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COMMUNICATIONS

CONTENTS

Volume 4

Satellite Communications

ISSUED 2000

CHAPTER 1

SPACE

The Final Fontier?

From Earth to the Moon

1. For many years, space travel was a practical impossibility, existing only in the minds of science fiction writers. In 1865, Jules Verne wrote a book entitled “From the Earth to the Moon” in which three space explorers were fired from a huge gun and propelled into space in a cone-shaped craft. After circling the Moon the craft returned to the Earth where it splashed down in the sea - the occupants being recovered safely. In due course the advance of technology, coupled with man’s inherent desire to seek new frontiers, converted science fiction into science fact - and the first men set foot on the Moon in 1969. Their craft - Apollo 11 - was not fired from a gun, it was sent by rocket. However, it did return to Earth for a safe splash-down in the sea, and the 3-metre high Command module in which they returned was conical! No men have since reached any other part of the Solar system, but by the mid 1990s all the planets except Pluto had been explored in close-up by unmanned probes, and several of those probes were subsequently on their way out of the Solar system, carrying messages in case any alien should intercept them.

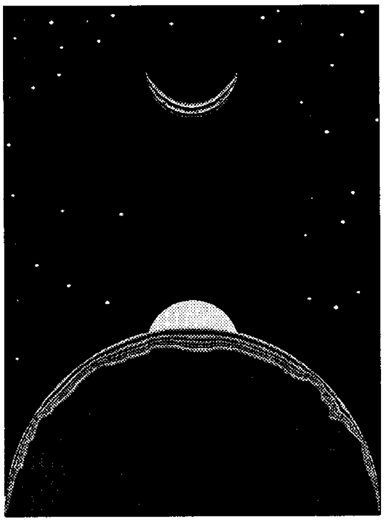


Fig 1-1 *How Jules Verne Imagined Space*

What is Space?

Space is a vacuum

2. The Earth is surrounded by a layer of air which shields it from the harsh environment of space. The air that we breathe at ground level is quite dense, but it

gets thinner and thinner the further from the surface you get. When the air thins out finally to nothing, space takes over. Space is a vacuum; that is, there is no air. Therefore, to stay alive you must take air with you - plus a means of regenerating oxygen from your waste gases if you are to stay there for long. Moreover, the absence of an atmosphere outside your craft brings many more problems - no outside pressure to counteract the air pressure inside your craft; no protection from cosmic and other radiations; no insulation from the searing heat of the Sun's rays on one side of the craft or from the absolute cold of space on the other side; and so on. To conquer this hostile environment man had to evaluate its properties and learn to master them, using new technologies involving a previously unknown level of research and development.

Operating in a Vacuum

First Animals

3. To put an astronaut into space needed the most careful planning and experimentation. The working environment was harsh and nobody knew how it would affect someone exposed to it. Special equipment and advanced technologies were required, and many tests were carried out. In particular, various animals were sent into space to test the risks and the new technologies before risking the lives of a man. Like most high technology projects the cost was high. Many people saw the cost of the "space race" (between America and the USSR) as a waste of money particularly since the Earth had many problems of its own. But there were many extra advantages gained from space technologies. One example is the microprocessor, a piece of electronics that has changed most people's lives so dramatically.

Steps in Space

Unmanned Probes

4. Sending animals into Earth orbit was one of the earliest steps in the human race's efforts to conquer space, and sending unmanned probes to the "gas giants" - Jupiter, Saturn, Uranus and Neptune - is one of the latest. In between there have been many others, in some of which men actually set foot on the Moon. However, the vast majority of space activities, past and current, putting objects into orbit around the Earth - and this is the subject of our next chapter.

Self Assessment Questions

Do not mark the paper in any way - write your answers on a separate piece of paper, in the form of a sentence.

1. What date did men first set foot on the moon?
   - a. 1966
   - b. 1969
   - c. 1970
   - d. 1964

2. What is the reason man can live on earth?

3. Why is man unable to live in space?

CHAPTER 2

INTO ORBIT

What is a Satellite?

Heavenly or Artificial Body

1. A heavenly or artificial body which orbits (that is, revolves round) a planet is a satellite of that planet. The Moon (a heavenly body) is a satellite of the Earth, and so is the American Space Shuttle (an artificial body) whilst it is in orbit. So too are the many hundreds of useful objects that now orbit the Earth for scientific and other purposes - observing the weather, relaying TV programmes, and so on. In fact, we routinely call them satellites -"satellite TV", for example. But how do they get into orbit?

Achieving Orbit

Gravity

2. If we take a tennis ball and drop it off a cliff it will fall (under gravity) to the ground. If we then kick another tennis ball off the cliff it will travel out a short way whilst falling to the ground. If we now place our ball on to a cross-bow and fire it, the ball will travel quite far before falling to earth. Firing it from a gun would be even better, because the faster we propel the tennis ball the further it will travel before reaching the ground. In fact, it can be shown mathematically that in theory, a horizontal speed of about 8 km/sec would be enough to send our tennis ball all the way round the Earth without falling to the ground. At that speed, some 83 minutes later it would give you a nasty shock from behind! However, in reality, long before that could happen, air friction would slow it down, and the ball would fall to Earth as before.

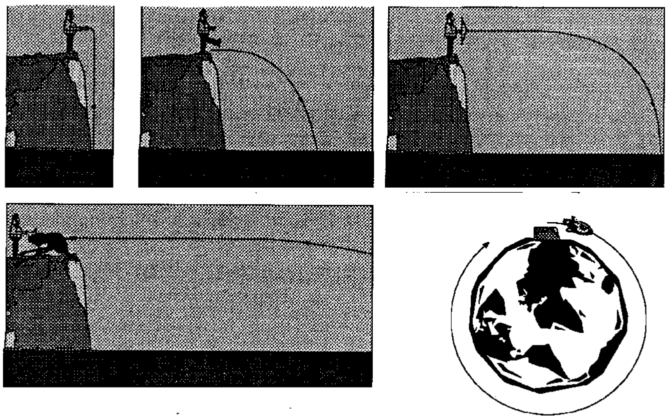


Fig 2-1 *The Tennis Ball Satellite*

3. So, perhaps the answer is to put the tennis ball into the nose of a rocket that is capable of being launched horizontally to a speed of 8 km/sec? Indeed, this would work well in theory, and your ball would be a satellite in low orbit for as long as the rocket could produce thrust, to combat air friction and keep the speed up to 8 km/sec. But once the fuel ran out, your satellite would slow down again and crash. The only way to eliminate air resistance is to go where there is no air - above the Earth's atmosphere. So now, instead of launching the rocket horizontally we shall send it vertically at first, to escape the atmosphere. Then, at a precisely calculated point we shall gradually alter the rocketís trajectory until it is horizontal, so that “injection” into orbit can take place. At injection the velocity and height of the satellite should be such that it will orbit the Earth without further help from the rocket. If this manoeuvre is attempted at too slow a speed the rocket and payload will fall back to earth under the influence of gravity, but successfully completed, they will achieve a circular orbit. The practical minimum height for a circular orbit is 200 km. Below this height there is enough air friction to slow down the satellite quite quickly, and it will soon fall to earth.

Centrifugal Force

4. To achieve circular orbit at 200 km, a satellite must be given an injection speed of about 7.9 km/sec. Circling at this height and speed, the centrifugal force on the satellite exactly opposes the pull of the Earth's gravity. Centrifugal force is the outward force on an object travelling in a circle; for instance, if you hold one end of a string with a ball on the other end, and whirl the ball around in a circle, centrifugal force keeps the string taut. The faster you whirl the ball, the tighter you need to grip the string to stop the ball flying away.

5. Because the Earth's gravitational pull falls off the further away from Earth you get, the centrifugal force required for a circular orbit is lower, hence the speed needed becomes lower. For example the Moon, whose orbit is about 60 Earth radii (or 380,000 km) from Earth, orbits at just under 1 km/sec. Fig 2-2 shows the relationship between orbital speed and the distance from the Earth.

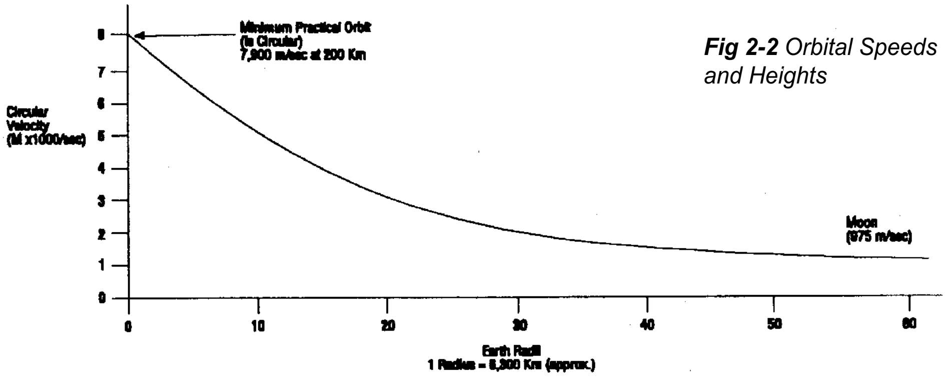


Fig 2-2 *Orbital Speeds and Heights*

Perigee

6. Many orbits are not circular. If we increased the orbit speed at 2000 km slightly - say, to 9.5 km/sec - the orbit would become elliptical (ie oval). The closest point to Earth of this type of orbit is called the perigee (in our example 200 km) and the other end of the ellipse (ie furthest away) is called the apogee (Fig 2-3).

Apogee

7. If the injection speed is increased further still, the elliptical shape will become more pronounced. We would have the same perigee but a larger apogee. An even higher injection speed of 11.3 km/sec is sufficient to overcome Earth's gravity altogether, and a satellite at that speed can break out of closed orbit. It would depart Earth on a curved path called a parabola - and instead of a satellite we would have a space probe. The minimum speed needed to break away from Earthís gravity is called "Earth escape velocity". At yet higher injection speeds the trajectory becomes a hyperbola. From Fig 2-2 you can see that circular and elliptical orbits are ìclosedî (ie the satellite never leaves Earth orbit), but parabolas and hyperbolas are open and are escape trajectories.

