircraft prolusion works and how to control it during every stage of the flight. These training programs would have to be certified by the FAA and these training programs would also have to be continuous programs so the crew members stay trained during times between launches[59].

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[58] http://ast.faa.gov/files/pdf/Human_Space_Flight_NPRM.pdf. Accessed 3/27/06.
[59] http://ast.faa.gov/files/pdf/Human_Space_Flight_NPRM.pdf. Accessed 3/27/06.

The Federal Aviation Administration would also require that the spacecraft carrying the passengers and crew members be able to sustain a livable atmosphere. This atmosphere must be able to keep the crew in a functioning condition so they will be able to control the vehicle. This regulation would be enforced by constant monitoring of the conditions inside the spacecraft and the issuing of licenses by the FAA confirming that the spacecraft is safe to fly. The FAA also mandates that there will be backup systems for oxygen and other vital atmospheric control systems to ensure the safety of the crew. The spacecraft will also need redundant systems to ensure that no de-pressurization of the cabin would occur at any time in the flight[60].

Regulations for the passengers are much more lax than those for the crew. The FAA will require that every passenger and crewmember sign a waiver stating that they are fully aware of the risks involved in spaceflight. This consent is required from every passenger that will take the trip into space. The document states that the FAA will not require, but recommends, that passengers have recent physical examinations. Passengers would also be required to be informed how to react to an emergency situation similar to the safety lectures given before a commercial airliner takes off[61].

While these proposed regulations deal with a lot of the human factor of spaceflight, there is very little regulation when it comes to the spacecraft themselves. This is due to the plan signed by President Bush. It allows great freedom for the spacecraft developers so they can help quickly develop this promising industry. Because this industry is only starting there are no other countries that have proposed regulations on commercial space flight yet. However in the future there will probably be standard safety regulations set up in every nation with a commercial space port.

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[60] http://ast.faa.gov/files/pdf/Human_Space_Flight_NPRM.pdf. Accessed 3/27/06.
[61] http://ast.faa.gov/files/pdf/Human_Space_Flight_NPRM.pdf. Accessed 3/27/06.

Commercial Spaceport Regulations

As the launching industry grew and the number of launches per year increased there became a need for privately owned spaceports. As with private launches governments impose regulations on these spaceports to help keep them safe and compliant with the laws of the nation where it is located.

Figure 9: Mojave Spaceport

In the United States commercial spaceports are regulated in approximately the same way that launch vehicles are regulated. In order to operate in the United States the Federal Aviation Administration must issue a license to the spaceport. At the moment there are 5 operating commercial spaceports in the United States. These spaceports are the Mojave Spaceport in California as in Figure 9, the Kodiak Launch Complex in Alaska, Florida Spaceport on Cape Canaveral, the Mid-Atlantic Regional Spaceport in Virginia, and the California Spaceport located with Vandenberg Spaceport. These licenses are good for 5 years and allow the spaceport to conduct a variety of missions. In order to receive a license the owners of the spaceport must prove to the FAA that it meets safety and environmental standards. The spaceport must have appropriate security to ensure that there is no tampering with any of the equipment on the premises. The spaceport must also have appropriate safety measures in place in case of an accident during a launch. In addition to protecting lives and property the spaceport must also have no negative impact on the environment. This enables spaceports to exist where there are endangered or protected animals. Due to these regulations the owners of the spaceports are forced to spend money to comply to the regulations, but without them there would be no way to ensure the safety of the public and all involved[62].

[62] http://ast.faa.gov/. Accessed 4/11/06.

International Cooperation in Space

History of International Cooperation

Space exploration is a massive undertaking that requires vast resources in manpower and funding. Many nations simply do not have or do not want to spend billions of dollars on each mission into space. In order to defray costs and to be able to do missions in space that would not have been done otherwise nations routinely cooperate in space exploration. Many smaller nations and nations that are new to space exploration are using cooperation to help build up experience in space and gain new technologies.

The Cold War made cooperation difficult for the two leading space nations until the final collapse of the Soviet Union in 1991. Despite these tensions the Unites States and the USSR did participate in one joint mission on July 17th 1975 when an American Apollo spacecraft linked up with a Soviet Soyuz spacecraft. However this mission was just a public display to show people that two competing nations can work together. After the collapse of the Soviet Union there has been much cooperation between the two largest space powers. In the mid 1990's there were many Shuttle-Mir dockings and joint experiments that involved crewmen from both nations. The Russian space agency has become poorly funded with the collapse of the USSR and has had to resort to international cooperation in order to continue with manned space flight programs[63].

European nations are industrialized and modernized compared to the rest of the world. However they are fairly small and do not individually have the resources to fund

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[63] Oberg, James. The Real Lessons of International Cooperation in Space. http://www.thespacereview.com/article/413/1 July 18th, 2005. Accessed 3/23/06.

large space programs to rival the United States or Russia. In order to become an active participant in space exploration the European Space Agency (ESA) was formed. The European Space Agency has 17 members which include Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom. In addition the countries of Canada, Hungary and the Czech Republic also participate in some of the missions run by ESA. Founded in 1974 it has its headquarters in Paris and installations in many of its member nations [64]. ESA has been a remarkable success and a perfect example of international cooperation. ESA has launched many successful missions to neighboring celestial bodies and many other projects that have studied the Earth. Without the cooperation of all these countries it is very likely that there would have been far fewer and less expensive projects coming from the European continent[65].

Present Space Cooperation

Today, as more nations gain access to advanced technology, these nations want to have their own foothold in space and have developed their own space agencies. However for many of these nations international cooperation is the only way for them to visit space due to the funding they would need. Many larger, well funded organizations such as NASA and ESA also look to international cooperation to get more missions out of their rather large but finite budget. Also with the end of the Cold War the former republics and allies of the dissolved Soviet Union are now involved in cooperation with the western nations. The following is an overview on how different nations are working together.

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[64] http://www.esa.int/esaCP/GGG4SXG3AEC_index_0.html. Accessed 3/23/06.
[65] http://en.wikipedia.org/wiki/Esa. Accessed 3/23/06.

Russia

With the collapse of the Soviet Union in 1991 Russia inherited many serious problems. The transition to a capitalist economy was extremely harsh leaving the new government with little money. As a result the new Russian space agency (RKA) was left with little in the way of funding. With Mir (Figure 10) absorbing millions of dollars the RKA had to look internationally to help keep itself alive. With the planed Freedom Space Station faltering, the US jumped at the chance to gain valuable experience with space stations from the Russians. In 1993 the Presidents of both countries agreed that the United States and Russia would work together on Mir. Millions of US dollars flowed into the RKA as many Shuttle-Mir dockings took place in the mid to late 1990's[66].

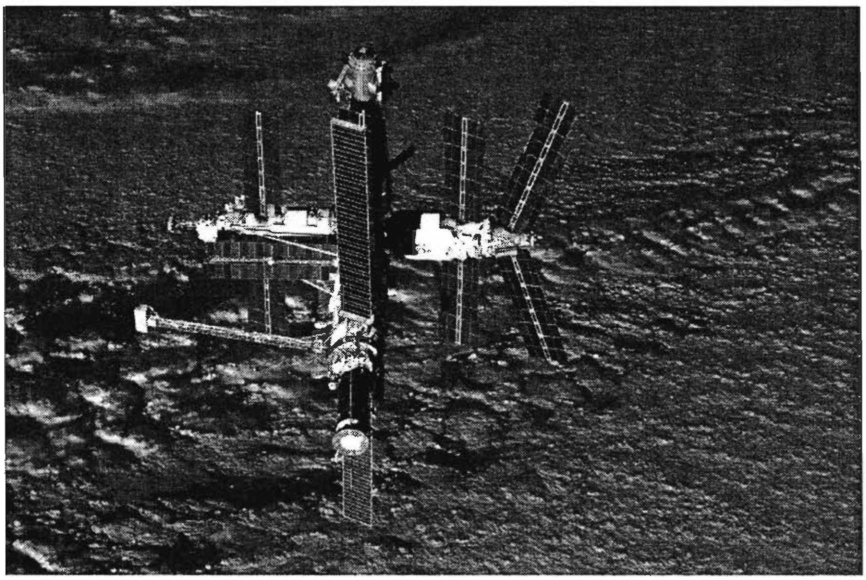

Figure 10: Mir in 1996

However it was taking a lot of money to keep Mir's aging equipment operational and plans for a new space station began to form. In the new global community this space station would be developed by many nations around the world. However Russia and

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[66] Pike, John. Russian American Space Cooperation. http://www.fas.org/spp/eprint/jp_931210.htm. Accessed 3/23/06.

