Senior and Master Air Cadet

Satellite and Data Communications

Module (Learning Outcome) 1:

Know the types and roles of satellites and principles of earth orbit

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Module 1 Learning Outcomes

- Know the **types** and **roles** of satellites and **the principles of earth orbit**, including:
  - Uses of satellites.
  - Orbits.
  - Mission phases.
  - Station keeping.
  - Satellite components and uses.

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Lessons in Module 1

1. Introduction to satellites and their uses.
2. Orbits.
3. Satellite mission phases.
4. Satellite communications.
5. Satellite components.

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Satellite & Data Communications

Lesson 1:

Introduction to satellites and their uses

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Satellites and Their Uses

- In this lesson you will learn about the early development, types and uses of satellites, including:
  - Definition of a satellite.
  - Concept of Extra Terrestrial Relays.
  - The first artificial satellite: *Sputnik.*
  - Early experimental satellites.
  - The first commercial satellites.
  - Types and roles of satellites.

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Introduction

- Man-made satellites are used extensively for a **variety of specialist purposes**, due to their **benefits over land-based alternatives**.
- The first artificial satellite was launched in 1957.
- There are over 1,700 satellites in operation, owned by various operators such as:
  - Treaty-based intergovernmental organisations.
  - Nationalised companies and organisations.
  - Private companies.
  - Governments and militaries.
- The oldest active satellite is the AMSAT-OSCAR 7 communications satellite, which was launched in 1974 and is still used by radio amateurs.

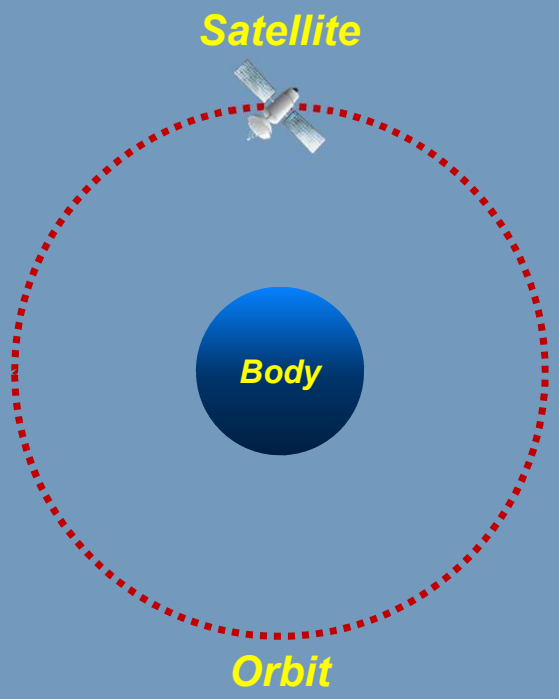


Image courtesy of Airbus

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Definition of a Satellite

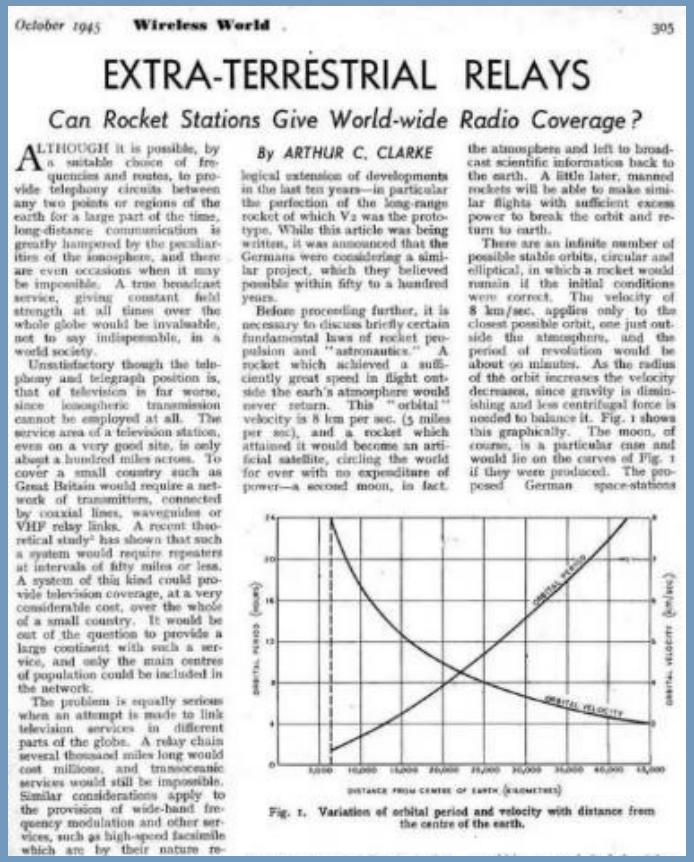
- A *satellite* is an object that moves around a larger object (known as a *body*) in space.
- The path that a satellite takes around a body is known as its *orbit*.
- There are two main types of satellite:
  - A *natural* satellite, such as a moon orbiting a planet.
  - A *man-made* or *artificial* satellite is a machine that is launched into space and orbits the Earth or another body in space.