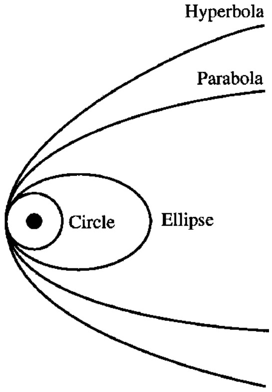


Fig 2-3 *Earth Orbits and Escape Trajectories*

Self Assessment Questions

Do not mark the paper in any way - write your answers on a separate piece of paper, in the form of a sentence.

1. What is the injection speed of a satellite?

2. What is centrifugal force?

3. What is the minimum speed needed to break away from Earth's gravity called?

CHAPTER 3

Launch Vehicles

Rocket Propulsion

1. Jet engines will not work in space; they need the Earth's atmosphere, because they draw in air and use the oxygen in it to burn fuel to operate the engine. The engine then throws gases backwards, so as to propel the aircraft forward. Rockets are much simpler and they carry fuel (or "propellants") that do not need atmospheric oxygen. A rocket is basically a tube, closed at one end, containing a propellant. The propellant burns very quickly, producing a fast-moving exhaust flow. The propellant might be a liquid chemical fuel (eg kerosene/paraffin) with an oxidising agent (liquid oxygen), or it might be a solid chemical.

Rocket Theory

2. Rocket propellants burn quickly or react together violently to produce a fast exhaust flow. Such a flow of gas constitutes an 'action'; and Newton's third law states that every action must have an equal and opposite reaction. The reaction to this rearward gas flow is a forward thrust on the rocket itself. The magnitude of the force is given by Newton's second law, which states that force is proportional to the rate of change of momentum (mass times velocity). In simple terms, this means that the larger the force produced by the burning fuel, then the faster the rocket will move! Note that all this is independent of the medium (eg air) that the rocket may be in. Thrust is derived from the reaction to the gas momentum, **NOT BY PUSHING ON THE MEDIUM**. A rocket works perfectly well in the vacuum of space - and in fact benefits from the absence of air resistance.

The Rocket Motor

3. The heart of a rocket motor is the combustion chamber and exhaust nozzle. At every instant, the momentum of exhaust products is producing a forward thrust which is transmitted to the forward walls of the combustion chamber and on to the rocket. If the burning is even, the thrust will be constant with time. If we ignore all other forces, the rocket will accelerate forwards in accordance with Newton's second law, Force = Mass x acceleration or F (M = a. For example a 5000 kg thrust engine

in a 5000 kg rocket will give an acceleration equal to the force of gravity (1g). However, as fuel is used, weight falls and the same 5000 kg thrust on the rocket, now reduced in weight to, say, 2500 kg will give an acceleration of 2 g.

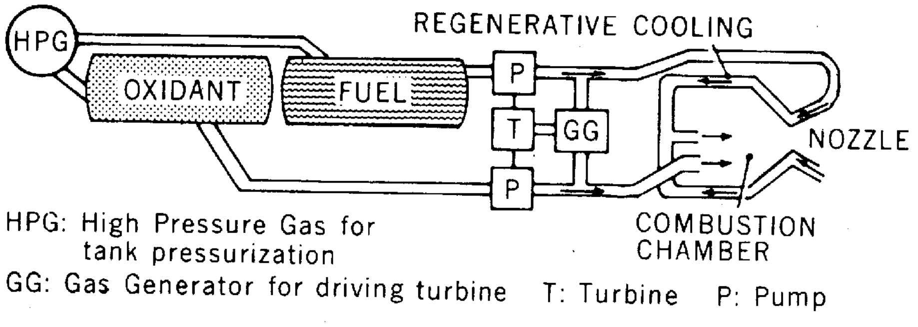
4. Apart from combustion to produce thrust, liquid propellants are put to other uses, particularly in a large rocket motor. As an example we can look at a rocket which uses liquid oxygen (the oxidant) and kerosene (the fuel). Liquid oxygen is pumped directly to the combustion chamber, but some is also used to drive a pump turbine. Pumping is needed because of the enormous fuel consumption of large rocket engines - the 5 engines of the Saturn V (which took the manned craft Apollo 11 to the Moon) used 12 tonnes of fuel per second! Gaseous oxygen from the gas generator can also be used as a power source for ancillary equipment.

5. The kerosene fuel is pumped along a very long tortuous path around the rocket nozzle, before entering the combustion chamber. There are 2 reasons for this arrangement:

a. The exhaust gases flow through the nozzle at very high temperatures (typically 3,000°C) which could destroy the material of the nozzle very quickly, unless some form of cooling were employed. The kerosene flowing through the tubes round the nozzle cools the metal - this function is called regenerative cooling.

b. As the kerosene cools the nozzle gets hot and it is next fed to the combustion chamber. There, because it has been pre-heated, it vaporises more speedily. This improves the combustion process.

Fig 3-1 *The Components of a Liquid Propellant Rocket Motor*

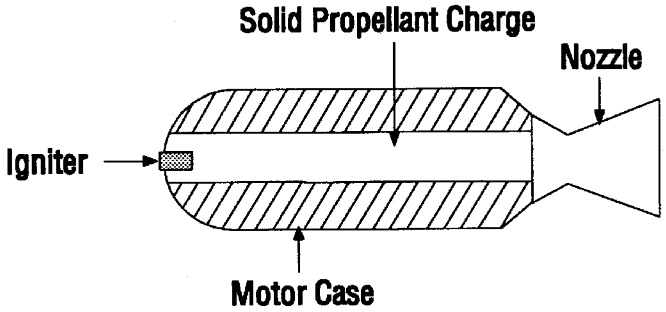


Solid Propellant Rocket

6. The essentials of a solid propellant rocket are shown in Fig 3-2.

7. This form of rocket has no moving parts and is by far the simplest in construction; it is reliable, and solid propellants are comparatively safe and easy to handle. However, it is difficult to control the exact thrust output of a solid propellant and the performance of solid fuels is generally not as high as that of liquids.

Fig 3-2 *A Solid Propellant Rocket*



Efficiency and Specific Impulse

8. For conventional air-breathing engines the fuel consumption gives a good indication of the efficiency of the motor. Rocket engineers rarely mention fuel consumption as it would be embarrassingly high by comparison with other large engines. They use another term to quantify the rocket engine efficiency, called Specific Impulse (SI). Here “impulse” means the force applied (ie the thrust) multiplied by the duration of its application - a measure of the momentum change achieved. “Specific” Impulse is this figure, divided by the mass of the propellants used. This, SI indicates the effectiveness of the propellant in producing a change in velocity of the vehicle it is propelling. For example, if propellant A can produce the same thrust for the same time as propellant B, but uses less mass than B in doing so, then A has a higher SI than B - ie it is more efficient than B.

9. SI = thrust (in kg) x time (in seconds) (mass of fuel used (in kg). The thrust kg mathematically cancels out the mass kg leaving secs. In other words, the unit for SI is seconds. An SI of 250 seconds, a typical value, would mean that 1 kg of propellant would give 250 kg of thrust for one second, or 25 kg of thrust for 10 seconds, or 2.5 kg of thrust for 100 seconds, and so on; thrust and time are

interchangeable in the equation. The actual burning time would depend on the nature of the fuel and the combustion conditions.

Typical Fuels

10. Four typical liquid propellants and one solid propellant are described below.

11. Liquid Hydrogen and Liquid Fluorine. Liquid hydrogen and liquid fluorine offer one of the highest SIs for a bi-propellant, 390 seconds at sea level (480 in space). However, there are disadvantages:

a. Liquid hydrogen boils at - 253°C, so special storage and fuel tanks are needed to stop it evaporating rapidly.

b. Liquid hydrogen has a very low density - one fourteenth of that of water - so huge fuel tanks are needed for quite a small mass of liquid hydrogen.

c. Fluorine is highly toxic, it boils at - 188°C, and it is one of the most chemically active elements known, combining with every gas except nitrogen, chlorine and inert gases. You can imagine the storage problems!

d. Finally, when the 2 liquids combine and combust they produce hydrofluoric acid, a very corrosive substance which is used for etching glass!

12. Liquid Hydrogen and Liquid Oxygen. The SI of liquid hydrogen and liquid oxygen nearly matches that of hydrogen and fluorine, and the product of combustion - ie steam, is harmless. The low density and temperature of liquid hydrogen remain a problem, but liquid oxygen is less demanding on storage as it is relatively dense (1.14 times that of water). The liquid hydrogen/oxygen combination has much to offer - in fact it is used for the main engines of the Space Shuttle.

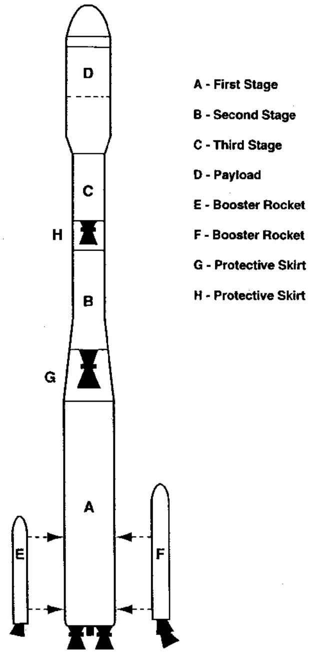
13. liquid Oxygen and Kerosene. Kerosene is cheap, plentiful and safe to handle. More importantly, its relative density of 0.8 (ie 80% of that of water) requires smaller tanks than liquid hydrogen; and it can be stored at normal temperatures. Despite having a lower SI than liquid hydrogen/oxygen, it has been a most useful propellant for the United States programme in the past and is still used for the Soviet Vostok craft.