America would have the largest roles in the making and supplying of the new International Space Station (ISS) (Figure 11). After fifteen years of service Mir was de-orbited and burned up in the Earth's atmosphere on March 23, 2001[67]. This allowed Russia and the US to concentrate their efforts on the ISS. In 1998 RKA launched the Russian made Zarya module which was the first part of the International Space Station. With the Columbia disaster grounding the shuttle fleet the RKA has had to take responsibility for re-supplying and delivering crews to the international space station using their Progress transports and Soyuz spacecraft. The United States has been paying its way however, and pays Russia $21 million per person each way for astronauts going to and leaving the ISS and $50 million per Progress flight[68]. Despite this the shuttle is needed to launch other sections of the space station that are not Russian made because other countries have built the sections with the assumption that a shuttle will carry them into space. Despite these setbacks today there is always a Russian cosmonaut living aboard the ISS along with an American or European astronaut.

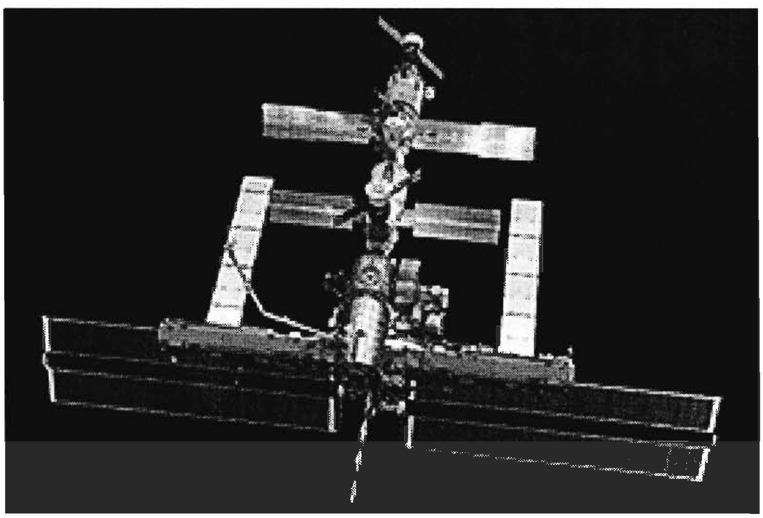

Figure 11: International Space Station

[67] http://www.russianspaceweb.com/mir_2001.html. Accessed 3/23/06.
[68] http://en.wikipedia.org/wiki/RKA. Accessed 3/23/06.

In addition to reaching out to the United States, the Russian space agency also looked to Europe as a partner in space. In 1995 ESA set up a permanent mission in Moscow to help facilitate cooperation between the two agencies[69]. Recently Russia and ESA have agreed to a deal that would allow Soyuz launches to occur from the Guiana Space Center in French Guiana. This would give RKA a second launch site and easier access to lower altitude orbits. The construction of a Soyuz launch platform has begun with the first launch of a Soyuz craft is slated to occur in November 2008. To keep this cooperation healthy the RKA wants the European Space Agency to become involved in the Kliper program. Kliper (Figure 12) is the planned Russian replacement for the aging Soyuz capsule. It is planned to be a small reusable manned spacecraft capable of holding 6 astronauts. During the Paris Air Show in 2005 ESA and RKA announced their cooperation in building the Kliper and ESA has stated that it intends to book at least two seats on every Kliper flight[70]. With the demise of the shuttle in 2010 it seems very likely that ESA and other space agencies will want to book flights with the only other nation that is capable of sending people regularly into space.

[69] http://www.esa.int/SPECIALS/ESA_Permanent_Mission_in_Russia/SEM8IIW4QWD_0.html. Accessed 3/23/06.
[70] Bordonaro, Federico. http://www.isn.ethz.ch/news/sw/details.cfm?id=13412 July 11th, 2005. Accessed 3/23/06.

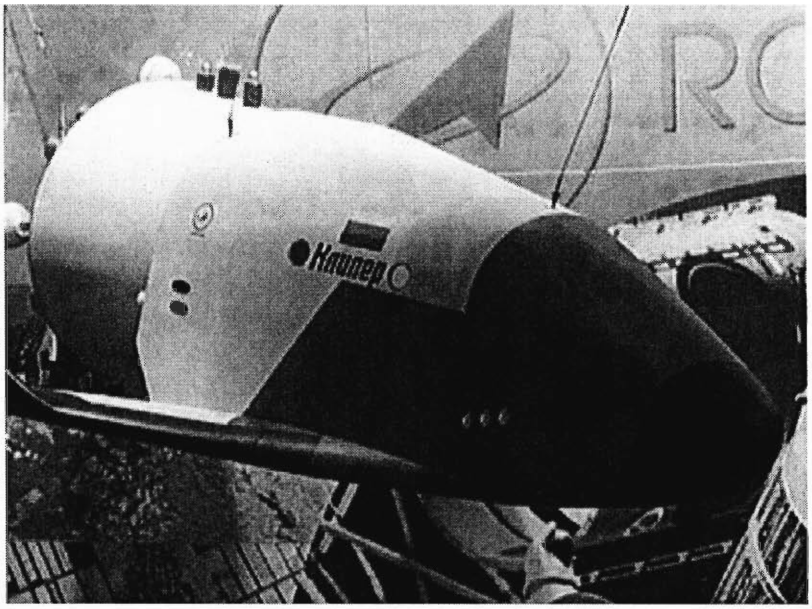

Figure 12: Mockup of the Kliper at the 2005 Paris Air Show

In addition to the two largest space agencies the RKA is attempting to secure funds and cooperation from other sources. China's developing space capabilities has earned itself a close look. Russia and China have both pledged to explore cooperation in large projects such as going to the moon. Unlike all other national space agencies RKA has used tourism to its advantage. On April 28, 2001 Denis Tito became the first space tourist as he visited the ISS for a week. Russia would charge him $20 million for the trip. This same price would be charged to Mark Shuttleworth in 2002 and Gregory Olsen in 2005[71]. The next planned tourist would be the Japanese businessman Daisuke Enomoto and it would cost him the amount of money as the pervious three tourists[72]. As private space companies begin to emerge we may begin seeing more national space agencies cooperate with the corporate world.

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[71] http://en.wikipedia.org/wiki/Space_tourism. Accessed 3/23/06.

[72] http://www.cnn.com/2006/TECH/space/03/07/japan.space.tourist.ap/index.html March 7th, 2006. Accessed 3/23/06.

United States

In addition to the partnership with the RKA, NASA cooperates with almost every space agency in the world. During the Cold War the western nations of Europe and the United States were closely allied against the East so it was natural for NASA and ESA to work together. The first project completed by both agencies was launched in 1978; it was the world's first high-orbit telescope. Since that first successful mission there have been many other deep space and Earth orbiting missions that have been successful collaborations between NASA and ESA. Today NASA still enjoys a strong relationship with ESA even as ESA becomes less dependent on America for its space needs. The European Space Agency has no spacecraft capable of bringing people into space so it has relied on NASA and RKA to secure passage for astronauts into space. Over the past many years NASA has brought many ESA astronauts aboard the shuttle for a variety of different missions. It seems that for the foreseeable future NASA will continue to work with ESA on a number of missions.

In addition to working with the RKA and ESA, NASA is also involved with the Indian Space Research Organization (ISRO) and the Japanese Space Agency (JAXA). Over the past decade the United States and India have steadily become better allies. As a result of this there has been some interest in joint US-India projects involving space. While the ISRO has not been focusing on any manned spaceflight there is possibility of NASA-ISRO cooperation in India's planned Moon probe. However it would be beneficial for NASA to encourage a stronger ISRO that is closely linked with the United States because it could provide additional resources and ideas[73]. The United States and India are planning to reach an agreement that would allow India to launch satellites with

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[73] Dinerman, Taylor. US-India Space Cooperation: the Next Level. November 15th, 2004. Available at: http://www.thespacereview.com/article/269/1. Accessed 3/23/06.

US equipment. This would be a large step forward for future cooperation between NASA and ISRO[74]. While cooperation is still somewhat limited between these two partners there is great potential as India is a rapidly developing country.

The relationship between America and Japan has been a longer and more eventful one. America and Japan have cooperated on a number of unmanned missions and a number of manned missions. Japanese astronauts have participated in a number of shuttle flights in the 1990s and in the 2000s. JAXA is one of the agencies that NASA hopes to increase cooperation with as its budget begins to shrink and the shuttle absorbs millions of dollars. Japan is also an instrumental partner in the International Space Station and will contribute the KIBO module, or "hope" module, once the shuttle is back in operation[75]. In addition to NASA, JAXA has also cooperated with the European Space Agency in satellite to satellite communication missions.