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Concept of Extra Terrestrial Relays

- In 1945, Arthur C Clarke, a member of the British Interplanetary Society and a RAF radar specialist, wrote a letter to *Wireless World* magazine proposing that rockets could be used to launch man-made satellites.
- Later that year he published an article titled "*Extra-Terrestrial Relays".*
- He suggested that if three satellites were placed into high altitude orbit over the equator, separated by 120º, they could act as repeater stations and provide television and radio coverage over most of the earth.
  - Key benefit of using satellites: global coverage.



October 1945 **Wireless World** 305

EXTRA-TERRESTRIAL RELAYS

Can Rocket Stations Give World-wide Radio Coverage?

By ARTHUR C. CLARKE

ALTHOUGH it is possible, by a suitable choice of frequencies and routes, to provide telephony circuits between any two points or regions of the earth for a large part of the time, long-distance communication is greatly hampered by the peculiarities of the ionosphere, and there are even occasions when it may be impossible. A true broadcast service, giving constant field strength at all times over the whole globe would be invaluable, not to say indispensable, in a world society.

Unsatisfactory though the telephony and telegraph position is, that of television is far worse, since ionospheric transmission cannot be employed at all. The service area of a television station, even on a very good site, is only about a hundred miles across. To cover a small country such as Great Britain would require a network of transmitters, connected by coaxial lines, waveguides or VHF relay links. A recent theoretical study[2] has shown that such a system would require repeaters at intervals of fifty miles or less. A system of this kind could provide television coverage, at a very considerable cost, over the whole of a small country. It would be out of the question to provide a large continent with such a service, and only the main centres of population could be included in the network.

The problem is equally serious when an attempt is made to link television services in different parts of the globe. A relay chain several thousand miles long would cost millions, and transoceanic services would still be impossible. Similar considerations apply to the provision of wide-band frequency modulation and other services, such as high-speed facsimile which are by their nature re-

logical extension of developments in the last ten years—in particular the perfection of the long-range rocket of which V2 was the prototype. While this article was being written, it was announced that the Germans were considering a similar project, which they believed possible within fifty to a hundred years.

Before proceeding further, it is necessary to discuss briefly certain fundamental laws of rocket propulsion and "astronautics." A rocket which achieved a sufficiently great speed in flight outside the earth's atmosphere would never return. This "orbital" velocity is 8 km per sec. (5 miles per sec), and a rocket which attained it would become an artificial satellite, circling the world for ever with no expenditure of power—a second moon, in fact.

the atmosphere and left to broadcast scientific information back to the earth. A little later, manned rockets will be able to make similar flights with sufficient excess power to break the orbit and return to earth.