14. Unsymmetrical Dimethyl Hydrazine and Red Fuming Nitric Acid (UDMH and RFNA). UDMH with RFNA is an effective but unusual fuel combination. A small amount of fluorine is normally added to prevent the nitric acid from eating away the steel fuel tanks. The 2 liquids do not boil off. The combination also has the advantage of being self igniting - the propellants ignite on contact and so no ignition system is required. There are however, obvious dangers in handling these chemicals.

Multi-Stage Rockets

15. At launch, a rocket has to lift its payload, plus its own weight and that of all its fuel. Typically, a single rocket might burn for 3 minutes and reach a height of 60 km, which is not high enough for any viable orbit. One solution would be to have a lot more fuel available at launch - but this would mean much more weight at launch (extra fuel plus extra tanks). So, although the rocket might now reach 60 km with some fuel left, much of that fuel would next be used in boosting the extra tanks - now empty - to a slightly higher altitude along with the payload.

Fig 3-4 *Multi Stage Rocket*



A much more efficient technique is to use multi-stage rockets. In the diagram, the huge first stage (A) does the giant's share of the job - lifting itself and the rest of the assembly off the ground and accelerating it to, say, 3 km/sec and a height of 80 km.

Stage A is now dead weight, so explosive bolts release it and it falls to Earth, breaking up and burning as it does so. Meanwhile, the second stage rocket (B) ignites and continues to accelerate the assembly to, say, 6 km/sec and 150 km. Stage B has a much easier job than stage A, as it has a much smaller mass to propel, and the atmospheric drag is a tiny fraction of what it was earlier in the flight. In our example, stage B is in due course discarded as was stage A, and the third stage (C) ignites, to take the payload up to orbit height and speed.

16. Depending upon the mass of the payload, some assemblies might have only 2 stages, whilst others might have 3 stages plus booster rockets (E&F), of various types and capability, clamped to the outside of stage A for launch. This gives extra flexibility in the size of payload to be carried. The booster rockets can be the liquid-fuelled or the solid-fuelled type. They are normally used in pairs, with either 2 or 4 on one vehicle. They can be mixed (liquid and solid fuel) when 4 are used, but not for 2 or 3, as their differing power and burning times would cause asymmetric thrust which could throw the vehicle off course, and could even make it crash. Typical burning times for booster rockets are around 45 seconds (solid fuel) and 2 minutes (liquid), which is the crucial early stage of launch when the vehicleís mass is vast and air resistance is high. Boosters are jettisoned as soon as they have used up their fuel.

17. There might also be more than one satellite in the payload (D). In this case the third stage motor would switch off at the desired orbit height and speed, and the satellite in the nose-cone would separate. The aerodynamic cone itself, which merely protects the satellite from air pressure and friction in the lower atmosphere - would probably have been discarded earlier. This satellite would almost certainly have its own rocket for adjusting, or even changing, its orbit. This on-board rocket would have small thruster nozzles on all sides for changing the satelliteís attitude (for example, to point its aerials in a specific direction), plus a main nozzle at the back for propulsion purposes (eg to adjust orbit speed, or to change orbit). The second satellite would be taken by the third stage rocket to another orbit height, or to another part of the sky at the same orbit height as the first, according to the jobs the satellites will have to do.

Re-Usable Vehicles

18. From the earliest days the cost of launching hardware into space was huge. Most launch rockets can be used only once. Having placed their payload into Earth orbit, they either remain in orbit as space debris, or re-enter the atmosphere and burn up. To reduce costs, the Americans and the Russians both developed re-usable launch vehicles. The American version is called the Space Shuttle and the Russian version is called Soviet Shuttle Buran. The American space agency NASA designed the Space Shuttle, to carry satellites in its cargo bay and launch them into orbit. It can simply place them into its own standard orbit at about 300 km above the ground, but if a higher orbit is needed, the satellite will have a built-in rocket. Such a rocket would, of course, be much smaller and cheaper than one which would be needed to lift the satellite all the way from the ground. The Space Shuttle can also be used to retrieve satellites from their orbits and repair them for re-release or bring them back to Earth for further work - a capability first proved during the Shuttle missions in 1984. The Hubble Space Telescope was a highly publicised repair operation in space, successfully carried out during a Shuttle mission.

The Space Shuttle

19. At launch, the American Space Shuttle has 4 main parts:

Two solid-fuel rocket boosters (SRBs)
One external tank (ET)
One orbiter

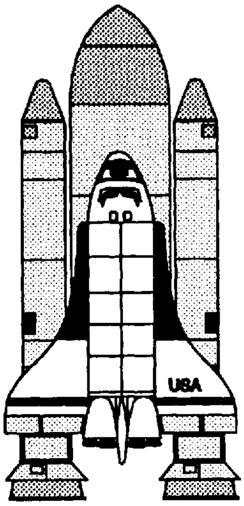


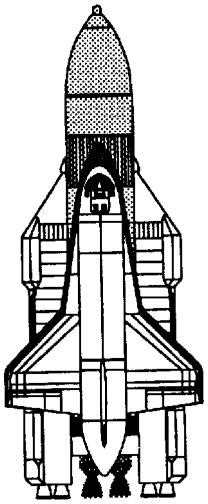
Fig 3-5*The American Space Shuttle*

20. During take off the Shuttle is propelled by its own rocket engine fuelled from the ET together with the 2 x SRBs. The SRBs separate at a height of 45 km, some 2 minutes into the flight. The booster rockets are parachuted to earth and are retrieved for future use. The next stage to depart is the ET. This falls away at a height of 120 km, nearly 9 minutes into the flight. The ET burns up when re-entering the Earthís atmosphere and is the only part of the vehicle that is not re-useable. The Shuttle has 2 on-board engines called orbital manoeuvring systems (OMS) which are used to position the vehicle in the required orbit before commencing the mission. For the return to Earth the OMS is used to correctly position the Shuttle into the descent attitude and trajectory for re-entry. Once it enters the atmosphere, the Shuttle can also use aerodynamic controls, and in due course it lands like a glider - but on a very long runway!

The Soviet Shuttle

21. The Russian Shuttle Buran has no engines of its own and for launching it relies solely upon the booster rockets it piggybacks.

Fig 3-6 *The Soviet Shuttle Buran*



Self Assessment Questions

Do not mark the paper in any way - write your answers on a separate piece of paper, in the form of a sentence.

1. What is Newton’s third law?

2. How is thrust obtained in a rocket?

3. Give 3 examples of typical fuels used in rockets

4. What are the 3 main parts of the American Space Shuttle?

5. Which part of the Shuttle is not retrieved for further use?

CHAPTER 4

SATELLITES

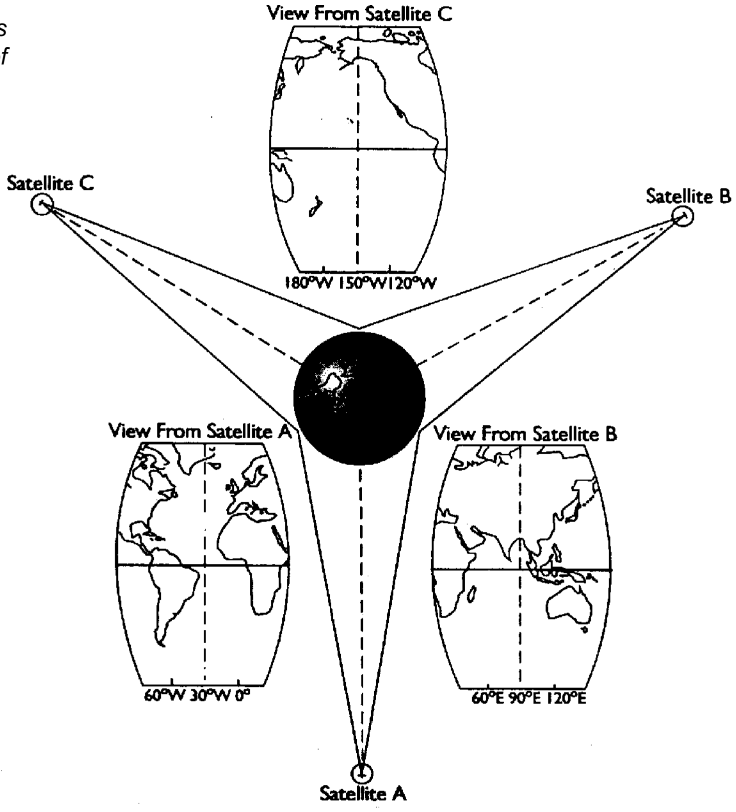
Introduction

Satellites

1. The Moon is the Earth’s only natural satellite, but through the revolution of space technology we now have hundreds of artificial satellites in orbit. Their many roles include communications, military intelligence, weather information, navigation aids, and so on. But how did the human race first perceive the need for them?

2. When Marconi invented radio in the early 1900s, it was a great step forward for communications. However, as radio waves travel in straight lines, the Earthís curvature initially limited the range of radio communications to line of sight. Range could be improved by placing transmitters on hills or tall buildings, but even then it was rarely possible to obtain a line of sight of more than 30 miles. The next great step came when it was found that if low-frequency radio signals were beamed skywards they were reflected back to Earth - and sent well over the line of sight horizon - by certain layers of ionised gases that occur naturally in the uppermost reaches of the Earth’s atmosphere, over 100 km above the surface. However, low-frequency radio signals have limited uses, and worse still, the reflective properties of the ionised layers vary accordingly to whether it is day or night, and also change with the weather. In 1945 the British engineer and science fiction author, Arthur C Clarke conceived how to overcome this problem. His revolutionary idea was to place artificial “relays” into space and use them to reflect the radio signals back to Earth. He theorised that if each relay was given a certain height and speed it would remain in the same position over the Earth. This meant that the satellite would keep pace exactly with the rotation of the Earth - an orbit of 24 hours. This condition is called a “geostationary” or “synchronous” orbit - and it can be achieved only over the equator. Arthur Clarke calculated that an orbital height of some 35,880 km above the equator was needed, and it would take only 3 satellites to relay radio signals from and to any point on Earth, except for some largely uninhabited areas at the North and South poles. Over the next 20 years or so his predictions were proved to be correct in all respects.