China

China is a relative newcomer to the space industry, but it is a country with great potential. China has the largest population of any country in the world and it is rapidly catching up to the rest of the world in technology. Some experts believe that China has the capability to become the world's next superpower in the coming years. On October 15th 2003 China launched Lang Liwei into space making it the third country capable of putting people into space. This drew international attention from every space agency in the world. However China's political orientation makes it hard for some countries to cooperate freely with China's space program.

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[74] Atkinson, Robson. US and India Set to Make Space Pact. February 16th, 2006. Available at: http://www.nasaspaceflight.com/content/?id=4301. Accessed 3/23/06.
[75] http://www.jaxa.jp/missions/index_e.html. Accessed 3/23/06.

China's space program, which is managed by the China National Space Agency (CNSA), is still in its infant stages so there has not been much cooperation between China and any other nation. Despite this many countries now want to be a part of the growing China space program. However the one country that China would most like to cooperate with has been very hesitant about agreeing to do anything with China, this country is the United States. America is hesitant to cooperate and share technology information with a country that has not signed international non-proliferation treaties and has been accused of human rights violations. New legal rules in the United States called International Traffic in Arms Regulations (ITAR) were designed to prevent military technology from falling into the hands of enemies. However this often hinders cooperation between US and other nations and completely precludes cooperation with China[76]. The Clinton administration refused to discuss space cooperation with the CNSA due to the human rights violations. Even though the Bush administration has been more open to working with the CNSA, there is still much hesitation regarding working with China. After the flight of Lang Liwei, China was hoping for a warmer reception by the United States, which did not materialize. Despite being told that their technology was not mature, China still hopes for cooperation with NASA and in anticipation of such friendship has made their Shenzhou spacecraft able to dock with the International Space Station[77]. In December of 2004 a meeting took place between the heads of NASA and CNSA. While no decisions where reached in this meeting, the fact that a meeting took place at all could help relations in the future[78].

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[76] De Selding, Peter. ESA Looks East for Future Space Cooperation. Available at: http://www.space.com/spacenews/businessmonday_050530.html. Accessed 3/23/06.

[77] Malik, Tariq. US Snubbed China's Offer for Space Cooperation: 'Technology Not Mature'. April 28th, 2004. Available at: http://www.space.com/news/us_china_040428.html. Accessed 3/23/06.

[78] Covault, Craig. The China Card: US Now Agreeable to Space Cooperation with China. March 2nd, 2005. Available at: http://www.spaceref.com/news/viewnews.html?id=1005. Accessed 3/23/06.

Despite its limited progress with the United States China has had remarkable success with almost every other space organization. Many nations are eager to become involved in China's budding space program. The European Space Agency has been looking into China as a possible partner in space exploration as ESA's cooperation with the United States has become more regulated and costly. ESA and China have already cooperated in the successful Double Star Program which will lead to more programs between the two agencies[79].

Canada is another nation that is making an effort to become involved with the CNSA. Canada believes that China's progress has been fast and will continue to be so over the coming years. Canada hopes that this cooperation will invigorate its own space advances. There have already been a number of meetings between the two nations concerning future cooperation plans[80].

Brazil also wants to take advantage of China's new abilities in space. The two nations have cooperated in the China and Brazil Earth resource satellites. In November of 2003 members from the Brazil National Space Administration (BNSA) visited the CNSA to conduct talks about the future of Sino-Brazilian space cooperation. The meeting was a success and ended with the signing of a memorandum stating the future development of joint coordination committee and plans to work closely in the future[81].

Russia also sees a future in cooperating with China. With China's space budget already exceeding that of Russia, it would seem that Russia has a lot to gain from China in terms of funds. In return the RKA can provide the CNSA with experience and technical expertise. Russia has already proposed that the two nations work together in

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[79] http://www.cnsa.gov.cn/english/news_release/show.asp?id=134. Accessed 3/23/06.
[80] Canada Hopes to Strengthen Space Cooperation with China. Available at: http://english.people.com.cn/200510/17/eng20051017_214831.html October 17th, 2005. Accessed 3/23/06.
[81] http://www.cnsa.gov.cn/english/internation_co/show.asp?id=18. Accessed 3/23/06.

any deep space and lunar missions in the future. Due to the fact that the deep space and lunar aspects of the CNSA are still in their infancy there has not been much cooperation between these two nations so far. However, both nations are hopeful that in the future they will be able to work closely together[82].

Over the years international cooperation in space has become more commonplace and an accepted way to get missions done without one agency paying the entire bill. It seems likely that in the future we will see more cooperation between more nations and even companies.

[82] Experts: Sino-Russian Space Cooperation "Beneficial Win-Win." Available at: http://english.people.com.cn/200511/05/eng20051105_219155.html November 5th, 2005. Accessed 3/23/06.

Market Analysis

Space Industry

The Space industry is part of the Aerospace Industry, which is a tremendously large and lucrative sector of the economy. The industry has been undergoing a rapid transition, as traditional players are increasingly challenged by new entrants. This section reviews the players, the role of prices and the development of new commercial spaceports.

Traditional Players

For the 2004 fiscal year, Boeing led the way in the space industry with sales of over 52 billion dollars. Boeing's market niche includes Satellite Manufacturing, Space Components, Launch Services, Launch Vehicle Manufacturing and Ground Systems. Behind Boeing were Lockheed Martin Corp, Raytheon Co., Northrop Grumman Corp., and EADS Space (European Aeronautic Defense and Space Company). These companies had sales of 35.5, 20.2, 29.8, and 3.5 billion dollars each, respectively[83].

Following the top three, in order are EADS, Raytheon, United Space Alliance, Alcatel Space, Science Applications International Corps, ATK and Hughes Network Systems to finish off the top ten. Other notable players included Mitsubishi Electric Corp and Honeywell. This classification includes sales and services for each of the companies. Figure 13 provides some data for the above companies and indicates the categories each company is involved in: Missile Defense, Satellite Manufacturing and/or Space Rocket Companies, Imagery Sales and Service, Launch Services and/or Launch Vehicle

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[83] http://www.spacenews.com. Accessed 11/15/2005.

Manufacturing, Ground Systems and Satellite Services, and Space & Engineering Services/Software. The ranking of the companies is by the 2004 space sales[84].

Rank	Company	2004 Space Sales (in billions USD)	Country	Total 2004 Sales (in billions USD)	Missile Defense	Satellite Manufacturing and/or Space & Rocket Components	Imagery Sales and Service	Launch Services and/or Vehicle Manufacturing	Ground Systems & Satellite Services	Space & Engineering Services/Software
1	The Boeing Company	10,310	USA	52,457	X	X		X	X	X
2	Lockheed Martin Corporation	9600	USA	35,500	X	X		X	X	X
3	Northrop Grumman Corporation	4573	USA	29,853	X	X			X	X
4	EADS Space	3537	Netherlands	3537	X	X	X	X	X	
5	Raytheon	3409	USA	20,200	X	X	X	X	X	X
6	United Space Alliance	2016	USA	2016				X		X
7	Allocated Space	1900	France	1900		X			X	X
8	Science Applications International Corporation	1700	USA	7200	X		X	X	X	X
9	ATK	1238	USA	2832	X	X		X		
10	Hughes Network Systems	1069	USA	1099					X	

Figure 13: Top 10 Companies by the 2004 Space Sales

New Entrants

Over the last decade, a host of new, smaller companies entered the space scene. They have been developing dozens of novel space technologies. This section reviews some of these companies.

[84] www.spacenews.com Boeing, Lockheed Martin Still Atop Space Industry. August 1, 2005. Accessed 11/29/2005.

Scaled Composites

Scaled Composites (SC) of Mojave California was founded in 1982 by Burt Rutan. SC specializes in air vehicle design, specialty composite structure design, tooling, manufacturing, developmental flight test, analysis and fabrication. Burt Rutan is a legend in the aerospace industry. During his career, he has designed unconventional aircraft such as the EZ series and the Beechcraft Starship, and the record breaking Voyager. His Spaceship One allowed the company to win the Ansari X-Prize. Scaled Composites has formed "The Spaceship Company" with Sir Richard Bransons' Virgin Galactic, a subsidiary of the Virgin Group. The Spaceship Company (TSC) is a production company which will build and launch manned suborbital spaceships. SC will develop the new systems which will allow TSC to build the other components for the space vehicles and their support systems. This will all take place at the Mojave Spaceport[85].