There are an infinite number of possible stable orbits, circular and elliptical, in which a rocket would remain if the initial conditions were correct. The velocity of 8 km/sec. applies only to the closest possible orbit, one just outside the atmosphere, and the period of revolution would be about 90 minutes. As the radius of the orbit increases the velocity decreases, since gravity is diminishing and less centrifugal force is needed to balance it. Fig. 1 shows this graphically. The moon, of course, is a particular case and would lie on the curves of Fig. 1 if they were produced. The proposed German space-stations

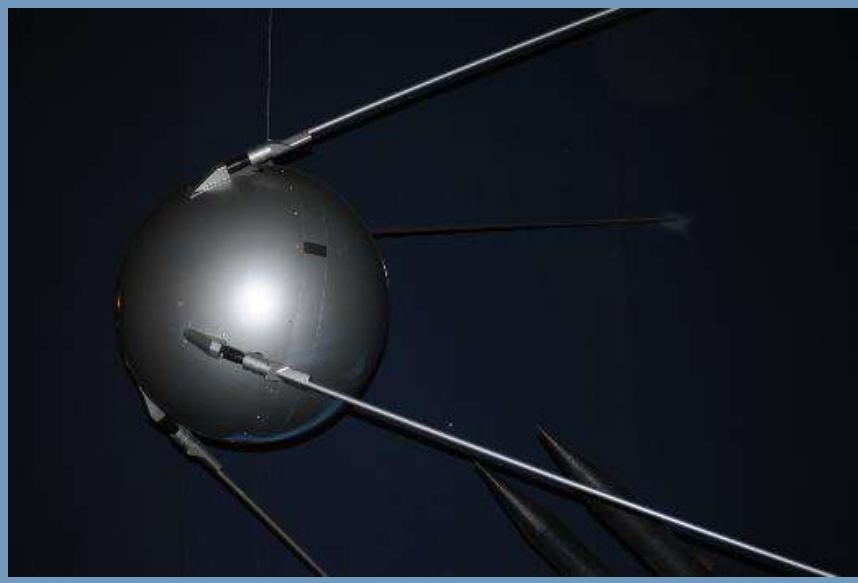
Fig. 1. Variation of orbital period and velocity with distance from the centre of the earth.

Image source Wireless World

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The first artificial satellite: *Sputnik*

- After World War II, advancements in missiles and microwave radio technology made man-made satellites a reality.
- On 4 October 1957 the first artificial satellite, named *Sputnik*, was launched by the Soviet Union.
- Sputnik 1, a 58 cm diameter sphere weighing 83 kg, was launched by an Intercontinental Ballistic Missile into an orbit varying from 225 km and 917 km above earth.
- It transmitted a characteristic *"beep-beep"* signal for 21 days before returning to earth.



Listen to the Sputnik signal

Image source jc⁴i

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Early Experimental Satellites

- The following years saw the launch of a series of experimental satellites:
  - SCORE (1958)
    - The first US-launched satellite. Transmitted a Christmas message recorded by President Eisenhower.
  - ECHO (1960)
    - A 30m aluminium-coated inflatable balloon, off which signals were passively reflected back to earth.
  - COURIER (1960)
    - The first electronic active store and forward repeater.
  - TELSTAR (1962) and RELAY (1962)
    - The first powered relay satellites to rebroadcast live television signal across the Atlantic.
  - SYNCOM (1963)
    - The first geostationary satellite. Broadcast live pictures of the Tokyo Olympic Games in 1964.



ECHO



TELSTAR



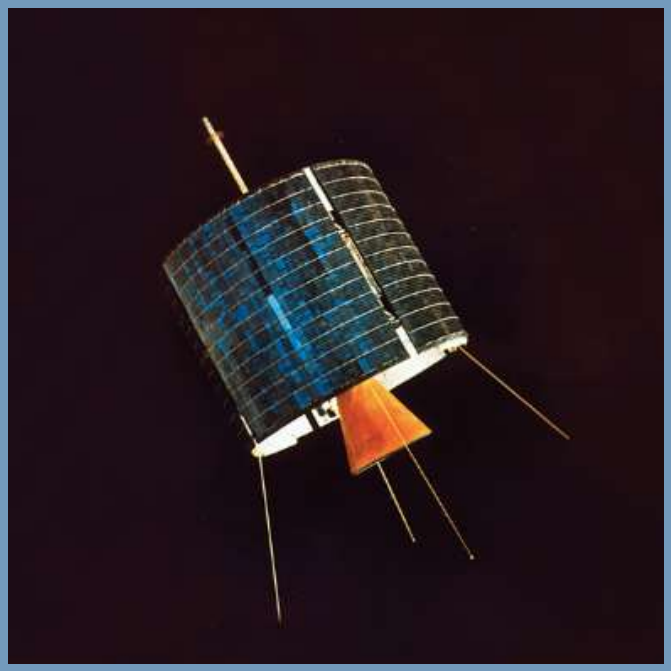
SYNCOM

Image source NASA

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The First Commercial Satellites