Fig 4-1 *Three Satellites for Coverage of most of the Earth*



You Can Use Satellites!

3. Telephone calls to America, Canada, Australia and elsewhere in the world are now commonplace. Imagine you are making one to a cousin in Canada. The route your call would probably take is from your house to the local telephone exchange, from there to the BT tower in London and then onto BT's satellite-link ground station at Goonhilly. At this point your call joins hundreds of others and goes extra-terrestrial, ie skyward. It will be bounced off a satellite and directed and distributed to your relativeís home. It sounds complicated, but with todayís technology the part you play - dialling your cousinís number - is simple. The same is true of satellite television, whereby you can watch a live sports event from the other side of the world in the comfort of your own home. This technology, although taken for granted today, has not been around for long. We will look at satellite communications and how they have developed over the years.

History and Development

4. In October 1957 the Soviet Union launched the very first artificial communications satellite, Sputnik 1. In 1960 the United States launched a satellite called Echo 1 which was designed for radio communications experiments. Echo 1 was in fact a folded up balloon that, once in position, expanded to its full 30 metre diameter. These early communications satellites were designed to operate in a passive mode.

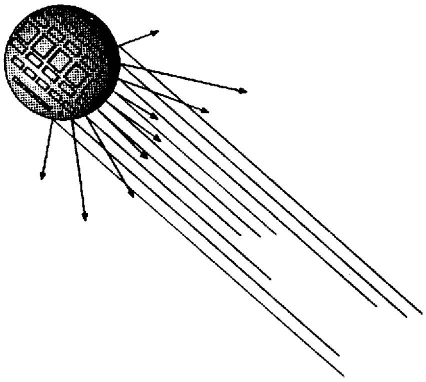


***Fig 4-2** "Passive" Satellite*

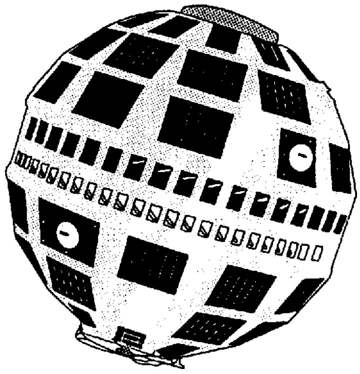


***Fig 4-3** Telstar*

This meant that instead of actively transmitting radio signals of their own, they merely reflected the signals that were beamed up to them from transmitting stations on the ground. The draw-back to this system of operation was that the signals were reflected in all directions, which meant that much of the signal was wasted by being reflected into space. Unfortunately Echo 1 did not last long; damage suffered from a meteorite shower caused it to collapse. Echo 11 (which was 41 metres in diameter) was launched in 1964 and again proved that "passive" satellites were not cost effective because of the way they scattered the signal. In 1962 Telstar was launched by American Telephone and Telegraph Co (AT&T). It made history by transmitting the first live TV pictures between the United States and Europe. Although it was only 90 cm in diameter Telstar could also relay several hundred voice channels. The satellite was launched into an elliptical orbit inclined at 45° to the equatorial plane. Telstar used one frequency band (500 MHz wide), and was divided into repeater channels of various bandwidths located at 6 Ghz for transmission upwards, (or uplink) and 4 Ghz for transmission downwards (or downlink). Solar energy cells mounted on large panels on the satellite provided power for reception and transmission. By now you will have noticed that satellites do not have to use the low-frequency radio signals that were necessary when the ionosphere was the only means of reflecting signals over long distances. Satellites can reflect signals that have extremely high frequencies - and the higher the frequency, the wider the band width, which means that the signal can carry vast amounts of information. One satellite can now handle thousands of telephone channels!

Commercial Interests

5. Commercial companies saw the benefits of using satellites and some began forming partnerships with others to share the cost of building and launching communication satellites into space. The first of these companies was Communications Satellite Corporation (COMSAT) in 1963. The next consortium was the International Telecommunications Satellite Organization (INTELSAT) in 1964. This company is owned by more than 120 countries world wide and COMSAT became the American member. The first of INTELSAT communication satellites, INTELSAT 1 (also known as Early Bird), was launched in 1965. To provide one TV channel takes about as much satellite capacity as 240 telephone circuits, and INTELSAT 1 provided either 240 voice circuits or one TV channel between America and Europe.

6. As time went by the capacity and complexity of successive satellites (INTELSAT 2, 3 and 4) were progressively increased by beaming the satellite power to only certain areas of the Earth. Concentrating a satellite’s power on small regions of the Earth also made possible smaller, lower-cost ground stations. The first of the INTELSAT 4 series was launched in 1971 and provided 3750 voice transmission circuits plus 2 TV channels. The launch of the INTELSAT 5 series in 1980 introduced multiple-beam operation, which increased capacity to 12,000 voice circuits and 2 TV channels.

7. New techniques continued to improve satellite performance, and the INTELSAT 6 satellites, which entered service in 1989 and can carry 24,000 circuits, have very sophisticated on-board switching of telephone circuits. This technique is called SS-TDMA (satellite-switched time division multiple access). By the early 1990s INTELSAT had 15 satellites in orbit, providing the worldís most extensive

telecommunications system. Alongside this growth in communications there has also been a boom in the transmission of TV programmes around the world. We can now see sport and entertainment from any country as it is happening, and even receive coverage of wars and natural disasters direct from where the action is. All this has brought in the phrase "global village", to describe what the Earth has now become.

8. With the introduction of digital communications, the latest satellites can each carry over 100,000 telephone circuits. Moreover, digital source coding methods have dramatically increased the capacity of existing facilities at ground stations. The International Maritime Satellite Organization (INMARSAT), formed in 1979, provides a mobile telecommunications network of digital data links, telephone and facsimile transmission (or fax) services between ships, offshore facilities and shore-based stations throughout the world.

9. The orbit selected for a satellite depends upon the work it will be doing. A low orbit (about 300 km up) is the easiest to achieve - and this is used by the Soviet space station Mir and the American Space Shuttle. However, a satellite in low orbit can "see" less of the Earth's surface at any one time than one in high orbit, so more would be needed for continuous coverage of any given area from low orbit. The inclination of the orbit (that is, the angle that the orbit makes with the equator) is also very important.

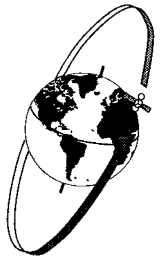


Fig 4-4 A Polar Orbit

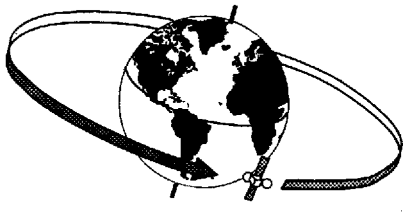


Fig 4-5 An Equatorial Orbit

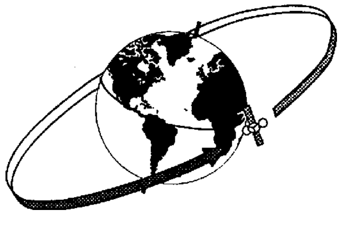


Fig 4-6 An Eccentric Orbit

An orbit with 90° inclination is called a “polar orbit”, and one with 0° inclination is an “equatorial orbit”; all others are called ìeccentric orbitsî. Satellites for surveying or spying tasks are normally put into polar orbit because, regardless of how high or low they are, they can in due course cover the whole globe whilst the Earth spins about its N-S axis. Weather and communications satellites usually use equatorial orbits at a height of 35,880 km (that is, a geostationary orbit), which enables them to hover over one spot and cover a large area. Moreover, being stationary relative to their ground stations, they can be used 24 hours a day. However, some countries do use eccentric orbits for communication satellites, particularly if their launch sites are at high latitudes, from which it is difficult to achieve equatorial orbits. A well-chosen eccentric orbit can place a satellite over the desired area for quite a lot of its orbit time - an example being the Russian communications satellites in the Molnya series.

10. Ideally, to achieve an equatorial orbit the launch site should be on the equator. Most sites are not, so their satellites have to be put initially into a “parking orbit”. In this eccentric orbit the satellite will eventually pass over the equator, but at an angle to it (the angle of inclination of the orbit). Just before it reaches the equator, the satellite’s rocket motor is used to provide precise amounts of thrust in exactly the right direction, to change the orbit from eccentric to equatorial. This manoeuvre is expensive because of the precious fuel needed to complete the change. The fuel is precious not by virtue of its price at ground level, but because of the huge cost of lifting it into space (bigger launch rocket, more weight, bigger engines needed).

11. Once a satellite has been placed into its orbit, maintaining the orbit can prove difficult. The satellite is subject to outside forces which, if not controlled, would cause it eventually to depart from its designated course. These disturbing influences are called “perturbations”. Some minor ones include the effect of the Earth’s magnetic field on any ferrous metal in the satellite, the pressure of radiation particles from the Sun, and the inertia of any moving parts within the satellite. However, there can also be some major perturbations, due to the fact that the Earth is not a perfect sphere. The Earth is in fact an “oblate spheroid” - it is slightly flattened at the poles and it bulges slightly at the equator. The amount is little - the Earth’s diameter is 12,638 km between the poles and 13, 368 km at the equator - but it is enough to make the Earthís gravitational pull vary slightly from point to point. This can affect

the plane of the orbit, the effect being zero in polar orbit and a maximum in near-equatorial orbit. Also, the drag of even tiny amounts of the Earth's atmosphere can cause a major perturbation. The density of the atmosphere at 120 km high is one millionth of that at sea level, and at 400 km it is one million millionth. Nevertheless, there can be enough drag to slow the satellite down over a period. This reduces the centrifugal force which is counteracting the Earth's gravity (remember the ball whirling around on the end of a string) and eventually gravity pulls the satellite lower, where it is still travelling fast enough to burn up due to air friction in the thicker atmosphere.