Space Adventures

Space Adventures entered the market solely to provide space flight services to paying customers. Created in 1998, it provides everything from Mig 25 sub-orbital flights to participation in Russian missions to the International Space Station. To date, it has put three patrons into space for a cost of 20 million US dollars apiece[86]. Space Adventures has four programs. The first program is the orbital flight experience. To date, Space Adventures is the only company to put a paying civilian into space. The second program will sell suborbital flights aboard XCORs' "Xerus" suborbital vehicle. Licensed flights are slated to begin around 2007/2008. Patrons aboard Zerus will

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[85] http://www.scaled.com/news/2005-12-14_virgin_new_mexico_spaceport.html. Accessed 3/16/2006
[86] http://www.spaceadventures.com/flight/orbital. Accessed 3/16/2006

experience about three minutes of zero gravity for an estimated cost of $98,000[87]. As a prerequisite to orbital flight, Space Adventures offers space-flight training. While the training can be done either as part of an orbital package or separately, there are a number of options available including state-of-the-art simulations and medical screenings. The last two programs are "Space-Related Flight Adventures." A customer can either fly to the edge of space in a Mig-25, or go for a parabolic flight aboard the IL-77 MDK, a Russian Military transport aircraft[88].

XCOR

XCOR does not intend to focus solely on space tourism. It intends on entering the markets of microsatelite delivery, and suborbital payload delivery. XCOR will build Xerus which will have several versions for each of these markets.

Xerus is much like a conventional airplane in that it takes off and lands on a runway (see Figure 14 and Figure 15). However, once to an altitude of 65 kilometers (km) the vehicle will coast to an altitude of 100 km achieving a velocity of approximately Mach 4 (about 1400 meters per second). The vehicle will then glide back to the runway for a landing. Figure 16 depicts the suborbital payload delivery version of the vehicle. Figure 17 shows a possible microsatelite delivery system attached to the top of Xerus.

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[87] http://www.spaceadventures.com/company. Accessed 3/16/2006.
[88] http://www.spaceadventures.com/steps/zerog. Accessed 3/16/2006.

Figure 14: Xerus

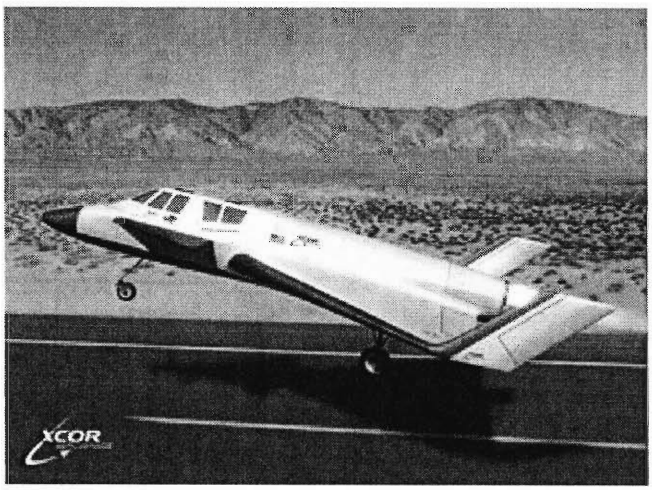

Figure 15: Xerus Landing Configuration

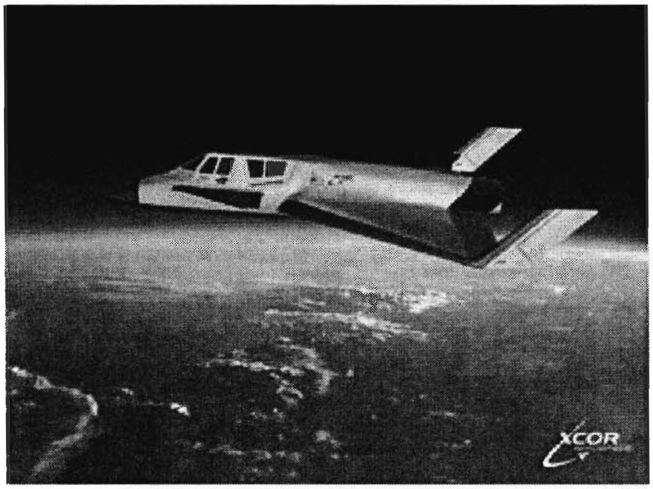

Figure 16: Xerus Payload Configuration

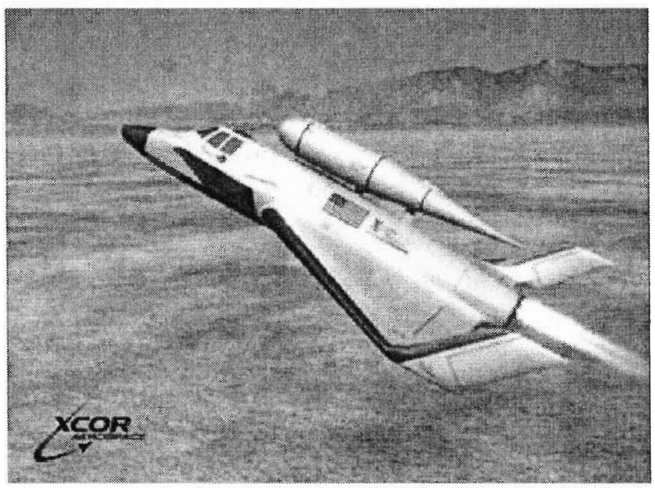

Figure 17: Xerus Micro-satellite Delivery Configuration[89]

t/Space

Transformational Space, or t/Space, was recently founded in 2004 in response to NASA's plans to implement the President's Vision for Space Exploration. Transformational Space was one of eight winners in NASA's "Concept Exploration and Refinement" competition. The goal of the competition was to advise NASA on the best architecture for Moon-Mars exploration and the best initial design for the Crew Exploration Vehicle (CEV). The competition started in August 2004 with a $3 million

[89] http://www.xcor.com/suborbital.html. Accessed 3/16/2006.

contract that was extended in March 2005 with another $3 million[90]. Transformational Spaces' idea for the CEV is that it will carry four crew members to the International Space Station (ISS) or other Low Earth Orbit (LEO) destinations for less than $20 million per flight (see Figure 18). Also in league with Scaled Composites, t/Space has recently test dropped experimental "dummy boosters" which used newly developed techniques to allow for safer air-launch trajectories[91].

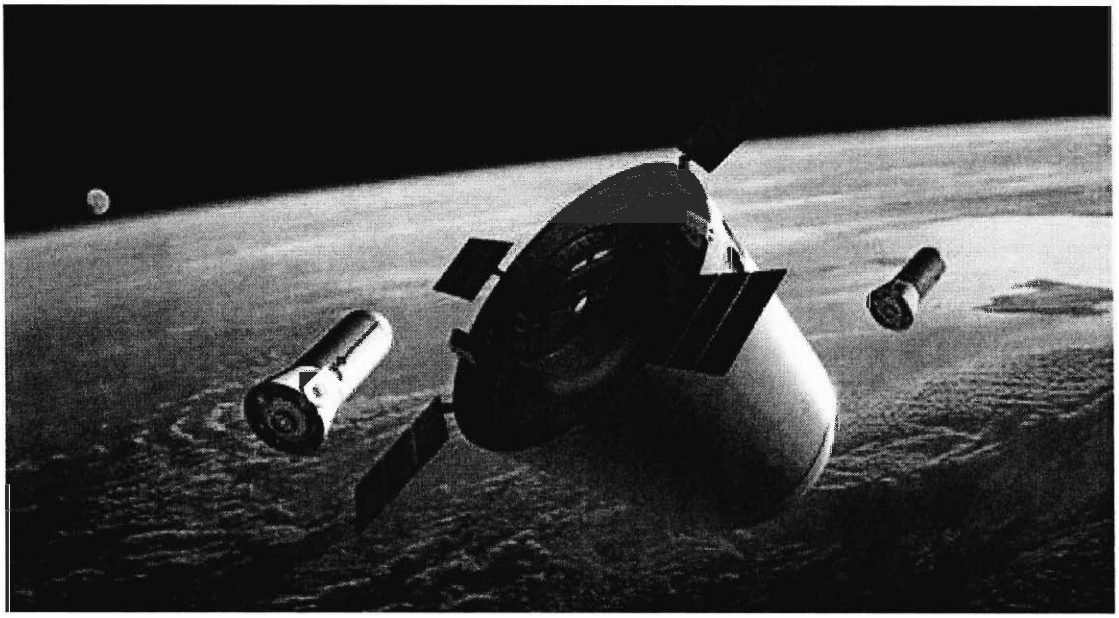

Figure 18: CEV

Starchaser

Starchaser, an English company, was founded in 1992 by Steve Bennett, who is its President and CEO. Starchaser specializes in development, operation and commercialization of space related products and services. Following a motto "one step at a time," Starchaser takes a different approach to the space industry than the companies previously mentioned. In fact, the approach taken by Starchaser is much more akin to

[90] http://www.transformspace.com/. Accessed 3/17/2006.
[91] http://www.transformspace.com/index.cfm?fuseaction=projects.view&workid=CCD3097A-96B6-175C-97F15F270F2B83AA. Accessed 3/17/2006.

that of Boeing, Lockheed Martin and the others at the top of the industry food-chain. Although Starchaser competed in the Ansari X-Prize, their traditional projects include sounding rockets, reusable launch vehicles and Bi-Lquid rocket engines such as the Churchill Liquid Oxygen/Kerosene MK-1, 2, and 3 engines (see Figure 19)[92].

