7.0 Space Flight

Space flight has received the attention of humankind ever since the Earth was first populated. Tales of people going to the Moon or the Sun are sprinkled throughout legends and literature from the past. Probably one of the most unusual "predictions" from one of these early adventure tales was in the novel "From Earth to the Moon," by Jules Verne, written in 1865. In this book, a spaceship was launched from Earth (actually shot like a cannon) to the Moon. The interesting feature is that the space shot took place in the middle of Florida, launched three people, in a capsule that weighed within ten percent of the Apollo capsule! Quite a coincidence. There were some features of the novel that were not quite true, one of them being that the only weightlessness was encountered when the vehicle passed from the influence of the Earth to the influence of the Moon. We know now that after the initial insertion into the Earth-Moon transfer orbit, the astronauts were "weightless" (really free falling) the entire way. Other features regarding the environment in space were not quite correct either, but we must remember the date when this was written. We now know more about the space environment and about what it takes to get to space. In this section of this course, we will explore some of these questions and see if we can determine what is required to have a successful space program.

Getting into Space

The first problem encountered in a space program is how do we define space, and the second is how do we get there. We need to define space so that we know when we are there! Unfortunately that is not a simple question and ultimately it comes down to a definition. For the purpose of awarding "astronaut pins" to those who have been in "space" it is defined as above 100 km (62.2 miles). At first, astronauts were created by putting people on sub-orbital flights. Allen Shepherd's sub-orbital flight on the Mercury 3 capsule Freedom 7 on May 5, 1961 was the first. It lasted 15 minutes and covered 304 miles. Later, the X15 test airplane made several sub-orbital flights allowing the test pilots to be designated as "astronauts." These early sub-orbital flights show us two ways to get into space, 1) using a rocket that carries its own fuel and oxidizer, and 2) using a basic aircraft to carry a smaller vehicle to a high altitude, and then use a rocket to launch the small vehicle from the high altitude and accelerate it to high speeds that would take it into space. Both of these methods have been used to achieve space fight and are continued to be used. Why are these two completely different techniques used to achieve space flight, and isn't one obviously better than the other?

Before we address those issues, let us see if we can get a "big picture" of the space environment and related ideas. Some of this material is drawn from the book "Interactive Aerospace Engineering and Design," by Dava Newman, McGraw Hill, 2002. The atmosphere about the Earth actually protects the inhabitants from some of the undesirable effects of space. It burns up meteors before they hit the surface, the ozone layer filters out ultraviolet radiation, a hazard to life, and the upper atmosphere absorbs cosmic and X ray radiation. If we scale the Earth down to the size of a basketball, the breathable atmosphere would be 1/100 inch (1/4 mm) thick!

Now we look at the problem of where "space" begins. At an altitude of 22 km vehicles can no longer (economically) compress the air from the environment to provide a breathable atmosphere inside a pressurized cabin. Consequently, above this altitude a sealed environment is required. Hence for humans, "space" may be considered to start at 22 km. If we consider the propulsion system, at about 45 km, propulsion systems (that burn fuel) require an independent supply of oxidizer since there isn't enough air above that altitude to sustain combustion. So one might say that 45 km is where "space" starts for aircraft. Or we can define it as 50 miles, 100 km (62.2) miles, or some other convenient value. The Air Force has defined an altitude that a person must exceed in order to get there "astronaut" wings. And the X-prize has defined the same value as the Air Force, 100 km as the beginning of space, and the minimum altitude obtained by the vehicle to claim the prize. (The X-prize will be described later). At about 100 km, the aerodynamic forces as we know them are minimal. In general, a satellite can not orbit below 200 km since the atmospheric drag would cause it to reenter after a few days (depending on the drag coefficient and mass of the satellite. In the exosphere, from approximately 300 to 600 km, the drag on the satellite is caused by atmospheric particles that impact the satellite on its surface. The magnitude of this type of drag is considerably smaller than are usual atmospheric drag, but still affects the satellite orbits. In addition, the numbers of "atmospheric particles" that are present at these altitudes are sensitive to the activity of the Sun. In the day time there are more particles than there are at night. These effects must be considered if highly accurate orbit prediction is to be done.

Some Space Flight History

Putting a Satellite in Space

The most common method of achieving space flight is to launch the vehicle using a rocket. There are fundamentally two different types of rocket, a solid propellent rocket (or solid rocket) and a liquid propellent rocket (or liquid rocket). The former was first encountered by the Chinese in the 11th century. Essentially, shortly after someone invented black powder (like gun powder) another person decided to pack it onto the back of an arrow to make a "fire arrow." These fire arrows were similar to today's skyrockets. There was considerable development to make these new devices behave so they could be used a predictable weapons.