12. Many satellites have a propulsion system to correct for perturbations. However, the fuel needed for the system must eventually run out. So how long can a satellite last? Primarily the height of the initial orbit is critical, especially the perigee in the case of elliptical orbits. Clearly, at perigee the satellite will encounter more drag-producing atmosphere than when it is farthest away, at apogee. If it has its own propulsion system it can compensate until the fuel runs out, but after that the crucial factor is the initial perigee of the orbit, as shown in this table.

Satellite	Perigee (Km)	Apogee (Km)	Life-time
"Close-look" Reconnaissance Satellite	118	430	15 Days
Sputnik 1	225	946	3 Months
Explorer 1	361	2,550	12 Years
Any geostationary	approx 36,000	approx 36,000	1,000,000 Yrs

13. Although satellites with a low orbit have a short life span they do have their uses and they can be fairly easily put into orbit. For example, there may be a short-notice need to put up a spy satellite to cover a particular country for a short time, so a cheap, low-orbit satellite at, say, 150 km would be used. By contrast, any satellite with a geosynchronous orbit is launched to last. This type includes communications (both military and commercial), meteorological, early warning satellites and navigational types (these will be described in more detail later). Moving in the same direction as the Earth's rotation, the satellite remains in a fixed position over a point on the equator, thereby providing uninterrupted contact between ground

stations in its line of sight. The first communications satellite to be placed in this type of orbit was the Syncom 2, launched by the USA's National Aeronautics and Space Administration (NASA) in 1963.

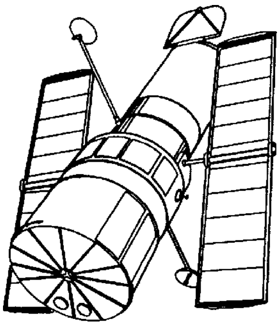
14. We have all heard of the "spy in the sky". This type of satellite is used to watch, from space, whatever is happening in another country. They gather intelligence by "listening" to radio communications, and they observe troop movements, track shipping (including submarines), and photograph installations of interest. The technology used on these satellites is very advanced and the cameras are so sensitive that even from 150 km in orbit they can see a person on the ground. Since the end of the "cold war" between the West and the Warsaw Pact countries, the Russians have been selling this type of photograph - perhaps you could buy one of your house!

15. Other satellites can give early warning of ballistic missile attacks by detecting the heat given off by the missiles' rocket motion. The satellites' infra-red sensors can spot a missile at launch and plot the position of the launch site to within 3 km. They can also detect nuclear explosions at or near the Earth's surface, which is very useful for the monitoring of nuclear test-ban treaties.

Observatories.

16. Telescopes on the ground are hampered by the Earth's atmosphere. Even on the clearest of cloud-free nights there is some distortion which detracts from the quality of pictures taken at observatories. So why not put one above the atmosphere? In fact, space observing satellites have been in use since 1970. The first was Uhuru and the latest was the Hubble Space Telescope, launched in 1990 from the Space Shuttle Discovery.

Fig 4-7 *Hubble*



Hubble can detect objects 50 times fainter and 6 times further away than is possible from the ground. Other satellites designed for astronomical observations include IRAS (Infrared Astronomy Satellite) and IUE (International Ultraviolet Explorer). In 1983, before its equipment failed TIRAS searched 99% of the sky and detected over a quarter of a million new astronomical objects from the heat (infrared radiation) that they emit. Launched in 1978, IUE has enabled scientists to calculate the weight of a “black hole”.

Earth Resources Satellites

17. Landsat us a series of United States satellites that have been used to chart and record the worldís resources since 1972. They observe forests, coal and oil fields, floods, drought and pollution, and they plot the movement of icebergs. They use infra-red and multi-spectral techniques, from polar orbits at a height of about 1000 km. It is a commercial venture, and its operators are able to sell vast quantities of valuable information to geographers, geologists, oceanographers, ecologists, agriculturists, governments and many others.

Weather Satellites

18. Meteorology was one of the earliest applications of satellites. From the first weather satellite TIROS (Television and Infra-Red Observation Satellite) launched by the US in 1960, to the current Meteosat in the European Space Agency’s series, the use of space has vastly improved weather forecasting. Lives are saved by early warnings that hurricanes are about to strike, and farmers can leave their crops to ripen fully, knowing that they will be given good advance notice that rain is on the way. Various orbits can be used. TIROS was in polar orbit at 700 km, whilst Meteosat is geostationary at 35,880 km.

19. Russia has recently launched a meteorological satellite (in geostationary orbit) as part of its contribution to the world-wide network of weather observation satellites. This satellite orbits at 76° East and covers to Arctic, Antarctic and Northern Seas giving accurate information on ice, wind and temperature conditions, using optical, microwave and radiolocation systems to achieve its task.

20. The European Space Agency’s ERS 1, launched in 1991, is a climate/ environment research type satellite that transmits high resolution pictures of the

areas it covers. These include pictures through cloud cover and fog banks. The satellite orbits Earth every 100 hours and takes some 30 days to survey the planet. Users have direct contact with the satellite and the data rate from the satellite is 105 Mb per second - 5,600 typewritten pages.

Communications Satellites

21. With the growth in computers, telephone and space technologies, satellite broadcasting is the biggest single advance in communications since Marconi invented the radio. The services provided by satellite broadcasting systems have given millions the possibility of access to a global network of information and entertainment. Even Telstar, which in 1962 was the world's first "active" communications satellite, offered more capacity across the Atlantic than the existing cable and radio links combined. The Intelsat series of satellites, from I in 1965 which could carry 240 telephone circuits, to VI in 1989 which had a capacity of 24,000, show the advancement of technology. There are numerous other commercial systems in use - for example the US Comstar, the most recent of which can handle 18,000 telephone calls at once - so the amount of information being carried world-wide by all the existing systems almost defies the imagination. The ability of communications satellites to use radio signals of extremely high frequency (which means that the signals have exceptionally wide wave bands), means in turn that they can carry vast quantities of information. This makes them very profitable commercially. Moreover, it is particularly useful for military purposes, as information can be put into complex codes which are virtually impossible to decipher by any potential enemy.

Satellite Navigation System (GPS)

22. The NAVSTAR Global Positioning System (GPS) is a space-based radio positioning system which uses information from satellites to provide a user anywhere on or near the Earth's surface with position, velocity and time. GPS requires a minimum of 21 satellites to give worldwide coverage, but 24 have been placed in orbit so that the system can continue to work in the event of satellite failures. The orbit height is 20,200 km and a complete orbit takes about 12 hours. The satellites are arranged in 6 orbital planes, all of which are includes at 55° to the equator. There are 3 or 4 operational satellites in each orbit, and the overall arrangement is

such that at least 5 are normally observable by a user anywhere on Earth. The system is available globally, continuously and under all weather conditions. As the receivers operate passively there can be an unlimited number of simultaneous users.

Space,Control and User

23. There are 3 major components or segments to the system, known as Space, Control and User:

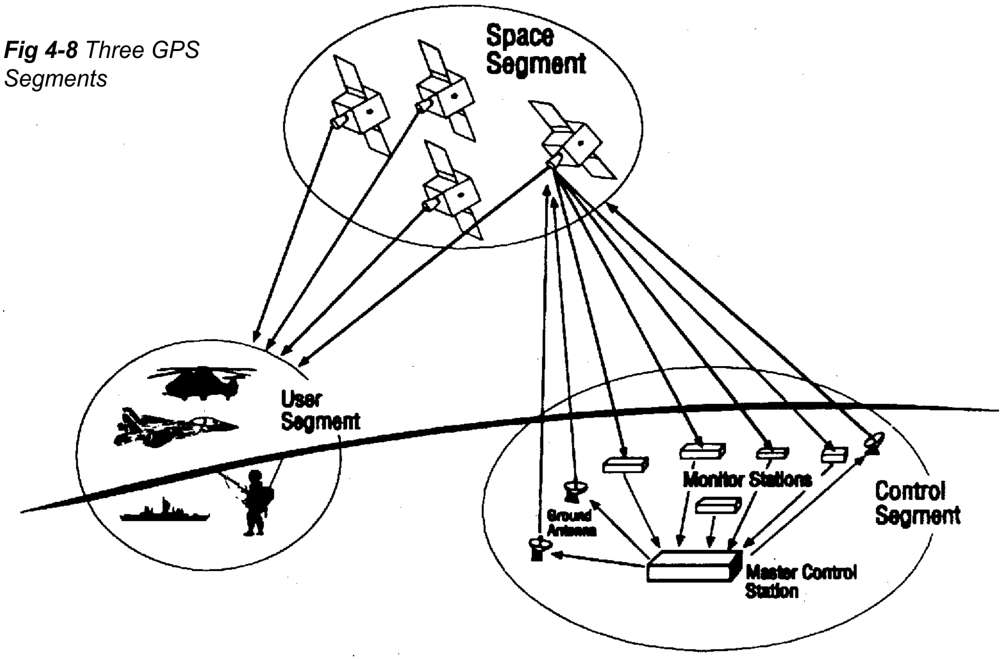
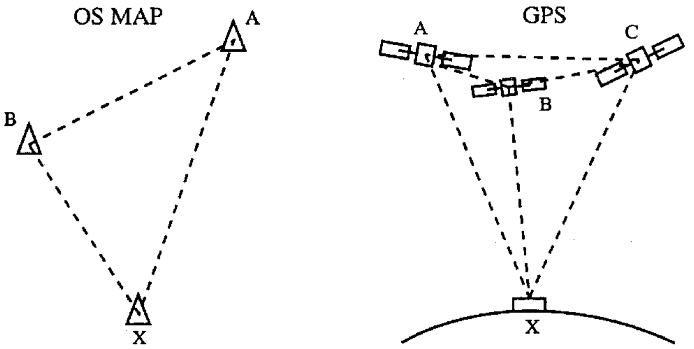