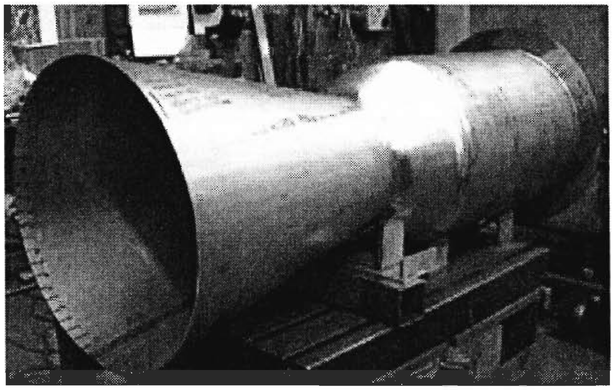

Figure 19: MKII Rocket Engine

Amroc & SpaceDev

Other American companies such as American Rocket Co. (Amroc) and SpaceDev, which bought rights to Amroc in August 1998, seek to provide specific component development to companies such as Scaled Composites and Space Adventures. For example, SpaceDev developed the rocket propulsion technology for Spaceship One. SpaceDev also develops microsatelites, and nanosatelites[93]. A ten year plan for SpaceDev is described in Figure 20.

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[92] http://www.starchaser.co.uk/. Accessed 3/16/2006.

[93] http://www.spacedev.com/newsite/templates/subpage3.php?pid=53&subNav=11&subSel=2. Accessed 3/16/2006.

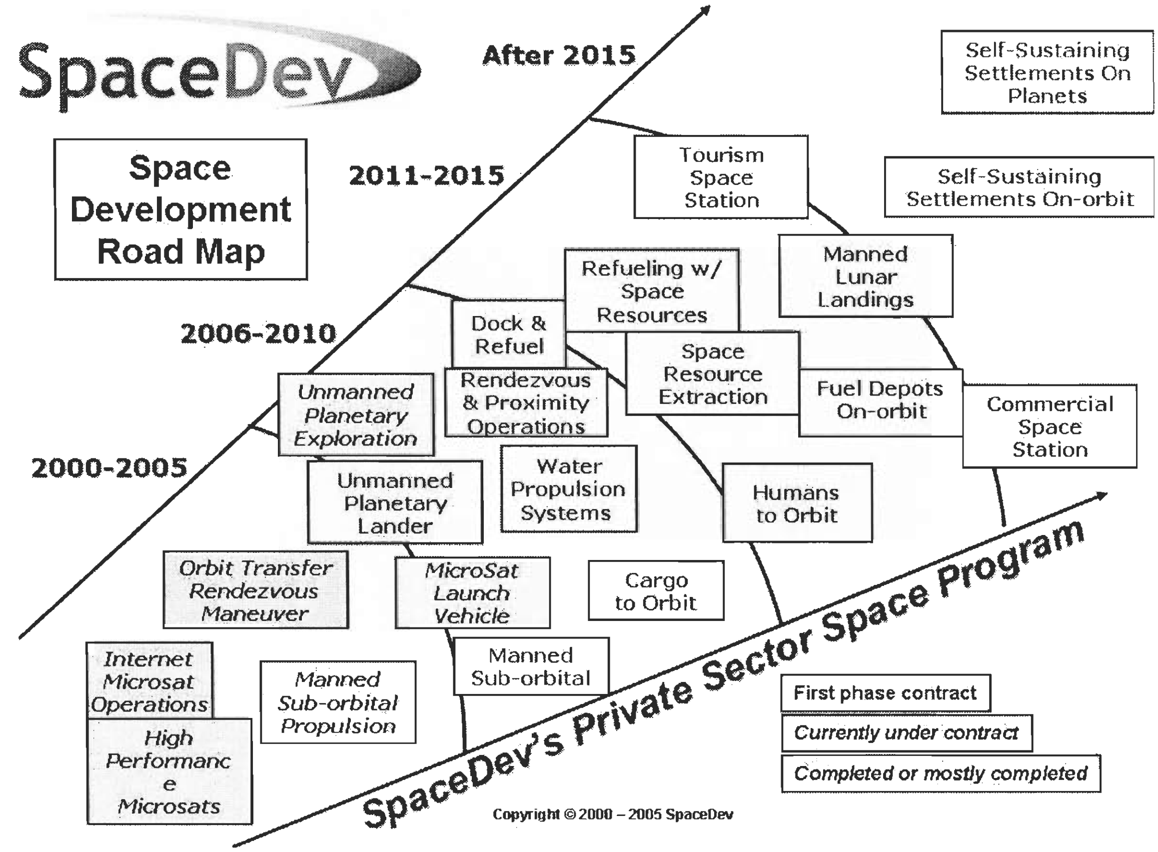
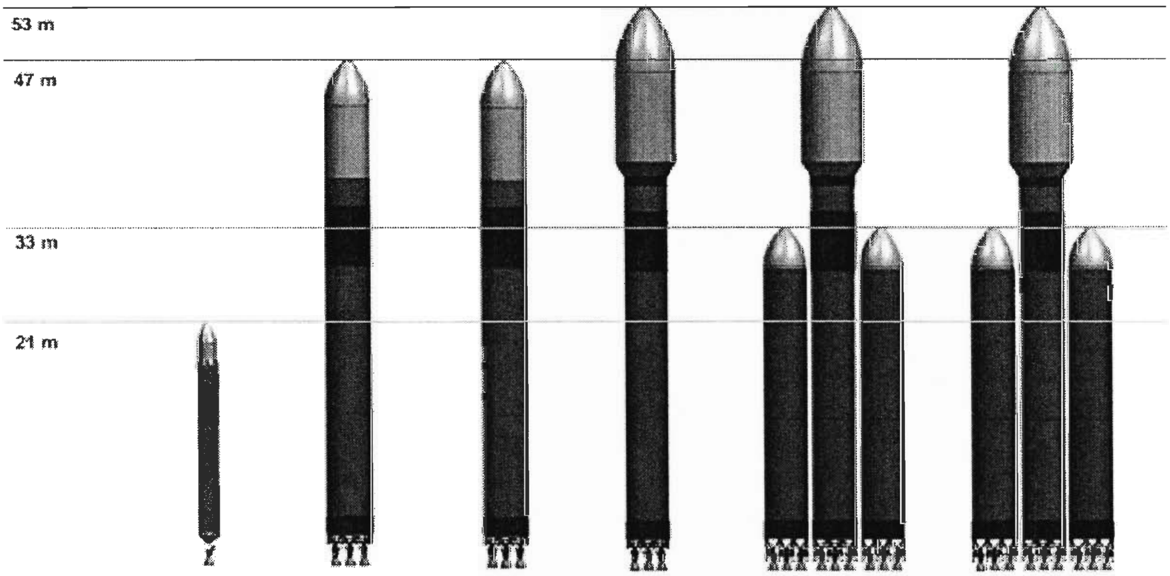


Figure 20: SpaceDev Road Map

SpaceX

Space Exploration Technologies, or SpaceX, was started by internet pioneer Elon Musk in June of 2002. While not taking a typical or even traditional approach to the rocket and space industry, Musk demands attention. Having made his riches on start-up internet companies like Zip2 Corps in 1995, which was bought in 1999 by Compaq Computer Corps for $307 million, and then co-founding PayPal which was bought by Ebay in 2002 for $1.5 billion, Mr. Musk can afford to do things most other space pioneers cannot. He invested approximately $100 million dollars of his own money into the company[94]. SpaceX plans to launch the first "low-cost" rocket into space in the later half of March 2006. This first launch is of the Falcon 1 rocket. The Falcon 1 has the world's lowest cost per flight to orbit of any production rocket. Falcon 5 and Falcon 9 will offer the lowest cost per unit mass to orbit. For customers with payloads between the capabilities of Falcon 1 and 5, a half bay flight of Falcon 5 is available at $9 million[95]. Figure 21 and Figure 22 illustrate SpaceX's fleet with costs and dimensions and intended flight schedules.



	Falcon 1	Falcon 5	Falcon 9	Falcon 9	Falcon 9 - S5	Falcon 9 - S9
LEO	570 kg	4,100 kg	9,300 kg	8,700 kg	16,500 kg	24,750 kg
GTO	--	1,050 kg	3,400 kg	3,100 kg	6,400 kg	9,650 kg
Fairing diameter	1.5 m	3.6 m	3.6 m	5.2 m	5.2 m	5.2 m
Price in millions *	$6.7	$18	$27	$35	$51	$78

* Prices are all inclusive of launch range, third party insurance and standard payload integration costs.