It was quite a bit later before the liquid rocket was invented and launched. This did not occur until March 16, 1926 in Auburn, Massachusetts by Dr. Robert H. Goddard. At the time he was a physics professor at Clark University in Worcester Mass. He received his undergraduate degree from Worcester Polytechnic Institute, and his PhD from Clark, where he stayed on as a professor. A replica of this first liquid rocket is in the Smithsonian Museum, write next to replica of the Wright Flyer. After a few launches in Auburn, a relatively populated area, people protested that no more launches should take place since it jeopardized life and limb. Subsequently, Dr. Goddard moved his operation to New Mexico where he made serious strides to developing the liquid rocket as we know it today. Unfortunately, most of his work went unnoticed by the US government (even though they were sponsoring the research.

Along comes World War II. Toward the end of the war, the Germans were launching two types of vehicle toward England, The V-1 and the V-2. The V-1 was an autonomously controlled pulse jet flying bomb. Because the propulsion system pulsed at a high rate, it became known as a "buzz bomb" and could be heard approaching from quite a distance away. Generally if you heard it going overhead, you knew you would be safe since the damage was done when the engine stopped and the bomb crash dived from the sky. These led to what were called the London Blitz. But we digress. Of interest here is the V-2, a liquid propelled rocket designed to launch for Germany and land in England. You may recall that we discussed directional stability of vehicles in a previous section. It turns out that rockets need to be directionally stable also. In those days they didn't have very good navigation systems and hence generally just aimed them in the direction they wanted them to go and adjusted the fuel to give them the desired distance. However if there was a strong wind blowing, the vehicles would "weathercock" into the wind and generally end up flying up-wind to wherever. These rockets were deadly if they reached there target, but that was never a sure bet. When the German Scientist who worked with the V-2 rockets were rounded up and asked how they developed these rockets, they simply said they followed the work of Robert Goddard, and were astounded that the US knew so little about what there own scientist was doing.

Subsequently some of these scientist came to the US and some went to the Soviet Union. Needless to say, both countries continued to develop rockets. The US leader was Dr. Werner Von Braun who was really interested in interplanetary travel. In order to move toward this objective, he immediate goal was to launch and orbit a satellite. Unfortunately, the Soviets were moving toward the same goal. The objective was to launch for the Earth Geophysical Union year (1957) that was dedicated to studying the science of the Earth and related phenomena. In October 4, 1957 the Soviet Union launched Sputnik 1 who stated purpose was to measure the temperature of space. It relayed these measurements using beeps which anyone could listen to. The satellite weighed 405 lbs and was a sphere 23 inches across. The orbit had a maximum altitude (apogee) of 560 miles and a minimum altitude (perigee) of 140 miles.It was in orbit three months and reentered the atmosphere on January 4, 1958. On November 8, 1967, the Soviets launched Sputnik II that weighed 1,120 lbs and carried a dog (named Laika) on board. Unfortunately, the dog paid the supreme price.

On January 31, 1958, the US launched its first satellite, Explorer 1. It was launched into space using a Juno 1 rocket booster, and it weighed 18 lbs. The orbit had and apogee and perigee of 957 and 212 mile respectively. Its purpose was to measure space radiation and to record micrometeorite hits. It discovered the Van Allen radiation belt and recorded 7 hits in the first month. Originally the Air Force had the go ahead to launch the first satellite. However, they ran into problems, blowing up a couple of misfired rockets. The task was given to the Army where Von Braun was ready to go. Their first launch was successful and provided the first US satellite.

The first active communications satellite was Telstar, launched on July 10, 1962. This satellite enabled the first live television broadcast across the Atlantic Ocean.

Putting a Human in Space

The first project to put a human in space was Project Mercury that was initiated in 1958 and consisted of six manned flights between 1961 and 1963. These were Mercury 3, 4, 6, 7, 8, and 9. The objectives of the program were to 1) orbit a human, 2) determine how humans function in space, and 3) recover the astronaut successfully. Mercury 3 and 4 were suborbital flights and used the Redstone rocket as the booster. Mercury 6 was the first orbital flight and it lasted 4 hrs 48 min and 27 sec. Subsequent flights increased time in orbit until the last lone astronaut was launched on Mercury 9 for a 34 hour mission.

The Gemini missions consisted of a two astronaut capsule that was to serve as the bridge between the Earth-orbit Mercury program and the Moon-landing Apollo program. The Gemini program went from 1961 - 1966 and included 12 flights. The important accomplishments of these flights were rendezvous and docking, extra vehicular activity (space walks), and general vehicle maneuvering. Success in these activities was crucial if the Apollo program was to work. In the Moon landing scenario, the vehicle had to rotate 180 degrees on the way to the Moon. Also it required a separation and re-attachment during this maneuver. On returning from the moon, a rendezvous and docking procedure was needed in lunar orbit. So all these activities had to be developed and practiced until there was 100% confidence that they could be done. That was the main purpose of the Gemini missions.