Fig 4-8 *Three GPS Segments*

a. The space segment consists of the satellites themselves. Each one “knows” its own position and is programmed to transmit a coded message which includes its position and the time of the transmission.

b. The control segment consists of one Master Control Station (MCS) in Colorado Springs (USA), together with additional monitor stations at Hawaii, Kwajalein (Western Pacific), Diego Garcia (Indian Ocean), and Ascension (South Atlantic). The monitor stations passively track all GPS satellites in view, collecting ranging data. They pass this to the MCS, where any errors in the information received from each satellite are corrected. This includes errors in the satellite’s own position and in the time provided by its own clock - very tiny errors by all normal standards, but vital to the operational effectiveness of this precise system. Having made the corrections, the MCS periodically uploads the data to each satellite, which immediately adjusts its own coded message.

c. The user segment consists of many different types of military and civilian GPS receivers which can decode and process the satellite signals. Receivers vary from a “stand alone” handset which can be carried in your pocket, to one which is an integrated part of a highly complex military system. There are also applications other than navigation, for example surveying. However, all receivers operate on the same general principle, using the coded messages from the satellites. Each coded message includes the time of transmission, and the receiver also uses a clock to mark the time when the message arrives. Thus the time delay from transmission to reception can be calculated. This time delay is directly linked to the distance between the satellite and the user, so the receiver now calculates that distance. By using several satellites the receiver calculates its position, using the technique called triangulation. The method used is similar to the way a surveyor calculates the position of a triangulation point on an OS map using the distance between the unknown point and other known points as shown at Fig 4-9.



1. Positions A and B, and distance AB are known.
2. Distances BX and AX are measured.
3. Surveyor can calculate position of X.

1. Positions A, B, C are known.
2. Distances AX, BX, CX are measured.
3. Receiver can calculate position of X.

Fig 4-9 Triangulation

The receiver continuously updates and displays the latitude and longitude of the user’s position and from the rate of change of the position it can also calculate and display the user’s velocity (speed and direction). Finally, as GPS works in 3 dimensions it can also give the user’s altitude.

24. GPS is funded and run by the American military, who currently authorise other users to operate the system free of charge. The American military can increase or decrease the accuracy of GPS at any time. For non-military users, on the vast majority of occasions the GPS latitude/longitude should be within 100 m of the true position. The system is a little less accurate in altitude, normally being within 180 m. For authorised military users these figures may be as good as 8 m and 11 m respectively, and possible military flying applications include:

Navigation (high and low level)

Target acquisition

Close air support

Missile guidance

All-weather air drops

Search and Rescue

Photo-reconnaissance

Range instrumentation

Precision surveys

Instrument approaches

25. Clearly GPS, as an all-weather, world-wide precision navigation aid which can accommodate any number of users, is one of the most valuable applications of satellite technology. It is justly popular, and at a few hundred pounds, receivers are within the reach of many groups and individuals.

Self Assessment Questions

Do not mark the paper in any way - write your answers on a separate piece of paper, in the form of a sentence.

1. What did Marconi invent in the early 1900s?

2. What year did the Soviet Union launch the first artificial communication satellite - Sputnik 1?

3. What is an orbit with zero degree inclination called?

4.What are all other orbits called?

CHAPTER 5

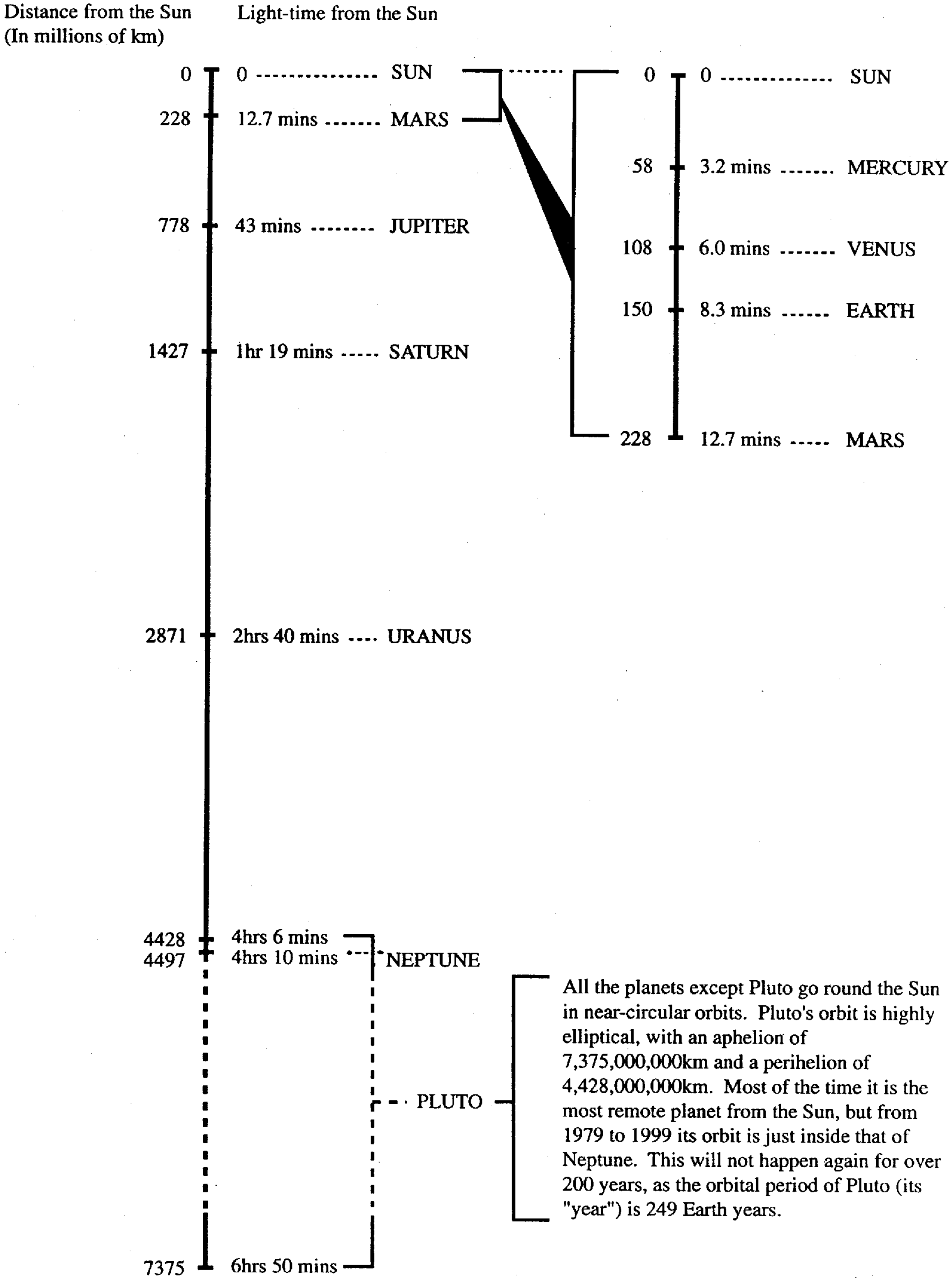
SPACE COMMUNICATIONS

Introduction

1. A logical step for satellite communications is to use the technology to improve our knowledge of the Solar system and the Universe, and to attempt to establish communications with any other beings that might be "out there". Although a space vehicle that has left Earth's orbit is no longer an Earth satellite, it will become a satellite of other heavenly bodies - the Sun, other planets, other stars perhaps - at various stages of its existence - and the principles are unchanged.

Leaving Earth Behind

2. If a spacecraft in Earth orbit is boosted to Earth escape velocity, it can escape the clutches of Earth's gravity and travel to other planets. However, at present there are no practicable plans for human beings to visit other planets, as the cost would be prohibitive - in fact it is doubtful whether the combined resources of all the major countries could support a manned mission, even to one of our immediate neighbours in the Solar system, Mars and Venus. Manned missions to the more distant planets pose, in addition, huge problems in terms of distance and time. Whereas a spacecraft could reach Mars in about 10 months, the travel time stretches to 2 years for Jupiter (the next planet out from Mars) and to around 12 years for Neptune and Pluto, the outermost planets. Apart from the fact that young astronauts leaving Earth to visit Pluto would return middle-aged, building a spacecraft large enough for an acceptable lifestyle on a round trip lasting a quarter of a century is far beyond our current capabilities. However, we do have the means of sending smaller craft, and in fact dozens of vehicles carrying scientific instruments have been exploring our Solar system since the early 1960s.



All the planets except Pluto go round the Sun in near-circular orbits. Pluto's orbit is highly elliptical, with an aphelion of 7,375,000,000km and a perihelion of 4,428,000,000km. Most of the time it is the most remote planet from the Sun, but from 1979 to 1999 its orbit is just inside that of Neptune. This will not happen again for over 200 years, as the orbital period of Pluto (its "year") is 249 Earth years.

Fig 5-1 *The Solar System*
- Distances from the Sun

How Far is "Far"?

3. Astronomical quantities and distances are virtually impossible for the mind to grasp. Our own Sun is a fairly insignificant star in our galaxy the Milky Way, which contains an estimated 200 billion (200,000,000,000 or 2 x 10^{11}) stars altogether - and there are probably 100 billion (10^{11}) other galaxies! It takes light, travelling at 300,000 km/sec, 8 $^1/_3$ minutes to reach us from the Sun, which is 150 million (150,000,000 or 15 x 10^7) km away from the Earth - but the Milky Way is so vast that it takes light 100,000 (10^5) years to cross it! In fact, astronomers use "light-years" (the distance travelled by light in one year) as a unit of distance. Thus, in km one light-year is 300,000 (km/sec) x 365 (days) x 24 (hours) x 60 (mins) x 60 (secs). Try working this out - it comes to about 9,500 billion (9,500,000,000,000 or 95 x $10^{11)}$ km - and you will soon understand why astronomers prefer light years to km. But it is still doubtful whether any of us can picture in our minds how vast a distance just one light-year really is, not to mention the distance across our galaxy of 100,000 light years! Fig 1-1 gives an indication of distances within our own Solar system.