Figure 21: Falcon Series

[94] El-Hansens, Muhammed. "Entrepreneurs Engage in Rocket-Ruled Competition." Copley News Service January 4, 2006. Accessed 3/16/2006.
[95] http://www.spacex.com/. Accessed 3/16/2006.

Customer	Launch Date	Vehicle	Departure Point
US Defense Dept (DARPA)	Q1 2006	Falcon 1	Kwajalein
US Defense Dept (OSD/NRL)	Q2 2006	Falcon 1	Vandenberg
Malaysia (ATSB)	Q4 2006	Falcon 1	Kwajalein
US Government	Q2 2007	Falcon 9	Kwajalein
Bigelow Aerospace	Q1 2008	Falcon 9	Kwajalein
SpaceDev	Q2 2008	Falcon 1	Vandenberg
MDA Corp.	Q3 2008	Falcon 1	Vandenberg
Swedish Space Corp.	Q4 2008	Falcon 1	Vandenberg
US Air Force	$100 million contract thru 2010	Falcon 1	TBD

Figure 22: SpaceX Launch Schedule

Kistler Aerospace

Kistler Aerospace Corp. acquired RocketPlane Ltd on Febuary 27 of 2006, to form a new subsidiary Rocketplane Kistler (RK). Creator of the reusable K-1 aerospace vehicle, Kistler hopes the K-1 will be a marketable alternative to high cost single use launch vehicles (see Figure 23).

Figure 23: K-1 Aerospace Vehicle

According to RK's website, the K-1 is becoming the industry leader in reliable, low-cost provider of launch services for commercial, civil, and military payloads destined for Low Earth Orbit (LEO), Medium Earth Orbit (MEO) and Geosynchronous Earth Orbit (GEO), as well as to and from the International Space Station (ISS). Orbital flight tests and commercial operations will be conducted from RK's commercial spaceport at Woomera, Australia, and performed by Kistler Woomera and Spaceport Woomera, wholly owned Australian subsidiaries. An additional commercial spaceport is planned within the USA[96].

Regional Analysis

Throughout the world, historically governmentally controlled space agencies, exercised nearly complete control over regional space programs. National agencies are realizing, however, that their budgets cannot support massive space plans. However private companies in designing, implementing and launching low-cost launch vehicles, communications satellites, and various other technologies are extremely appealing to national agencies. For example, NASA's current budget is $16.2 billion and has averaged for the last decade between $14 and $15 billion. The cost of the International Space Station (ISS) has been over $100 billion and that has taken over 20 years. Reaching the Moon, and then Mars by 2030, according to President Bush's Vision for Space Exploration (VSE), will most likely cost at least $500 million[97]. Therefore, not unlike earlier in history when private dollars supplemented government dollars in the development of the airline industry in the US, the National Automobile Program of the early 1900's, and the National Railroad program of the later half of the 1800's, these

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[96] http://www.kistleraerospace.com/index.html. Accessed 4/11/2006.
[97] Caeres, Marco. "Creating a Space Exploration Industry." American Institute of Aeronautics and Astronautics, August 2005. Accessed 11/15/2005.

programs did not wither and die, but instead grew and prospered[98]. These programs will be the benchmark for the growing space market as it becomes more decentralized.

Small space-related companies and their trade organizations are also gaining momentum in Europe. For the last half decade, small organizations are banding together to become represented by Regional Aerospace Associations (RAAs). While these groups include companies whose scopes are beyond that of this inquiry, their actions are setting a benchmark for other companies focused on the space industry. In many parts of Europe, increasing financial resources are flowing to Local Developmental Agencies (LDAs). LDAs are generally the main funding sources of RAA activities. With this, RAAs are gaining bargaining power and forming their own contracts, partnerships and research and development (R&D) programs[99].

EURADA, the trade association of European regional development agencies, says that "Regions – and especially 'average' regions – need to make strategic choices and focus the bulk of their effort on science with a bearing on the regional socioeconomic fabric while clearly mapping out their future[100]." Clearly, the role of smaller companies especially in Europe, and the organizations they belong to are becoming more and more powerful, and will make much more of an impact on the space industry than in prior years.

In France, the government has recently announced a new policy, dubbed "competitive clusters," in which companies in certain industries will be encouraged to develop and relocate to areas of France so that they are close to each other. A proposed 1.5 billion euro has been allocated to support this program for the first three years. Other

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[98] Caeres, Marco. "Creating a Space Exploration Industry." American Institute of Aeronautics and Astronautics, August 2005. Accessed 11/15/2005.
[99] Butterworth-Hayes, Philip. "Europe Boosts Regional Support for Aerospace." American Institute of Aeronautics and Astronautics, November 2005. Accessed 11/29/2005.

support will be given in the form of social measures and tax incentives[100]. Similar programs have been planed and initiated in Hawarden, Wales.

Even though Canada's current space budget is only $300 million, its space industry is growing with each year. In 2005, sales were up 22 percent to $2.4 billion. Canadian technology was used on the recent Discover shuttle mission. This was done with the robotic, Canadian built "Canadarm" to check the more than 20,000 heat-resistant tiles covering Discovery[101].Without dramatic increases in funding, the Canadian Space Agency will most likely be assisting other larger agencies such as NASA, and the China National Space Administration.

With one of the fastest growing space programs around, China is also making astounding progress into space. With plans of launching 100 satellites and landing an unmanned ship on the moon and bringing it back within the next ten years, China may well become the second leading space power[102].

Japan also has a fast growing space program with high goals. Combined with the pressures from the ambitious Chinese space program and President Bush's Vision for Space Exploration announcement, Japan has rushed to announce its own: JAXA 2025 vision. This program has five distinct goals described in Figure 24.

[100] Butterworth-Hayes, Philip. "Europe Boosts Regional Support for Aerospace." American Institute of Aeronautics and Astronautics, November 2005. Accessed 11/29/2005.
[101] Deruyter, Ron. "Space Awaits Canada, Garneau Says." Toronto Star Newspaper. October 28, 2005. Accessed 2/23/2006.

The Vision

1. **To build a secure and prosperous society through the utilization of aerospace technology**
    - Establishing a system for natural disaster management
    - Establishing a system for global environmental issues
2. **To prepare for the unraveling of the mysteries of the universe and for lunar utilization, in order to seek the origins of the Earth and humankind**
    - Turning Japan into the world's leading science center through experiences of space observation and asteroid exploration
    - Establishing technologies for future lunar utilization
3. **To implement world-class space transportation and Japan's indigenous space activities**
    - Establishing space transportation systems, such as launch vehicles and orbital transfer vehicles, with the greatest reliability and competitiveness in the world
    - Establishing technologies for future lunar utilization
4. **To develop aerospace as Japan's next key industry**
    - Promoting the space industry as Japan's key industry of the future
5. **To establish Japan's aviation industry and develop supersonic aircraft**
    - Reviving aircraft manufacturing as a key industry in Japan
    - Demonstrating the technologies for hypersonic aircraft that can cruise at Mach 5 speed across the pacific Ocean within two hours

Figure 24: JAXA's Five Goals

From these goals, it can be seen that Japan does not want to be left behind. However, Japan does not believe it has the capabilities to match national space programs of China, ESA and the United States. As such, the program focuses on research, an activity that Japan has succeeded at in other markets such as electronics[102].

The Russian space program experiences similar budgeting constraints as the American program. Recently, Russia and Ukraine formed an international company called Kosmotrans to help keep Ukraine's space industry from withering. This company

[102] http://www.jaxa.jp/2025/index_e.html. Accessed 4/11/2006.

aims to promote launching of a converted Satan (RS-20) rocket. Launching this rocket involves the use of the Ukraine built Zenit rocket, and a partnership between Russia, Ukraine, Kazakhstan, and the international Sea Launch project[103].

Current Trends

Space Races and Prizes

Entrepreneurs as well as NASA have turned to the prize competitions in an effort to foster development of the new space technologies. On October 4, 2004, Scaled Composites won the Ansari X-Prize. Peter H. Diamandis, chairman of the X Prize Foundation said this about the competition:

> By creating the first private race to space, the X PRIZE Foundation gave birth to a new industry with dramatic technological, social and investment opportunities. As a result of the dramatic nature of this achievement, the X PRIZE is now widely recognized as the leading model to foster innovation. The X PRIZE model is very unique. Rather than awarding money to honor past achievements or directly funding research, the X PRIZE spurs innovation by tapping into our competitive and entrepreneurial spirits. We are now evolving the X PRIZE Foundation into a world-class prize institute to create additional radical breakthroughs for the benefit of humanity. We are actively researching the feasibility of new prizes in space, energy, genomics, education, nanotechnology, and prizes in the social arena.