Finally, the Apollo program - to put a man on the Moon and to return him safely to Earth. There were several unmanned orbital flights prior to the first manned flight. Apollo 7 and 9 were earth orbit flights launched in11 Oct., 1968 and 3 March 1969 respectively. These were for the purpose of testing the command and lunar modules. Apollo 8 and 10 were Moon orbiting flights where one purpose was to take pictures of the lunar surface. These were launched on 21 Dec. 1968 and 18 May, 1969 respectively. Apollo 11, 12, 14, 15, 16, and 17 were all lunar landers. These were launched on 1July, 1969, 14 Nov. 1969, 31 Jan. 1971, 26 July, 1971, 16 April, 1972 and 7 Dec. 1972. These missions collected over 400 kg of lunar samples. Apollo 13, launched 11 April, 1970 had a failure, but with some extraordinary engineering and problem solving, the crew was brought back alive. It is best known for the quote “failure is not an option.”

All of these efforts were sponsored by the US government, and used tax payers monies to provide the necessary funds. As a result, the access to space by the common individual is difficult or impossible to come by, unless the individual has a large amount of money. In the early days of the aircraft, many prizes were offered to try and promote flying and make it available to the common people. Between 1905 and 1935, over 100 aviation prizes were offered in order to promote flying, get more people involved, promote commercialism, and improve the product. To this same end, a prize has been offered to the first privately funded organization that can but an astronaut in space, and bring s/he back safely, the X-Prize.

The X-Prize

The X-Prize foundation was founded on May 18, 1996 in St. Louis for the sole purpose of promoting tourism in space and to open space to the public. The X-Prize consists of $10,000,000 to be given to the first person or group that satisfies the following requirements:

1) Privately financed enterprise that builds and launches a spaceship, able to carry three people to 100 km (62.5 miles). However, only one person needs to fly, but if so, one must carry ballast for the other two. People are assumed to be 6 ft 2 in, and weigh 180 lbs each. The X-Prize foundation will provide a flight recorder for the flight.

2) The vehicle and passenger(s) must return safely to Earth, and the vehicle must be re-useable after each flight.

3) The launch must be repeated within 14 days with the same ship. No more the 10% of the non-propellant mass is allowed to be replace for the second flight.

Some of the expected benefits of the X Prize are

1. Develop a new generation of heros
2. Inspire and educate students
3. Focus public attention and investment capital in this new business frontier
4. Challenge explorers and rocket scientists
5. Promote space tourism
6. Develop low cost satellite launching
7. Provide a means of same day package delivery
8. Develop rapid point to point passenger travel
9. Other

There are 20 companies from 5 different countries in competition at this time for the X-Prize. One approach to solving this problem is proposed by Scaled Composites of Mojave, CA. Let us examine their approach to solving this problem.

Rutan - Scaled Composite X-Prize competition

The approach that Burt Rutan, a well known aircraft designer (Veri-eze, Long-eze, Voyager, and an influence on the Beech Starship plus about 30 other designs) has used to achieve the X-Prize goal is to use an aircraft (the White Knight) to take the spaceship (SpaceShipOne) up to a high altitude and to launch the rocket propelled spaceship from there into space (100 km). The flight schedule is as follows:

1) The White Knight, with SpaceShipOne attached to its underside takes off and in one hour climbs to 50,000 ft so that it is above 85% of the atmosphere.

2) At 50,000 ft, drop the spaceship, fire the rocket and climb steeply to reach the speed of 2,500 miles per hour.

3) Coast up to 100 km (62+ miles) in a weightless condition for three minutes. During this three minutes it will reach the peak of the trajectory and start back down

4) SpaceShipOne then converts into a high drag configuration and decelerates for about one minute until it approaches the speed of Mach 1+

5) SpaceShipOne reverts to a glider configuration and returns from 80,000 ft to land conventionally a the Earth's surface.

The project originated in 1996 and preliminary development was carried out through 1999. Full development was started in April, 2001 in secret. The design included the launch aircraft (White Knight), a three place spaceship (SpaceShipOne), and a hybrid rocket propulsive system (features from both solid and liquid rockets). Included in the project is the development of a propulsion test facility, a flight simulator and an associated pilot training program, a mission control center, and a flight test program. The fuel to be used in the hybrid rocket was nitrous oxide (commonly known as laughing gas) as the oxidizer, and hydroxy-terminated polybutadiene (HTPB - rubber) as the fuel.

In April, 2003, the project was announced publicly and promoted the fact that it would launch the first non-government astronaut, being fully privately funded.

With this background in history, and some current projects, we now would like to examine some of the basic physics that governs space operations and how to get there.