How Fast is "Fast"?

4. At present, humans can travel light-year distances only within the realms of science fiction. The speed of light (which is also the velocity of other waves in the electro-magnetic spectrum (eg radio) is a kind of absolute speed limit. Only light and similar waves that have no intrinsic mass can travel at that speed. Anything that has mass - a space vehicle, for example - is limited to sub-light speeds. This stems from Einstein's special theory of relativity from which Einstein concluded in 1905 that mass and energy are the same thing. He produced a formula showing the relationship between the energy and mass of a moving body: $E=Mc^2$, where E = energy, m = mass and c = the speed of light. The concept in the formula is that the energy of motion adds to the mass of a moving body. The effect is noticeable only at really high speeds. For example, if you weighed 60 kg and then travelled at one tenth of c, your mass would increase by only 0.3 kg (ie 1/200th). Even that speed is not practicable at present - to put it in perspective, you would reach the Moon in just 13 seconds! However, taking it further, at 9/10c your body mass would be doubled, but as your speed approached even closer to c, your mass would rise immeasurably - to infinity, in fact - and the energy needed to get your body finally to the speed of light would also be infinite. In other words, even if your body could

withstand the forces involved, you could never find an energy source great enough. However, science fiction enthusiasts can take heart, as we shall see. Einstein's 1905, "special" theory of relativity left some doubt as to the nature of gravity. Gravity is a force of attraction between bodies - the Sun and the Earth, the Earth and you, and so on - which varies with the distance between the bodies. The area of doubt was, that if one body is moved so as to change that distance, the gravitational force appears to change instantaneously, but unfortunately the idea that a force can move with infinite speed does not fit in with the idea that the speed of light is the universal upper speed limit. However, in 1915 Einstein resolved this with his "general" theory of relativity, concluding that gravity is not a force in the normal sense, but is due simply to the fact that space-time, instead of being flat as was then thought, is curved (warped) by the influence of energy and mass. Perhaps the "warp drive" of fiction's Starship Enterprise will eventually become real life? Certainly, Einstein's theory has been verified by observations such as light appearing to curve as it passes close to large masses such as the Sun.

Problems in Space

5. Meanwhile, back in the present we still have the problems of astronomically huge distances and strict practical limits to the size and speed of space vehicles. Although unmanned exploration of our Solar system is well under way, similar expeditions for outside that system are not really feasible, as even the nearest star (Proxima Centauri) is 4.3 light-years away. Even within our Solar system, the distances involved bring problems that do not trouble satellites in Earth orbit. For example, power is needed to operate, and to keep at working temperature, the scientific and directional instruments in satellites and space probes. Solar cells (which convert sunlight into electricity) are used as a power source on many Earth satellites and some probes. However, sunlight is much too weak for this at the outer planets, so probes that are to travel far from the Sun must carry their own energy - typically, a radioactive source powering an electric generator. Similarly, probes travel so far from Earth as to be outside the range of any immediate control from base. Radio signals to and from them take hours, rather than the fraction of a second in Earth orbit. Consequently they must be able to operate independently - that is, to alter course in emergency, and use their computer programmes to diagnose and overcome faults in their instruments as far as possible.

Getting There - In Theory

6. Ultimately, space probes must be capable of reaching their destinations largely by "coasting" through space, as prolonged use of engine power would consume impossible quantities of fuel. This is achieved initially by launching them from Earth on a path that will intercept the orbital plane of the desired planet at a time when the planet will be there! Fortunately, apart from Pluto's, the planetary orbits are nearly circular and lie in the same plane - ie the system is flat, as in Fig 5-2.

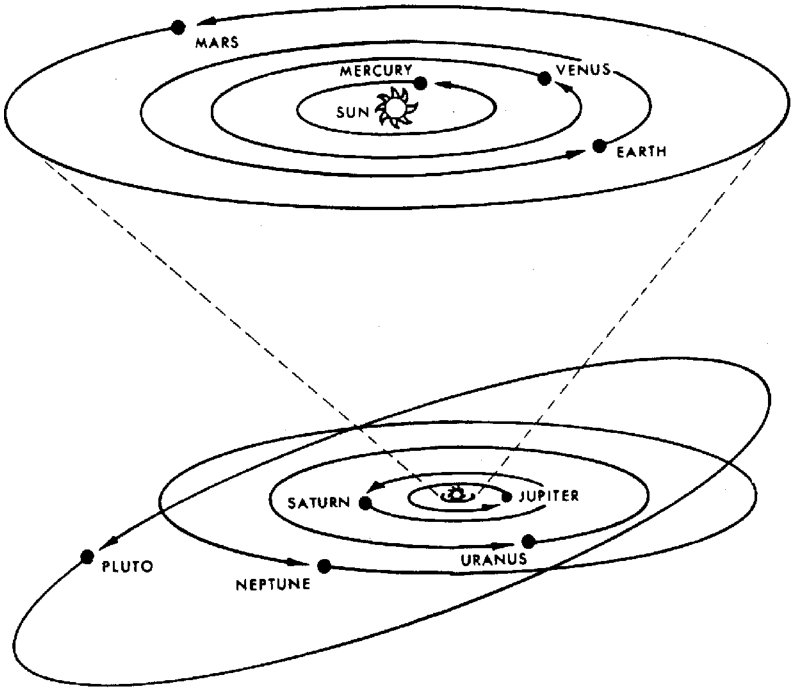
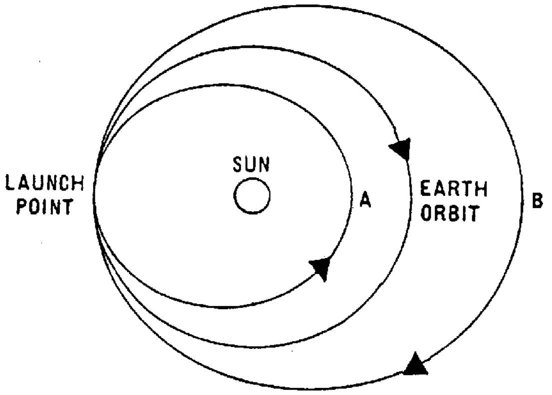


***Fig 5-2** Solar System - Orbital Planes*

(Viewed from a Slight Angle Above the Plane of the Orbits)

This makes it a relatively simple matter to launch a probe into a Sun orbit which will in due course intersect the orbit of the destination planet. In Fig 5-3 (next page), imaging launching 2 space vehicles simultaneously from Earth, one in the opposite direction to that of Earth's orbit around the Sun, and one in the same direction. We shall give each the same velocity relative to Earth - escape velocity - but after escaping Earth to become satellites of the Sun, they will have different velocities relative to the Sun. The Earth orbits the Sun at about 30 km/sec, so this amount will be deducted from the Sun orbit speed of the first craft, and added to that of the second. These are shown as orbits A and B respectively on the diagram. Orbit A would be used if visiting planets closer to the Sun than Earth - Mercury and Venus - whilst orbit B would be preferred for the outer planets.

Fig 5-3 *Two Types of Sun Orbit (Viewed from directly above the Orbital Plane)*



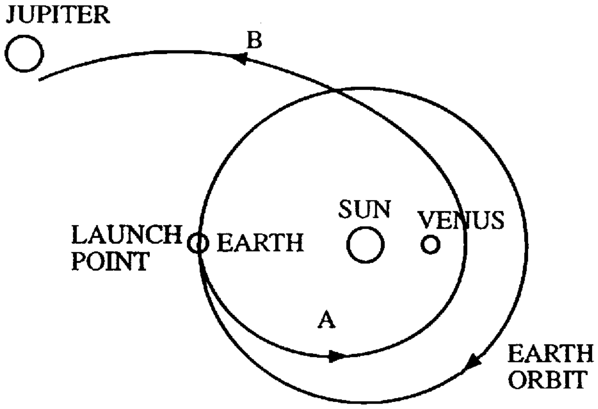
7. When a probe intercepts its target planet's orbit it may crash onto the planet, or it may "fly by" at a distance according to the type of readings to be taken by its instruments. Alternatively it can be slowed down by its own motor, such that when it reaches the planet it is below that planet's escape velocity; it can then orbit the planet and, if required, make a soft landing for surface investigations.

Getting There - For Real

8. Our description of how to launch space probes is, of course, very much simplified. In practice the calculations for launch points, launch times and injection speeds are immensely complex - and one of the most important factors is the optimum launch date for the shortest journey time. This applied particularly to the journey of Voyager 2, which left Earth in 1977 and reached Jupiter in 1979, Saturn in 1981, Uranus in 1986 and Neptune in 1989. All this was made possible by 2 features. One was a natural event - namely, the 4 planets being for a time on the same side of the Sun and approximately aligned with each other. This happens only once every 175 years, as the planets have such widely differing personal "years" (Jupiter circles the Sun in about 12 Earth years, Saturn in just over 29, Uranus in 85, and Neptune in nearly 165). The other feature was a brilliant concept in space travel. The approach path to each planet was carefully calculated and adjusted,

such that the planet's gravity could be used to accelerate the probe and boost it onwards to the next planet. The technique has been variously described as "gravity boost", "sling-shot" or, more widely, "gravity assist". The technique can also be used to send a probe first to one of the inner planets and then to the outer planets. It would initially leave Earth on Orbit A at Fig 5-4, and on reaching the inner planet (eg Venus), gravity assist from that planet would be used to accelerate it into highly elliptical Orbit B. This orbit is wider than that of Earth around the Sun, hence the probe can travel to an outer planet (say, Jupiter).

Fig 5-4 *Visiting an Inner and an Oiuter Planet*



Is There Anyone Out There?