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[103] Zaitsev, Yuri. "Outside View: Squeezing Ukraine in Space." UPI, December 16, 2005. Accessed 2/23/2006.

> Our goal is to look at creating breakthroughs in these fields in the same fashion that we helped drive the spaceflight industry. Put simply: offer a large enough cash prize with a well thought out set of rules, and you will achieve a solution. This is the leverage that an 'X PRIZE' provides. We would be honored if you would consider continuing your support of our mission[104].

The competition itself was modeled after the Orteig Prize which was awarded to Charles Lindbergh for being the first to cross the Atlantic non-stop from New York to Paris in 1927. The X Prize competition was announced on May 5, 1996 in Saint Louis in honor of Al Shepard's 1959 flight in the Freedom 7 spacecraft. A total of twenty six teams from seven nations competed in the competition[105].

The Bigelow Aerospace's "America's Space Prize" is a 50 million dollar award for the first team to meet the rules of the competition by January 10, 2010. There are just ten stipulations to the competition; however it is their depth that will require new thinking and technology. The first is that the spacecraft must reach an altitude of 400 km and secondly that it completes two full orbits before returning to Earth. Other demanding features include a requirement to carry at least 5 crew members, and complete two orbital missions in a period of sixty days. No government funds can be used for funding of any kind, and the team or contestant must be "domiciled" in the US[106]. Figure 25 summarizes various prizes.

NASA's support for space prizes is increasing as well. The "Centennial Challenge" Program is a series of prizes for numerous space-related contests. Not all contests deal with space vehicles, but some have to do with other transport technologies

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[104] http://www.xprizefoundation.com/index.asp. Accessed 2/25/2006.
[105] http://www.xpcup.com/index.cfm?goto=about_us.aboutansarixprize. Accessed 2/25/2006.
[106] http://www.bigelowaerospace.com/prize.html. Accessed 2/25/2006.

such as a space tether. In regard to the purpose, NASA states “instead of proposals, Centennial Challenges seeks novel solutions to NASA's mission challenges from non-traditional sources of innovation in academia, industry and the public[107].” Figure 26 describes briefly each current challenge, the allied organization, and the proposed prize.

[107] http://exploration.nasa.gov/centennialchallenge/cc_index.html. Accessed 4/11/2006.

Race Name	Start Date	End Date	Mission	Prize Value	Winner
Ortig	1919	05/21/1927	Fly non-stop from New York to Paris[108]	$25000 (in 1919 dollars)	
Ansari X-Prize		10/04/2004	Build and fly a spacecraft capable of carrying three people to 100 km and then within two weeks repeated the flight to win[109].	$10 Million	Scaled Composites/Paul Allen "Space Ship One"
Americas Space Race		1/10/2010	Launch 5 people aboard a privately funded vehicle to an altitude of at least 400 km and complete 2 orbits. The vehicle must also complete this again within 60 days[110].	$50 Million	
Cheep Access To Space (CATS) Prize	November 1997	11/08/2000	Launch a 2 kilogram payload into space, 200 km or higher, by November 8, 2000, using a privately-developed launch vehicle[111].	$250,000	None
V-Con Space Prize		10/22/2004	Using Microsoft Flight Simulator 2002/2004 or X-Plane, design and launch a rocket or airplane like vehicle, with and necessary launch systems to an altitude of 62 miles[112].	Web Trophy, $50	Team Apex
Heinlein Prize			The purpose of the Heinlein Prize is to encourage and reward progress in commercial space activities that advances their dream of humanity's future in space[113].	$500000, a Medallion and a Diploma	

Figure 25: Prize Summary

[108] http://www.charleslindbergh.com/plane/orteig.asp. Accessed 2/25/2006.
[109] http://www.xpcup.com/index.cfm?goto=about_us.aboutansarixprize. Accessed 2/25/2006.
[110] http://space.com/spacenews/businessmonday_bigelow_041108.html. Accessed 2/25/2006.
[111] http://www.space-frontier.org/Projects/CatsPrize/. Accessed 2/25/2006.
[112] http://www.space-frontier.org/Projects/CatsPrize/. Accessed 2/25/2006.
[113] http://www.heinleinprize.com/. Accessed 2/25/2006.

Challenge Name	Allied Organization	Rules*	Challenge Date	Status	Winner/Purse
2006 Astronaut Glove Challenge	Volanz Aerospace Inc./Spaceflight America *(non-NASA link)*	-	Mar 2007	open	TBD/$250k
2006 Beam Power Challenge	The Spaceward Foundation *(non-NASA link)*	rules *(non-NASA link)*	Aug 4-6, 2006	open	TBD/$200k
2005 Beam Power Challenge	The Spaceward Foundation *(non-NASA link)*	-	Oct 21-23, 2005	complete	None/$50k purse combined with 2006
Moon Regolith Oxygen (MoonROx) Challenge	Florida Space Research Institute (FSRI) *(non-NASA link)*	rules *(non-NASA link)*	Jun 1, 2008	open	TBD/$250k
Personal Air Vehicle Challenge	CAFE Foundation *(non-NASA link)*	rules *(non-NASA link)*	Jun 2006	open	TBD/$250k
2007 Planetary Unmanned Aerial Vehicle Challenge	California Space Education and Workforce Institute *(non-NASA link)*	-	Oct 2007	open	TBD/$250k
2006 Regolith Excavation Challenge	California Space Education & Workforce Institute (CSEWI) *(non-NASA link)*	rules *(non-NASA link)*	Oct 2006	open	TBD/$250k
2008 Telerobotic Construction Challenge	Spaceward Foundation *(non-NASA link)*	-	Late 2008	open	TBD/$250k
2007 Telerobotic Construction Challenge	Spaceward Foundation *(non-NASA link)*	-	Aug 2007	open	TBD/$250k
2006 Tether Challenge	The Spaceward Foundation *(non-NASA link)*	rules *(non-NASA link)*	Aug 4-6, 2006	open	TBD/$200k
2005 Tether Challenge	The Spaceward Foundation *(non-NASA link)*	-	Oct 22, 2005	complete	None/$50k purse combined with 2006

Figure 26: NASA's Centennial Challenges

Spaceports

Another trend that is starting to spread is the idea of a spaceport. Simply put, this is a glorified airport for the sole use of space bound vehicles. Several are being planed in the United States, most notably the New Mexico Spaceport. Others are being planned around the world including in the United Arab Emirates and in Singapore and Japan.

In the US, the most famous spaceport is in New Mexico. In December of 2005, Virgin Galactic announced it would be building a spaceport. The proposed site is near Upham, New Mexico and will cost an estimated $225 million. Of that cost, the state of New Mexico has already pledged $100 million. The site is slated to be complete between 2009 and 2010. In addition to Virgin Galactic, Starchaser and UP Aerospace have put in claims to use the completed site and more are expected. Two separate studies were done on the possible impact of a spaceport. Both studies projected positive findings, but were slightly differing in their intricate depictions. In the study conducted by New Mexico State University, suggested figures of $1 billion in spending, a payroll of $300 million and employment of 2,300 people by the spaceport's fifth year of operation (approximately 2014). A similar study by private sector consulting firm Futron Corporation, estimates that by 2020 the spaceport will generate $750 million in total revenues and employ more than 3,500 people[114]. A cartoon rendition of the spaceport is shown in Figure 27.

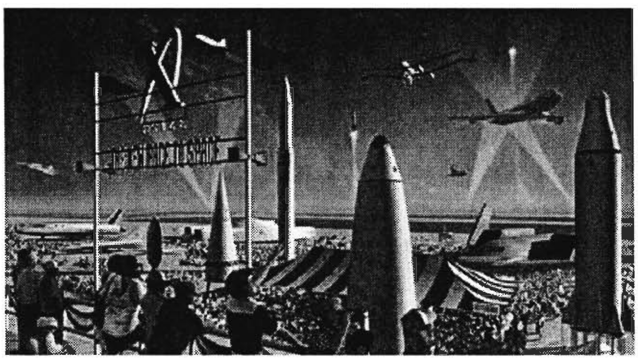

Figure 27: Spaceport New Mexico

[114] http://www.edd.state.nm.us/index.php?/about/. Accessed 4/11/2006.

The Southwest Regional Spaceport, as it will officially be known, will not only be a destination for orbit bound travelers, but it will also be the home of the new X Prize Cup. This event, which started in October of 2005, was and will continue to be a showcase of the current space technology. In 2005, companies came and displayed, some even flew, their respective ideas of what space travel will look like. A snapshot of this event is depicted in Figure 28[115].

Several other US states have expressed interest in the prospects of building a spaceport including Florida. Florida's Space Authority (FSA) is taking a slightly different approach than New Mexico. Instead of building a new spaceport facility, FSA has asked several airports if they would be able to adapt their facilities and use existing runways. This would effectively reduce costs of building a new spaceport tremendously. Several airports in Florida such as Titusville and Cecil Field in Jacksonville already have made inquires about being the site of a future spaceport in Florida[116]. Tracy Hegler, TSA's director of planning and spaceport transportation, believes that a spaceport would have an economic impact of between $7.4 and $25.5 million and employ 40 to 115 workers for 2010 and 2015[117].

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[115] http://www.thespacereview.com/article/366/2. Accessed 11/15/2005.
[116] Schneider, Mike. "Florida looks at options for building spaceports around state." Associated Press State and Local Wire, December 7, 2005. 2/23/2006.

Figure 28: X Cup 2005

Cecil Field on the Westside of Jacksonville Florida appears to be Florida's' most promising venture. The reasons for this include the existing runway and alternate infrastructure of Jacksonville. The runway is 12,500 feet long and 200 feet wide thus meeting the "ideal" requirements of at least 10,000 feet by 200 feet. The airport does not operate commercial traffic, and currently only sees about 95,000 operations per year. This presents a lack of air-traffic, ideal for a developing space-tourism industry. Yet, being on the outskirts of one of Florida's largest cities, roads and other infrastructure exist to support increased land travel to and from the spaceport. All these things are lacking from other possibilities the FSA has looked into. Titusville's airstrip is only

7320' by 150', almost half the 'ideal' requirement[117]. Whichever possibility the FSA chooses, the costs of implementing a spaceport at an existing airfield is estimated to cost between $10.5 and $28 million, which is miniscule compared to the $225 million required for New Mexico's venture.

Florida and New Mexico are not the only states interested in a spaceport. In fact, Alaska has been operating a FAA licensed spaceport since 2000. The spaceport first conceived in the early 1990's to spearhead the rapidly growing telecommunications satellites launch schedule, is situated on 3100 acres of Kodiak Island. The Kodiak Launch Complex is more situated for vertical launch vehicles and has sustained itself on the launching of micro-satellites and suborbital defense industry launches. It is not clear whether this facility plans on entering the space-tourism[118].

Oklahoma is also pondering the thought of a spaceport. The Oklahoma Space Industry Development Authority (OSIDA) has plans of building a spaceport at the Clinton-Sherman Air Force Base near Clinton OK. According to the OSIDA website, the facility would be 2700 acres, have a 13503' by 300' runways with 1000' of over-runs and a number of other field facilities and options[119].

Sheboygan, Wisconsin already has FAA certification for suborbital flights due to an annual rocket event. Proposals to upgrade the scale to include a spaceport have been given[119].

The United States is not the only government throwing financial support behind spaceports. Singapore and the United Arab Emirates have expressed interest, with a high

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[117] Decamp, David, Gibbons, Timothy J. . "Is Space in Cecil's Future?" The Florida Times-Union, 11/30/2005. Accessed 4/11/2006

[118] Webb, Andrew. "Other Spaceports; New Mexico's would be the First Built for Tourism." Albuquerque Journal, 2/6/2006. Accessed 4/11/2006.

[119] http://www.okspaceport.state.ok.us/index.html. Accessed 4/11/2006.

level of intent. Spaceport Singapore will be located near the Changi International Airport. This facility will also include an area for training. So far, Space Adventures is the sole company that has expressed that it will use this spaceport for its operations. Space Adventures will fly the Explorer space vehicle with the help of the M-55X lift vehicle for sub-orbital jaunts. A cartoon rendition of Spaceport Singapore and the Explorer are shown in Figure 29 and Figure 30 respectively[120].

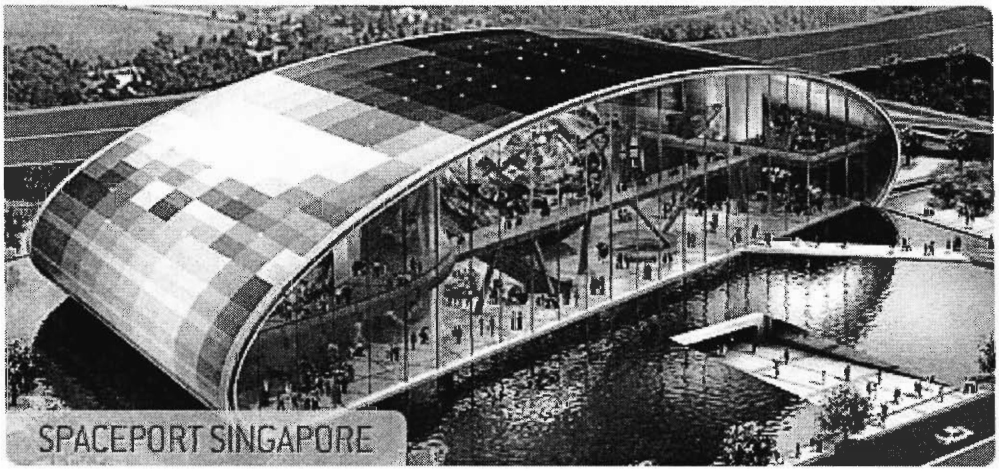

Figure 29: Spaceport Singapore

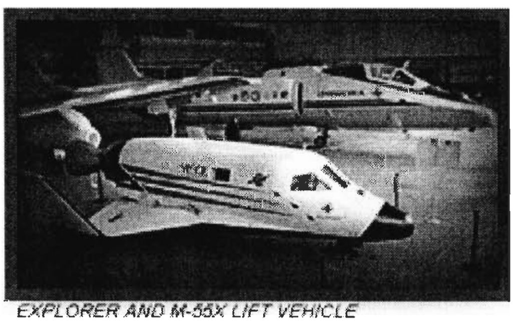

Figure 30: Explorer and M-55X

[120] http://www.spaceportsingapore.com/ Accessed 3/28/2006.

Space Adventures also has a firm grasp on the spaceport in the United Arab Emirates. The company plans to build the $265 million dollar facility. The UAE government has pledged $30 million. The spaceport is to be located not far from Ras Al-Khaimah near the southern end of the Persian Gulf. A depiction of the spaceport made public by Space Adventures is presented in Figure 31[121]. It is also apparent in this figure that Space Adventures plans to fly the Explorer form UAE, as in Singapore.

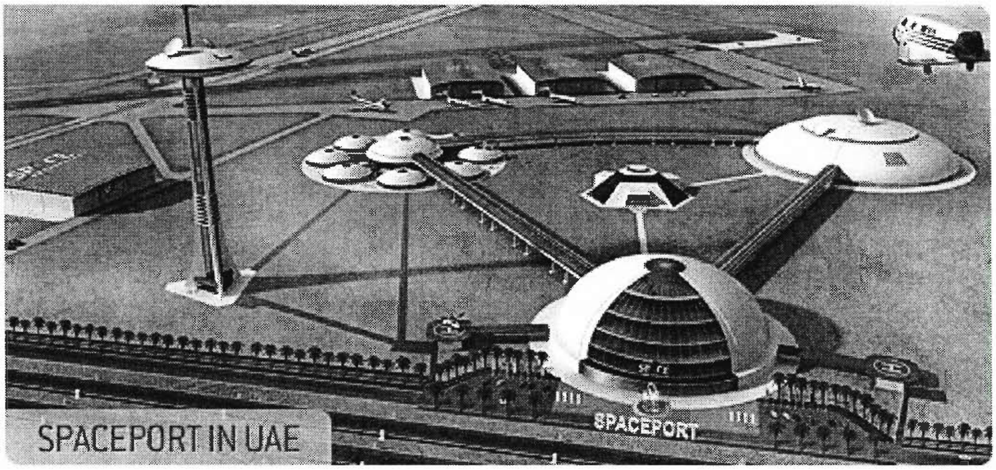

Figure 31: Spaceport UAE

[121] http://abcnews.go.com/Technology/wireStory?id=1634394. Accessed 3/28/2006.

Conclusion

This report introduces the reader to the space industry. It begins with a short history of space exploration. It then walks the reader through the fundamentals of space technology. In addition to technology the industry is shaped by the legal and regulatory frameworks it has to operate within. Hence, we devote several sections of the report to the relevant laws and regulations. As discussed in one of the sections, financial demands and insufficient technological knowledge of some players lead to international cooperation. The market analysis section makes it clear that the space industry is an expanding and changing marketplace. The section reviews traditional and new players and looks at current trends such as deployment of new spaceports and prizes, which encourage space races. Spaceports and space races are the trends that will change the face of the space industry. They will drive space technology to new standards and will encourage cooperation between companies and countries for the common goal of space exploration.