9. Using this superbly conceived and faultlessly implemented notion, Voyager 2 (and some similar probes) eventually achieved Sun escape velocity, so they could leave the Solar system for deep space. These probes carry messages that should give basin information about the human race to any aliens who might find and retrieve the spacecraft. However, the chances are slender, as the craft are travelling at only a tiny fraction of the speed of light, and will take some 18,000 years to reach even the nearest star (Proxima Centauri). Perhaps a better hope for contact with another species is the radio signals that have been accidentally leaking into space - at the speed of light - since radio began in the early part of the 20th century! Or, failing the invention of a "warp drive", the radio message that was beamed from the radio telescope in Arcebo, Puerto Rico, in 1974 to a "globular cluster" of stars known as M13 might succeed. The "message" will require a level of intelligence similar to that of the human race to decipher it. It comprises 1,679 on-off commands - and the clues are that 1,679 = 23 x 73, and that no other numbers equal 1,679 when multiplied together. Once this is realised, and the on-off commands are arranged in

a rectangle whose sides are in the ration 23 by 73, they make a picture which gives some information about the human race. If anyone receives it at M13 and sends a message back, let us hope they have a quicker system than light-speed - ours will take 25,000 years to reach M13!

Hubble Space Telescope

10. The Hubble Space Telescope was launched into orbit around the Earth in 1990. Unfortunately, NASA scientists soon discovered that a microscopic spherical aberration in the polishing of the Hubble's mirror significantly limited the instrument's observing power. During a previously scheduled servicing mission in December 1993, a team of astronauts performed a dramatic series of space walks to install a corrective optics package and other hardware. The hardware functioned like a contact lens and the elegant solution worked perfectly to restore Hubble's capabilities. The servicing mission again demonstrated the unique ability of humans to work in space and enabled Hubble to make a number of important astronomical discoveries.

R = Russia,

A = America,

E = European

DATE	*SPACECRAFT	EVENT
1959	Luna 2 (R)	First probe to land on the Moon (unmanned, crash landing)
1966	Luna 12 (R)	First successful transmission of images from Moon's surface (unmanned, soft landing)
1968	Apollo 8 (A)	First manned flight around the Moon
1969	Apollo 11 (A)	First man to set foot on the Moon (Neil Armstrong)
1972	Apollo 17 (A)	Last man to set foot on the Moon (Jack Schmitt)
Mar 73	Mariner 10 (A)	Launched, destination Venus and Mercury (the first probe to visit two planets and use gravity assist to reach the second)
Feb 74	Mariner 10 (A)	Venus flyby
Mar 74	Mariner 10 (A)	} Three close encounters (ie flyby) of Mercury
Sep 94	Mariner 10 (A)	} Transmitted back photographs of most of Mercury's
Mar 75	Mariner 10 (A)	} surface

Mariner 10 was the only probe sent to visit Mercury. It now orbits the Sun.

DATE	*SPACECRAFT	EVENT
1962	Mariner 2 (A)	First flyby of Venus, and the first successful mission to another planet
1970 to 1984	Venera (R)	} Total of 16 Venera probes. The first 6 which attempted a landing were destroyed by Venus' atmospheric pressure and temperature (respectively 90 times Earth sea-level pressure, and 460° surface temp)
1975	Venera 9 & 10 (R)	First photograph of Venus' surface sent back (soft landings)
1978	Pioneer 12 (A)	First radar images of Venus for map-making (50 km resolution)
1983	Venera 15 (R)	First detailed radar images from orbit (2 km resolution, equivalent to optical telescopic view of the Moon)
1984	Vega 1 (R)	Deployed balloons with instruments into Venus' atmosphere
May 89	Magellan (A)	Launched
Aug 90	Magellan (A)	Entered Venus polar orbit, began mapping planet with good resolution radar images (100 m resolution)
May 92	Magellan (A)	Completed radar mapping of 98% of Venus' surface (optical observations impossible as Venus always has total cloud cover)
More probes have been sent to Venus than to any other planet		

DATE	*SPACECRAFT	EVENT	
1964	Mariner 4 (A)	First photographs of Mars' surface; this was a flyby. Covered 1% of surface	
1971	Mariner 9 (A)	First survey of Mars from orbit. Covered whole globe (at 1 km resolution)	
Aug 75	Viking 1 (A)	Launched	Each Viking was in 2 parts - an orbiter and a lander. The landers sampled soil and atmosphere in a search for microorganisms (no life was found); they also signalled back weather conditions and functioned for 6 years. The orbiters circled Mars for a similar period, surveying the planet and sending back excellent images (10 m resolution).
Sep 75	Viking 2 (A)	Launched	
Jun 75	Viking 1	Entered Mars orbit	
Jul 76	Viking 1	Soft landing	
Aug 76	Viking 2	Entered Mars orbit	
Sep 76	Viking	Soft landing	
1993	Mars Observer (A)	An orbiting mission, to study Mars' climate and atmosphere	
1995	Mars 94	A lander mission, to deploy several small landers plus a balloon with instruments for atmospheric readings.	
Mar 72	Pioneer 10 (A)	Launched - primary mission tasks were to assess the dangers of travelling through the asteroid belts (main one is between Mars and Jupiter) and through the radiation hazards found around Jupiter	
Apr 73	Pioneer 11 (A)	Launched - mission as Pioneer 10	
Dec 73	Pioneer 10	First ever flyby of Jupiter, plus gravity assist out of the Solar system	
Dec 74	Pioneer 11	Jupiter flyby, plus gravity assist to Saturn	
Sep 79	Pioneer 11	Saturn flyby, plus gravity assist out of Solar system	

Pioneers 10 and 11 each carry an engraved plaque for the benefit of any alien who might retrieve it. It shows our Sun and its planets, the position of Earth in the Solar system, and a drawing of a man and a woman

DATE	*SPACECRAFT	EVENT
Sep 77	Voyager 1 (A)	Launched, carrying cameras plus instruments to measure magnetic fields, the composition of matter, electromagnetic wavelengths etc
Mar 79	Voyager 1 (A)	Jupiter flyby - plus gravity assist for journey to next planet
Nov 80	Voyager 1 (A)	Saturn flyby, including close approach past Saturn's largest moon, Titan (diameter 5,150 km)

During the Saturn/Titan flybys, gravity assist gave Voyager 1 escape velocity with respect to the Sun. It carries a long-playing record with greetings in 55 Earth languages (plus a selection of typical sounds found on Earth) for the benefit of any alien species that might find Voyager 1 in its journey through our Galaxy

DATE	*SPACECRAFT	EVENT
Aug 77	Voyager 2 (A)	Launched - instruments and cameras as Voyager 1
Jul 79	Voyager 2 (A)	Jupiter flyby, plus gravity assist to Saturn
Aug 81	Voyager 2 (A)	Saturn flyby, plus gravity assist to Uranus
Jan 86	Voyager 2 (A)	Uranus flyby, plus gravity assist to Neptune
Aug 89	Voyager 2 (A)	Neptune flyby, including close Triton flyby (Neptune's largest moon, diameter 2,700 km)

The Voyager missions brought us an immense wealth of information about the Solar system and the outer planets - including, for example, the discovery of 6 more moons of Neptune (in addition to those already known, Triton and Nereid). Voyager 2 achieved Sun escape velocity and is now heading towards the star Ross 248, over 40,000 light-years away. It carries the same messages as Voyager 1

Mar 86	Vega 1 (R)	Flyby the nucleus of Halley's Comet (within 8,000 km)
Mar 86	Vega 2 (R)	As Vega 1
Mar 86	Giotto (E)	Flyby the nucleus of Halley's Comet (within 500 km)

Primary aim of these missions was to determine the composition of the comet's head

DATE	*SPACECRAFT	EVENT
Oct 90	Ulysses (A)	Launched - primary aim to gain information about the Sun’s magnetic field and conditions at its poles (not visible from Earth)
Feb 92	Ulysses (A)	Jupiter flyby, plus gravity assist to achieve a Sun orbit with a view of the Sun’s poles
Oct 89	Galileo (A)	Launched-mission tasks include a series of close flybys of Jupiter’s “Galilean” moons (ie those found by Galileo - Io, Europa, Ganymede, Callisto - which are the four largest of the 16 moons of Jupiter presently known), and releasing a probe into Jupiter’s atmosphere for detailed studies of the atmosphere
Feb 90	Galileo (A)	Venus flyby
Dec 90	Galileo (A)	Earth flyby
Oct 91	Galileo (A)	Gaspra flyby (an asteroid)
Dec 92	Galileo (A)	Second Earth flyby
Aug 93	Galileo (A)	Ida flyby (an asteroid)
Dec 95	Galileo (A)	Arrival at Jupiter

Self Assessment Questions

Do not mark the paper in any way - write your answers on a separate piece of paper, in the form of a sentence.

1. What is gravity?

2. What do Solar cell do?

3. What speed does the Earth orbit the Sun?

Self Assessment Questions - Answer sheet

Chapter 1 Page 35.4.1-3

1. b
2. We have air
3. Space is a vacuum - no air

Chapter 2 Page 35.4.2-4

1. 7.9 km/sec
2. The outward force of an object travelling in a circle
3. Earth escape velocity

Chapter 3 Page 35.4.3-7

1. Newton’s third law states that every action must have an equal and opposite reaction
2. Thrust is obtained from the reactioin to the gas momentum, not by PUSHING ON THE MEDIUM.
3. Typical fuels are Liquid Hydrogen and Liquid Fluorine and Liquid Oxygen and Liquid Oxygen and Kerosene.
4. The 3 main parts of an American space shuttle are:

   Two solid-fuel rocket boosters (SRBs)
   One external tank (ET)
   One orbiter

5. The external tank (ET)

Chapter 4 Page 35.4.4-12

1. Radio
2. 1957
3. Polar Orbit
4. Equatorial Orbit
5. Eccentric Orbits

Chapter 5 Page 35.4.5-8

1. Gravity is a force of attraction between two bodies
2. Convert sunlight into electricity
3. 30 km/sec