- In 1965, the first commercial telecommunications satellite, known as *Early Bird* (and later known as *Intelsat 1*) was launched into geostationary orbit.
- It transmitted telephone and television signals across continents, to supplement the capabilities of submarine cables.
- It provided capacity for only 480 telephone channels and one TV channel.
- The Soviets also launched their first *Molynya* satellite in the same year.



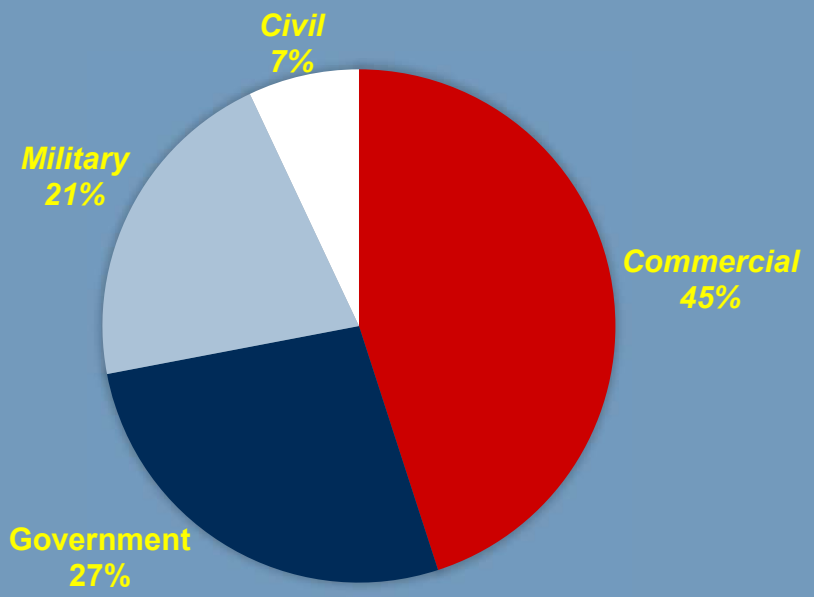
Early Bird

Image source NASA

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Types and Roles of Satellites

- A satellite is launched for a specific purpose and is classified according to its role.
  - Communications
    - Broadcasting, Telecommunications, Data Distribution and Exchange
  - Radiodetermination
    - Positioning, Navigation, Timing
  - Surveillance
    - Reconnaissance, Remote Sensing, Meteorology, Search And Rescue
  - Space Science
    - Astronomy



Satellite usage in 2017

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Cadet Activity

- Cadets should now investigate the different types and roles of satellites from the Internet and other sources, comparing outcomes with the group.
- 4 groups:
  1. Communications satellites
  2. Radiodetermination satellites (Positioning, Navigation, Timing)
  3. Surveillance satellites (Reconnaissance, Remote Sensing, Meteorology, Search And Rescue)
  4. Space science satellites (e.g. space astronomy)
- Think about:
  - What are satellites of this type used for? (What do they do?)
  - Why is that useful? (How might it be easier than doing the same thing from the ground?)
  - Who uses/operates satellites of this type?

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Communications

- Communications Satellites, or “COMSATS”, are the most common satellite in use with around 750 operational in 2017.
- They provide capabilities not readily available with, or which can supplement, land based communication systems.
- Commercial COMSATS are used for services such as:
  - Direct broadcasting (e.g. television and radio).
  - Digital telecommunications (e.g. telephony, mobile communications).
  - Data distribution and exchange (small terminal low capacity data transmission, multimedia and Internet access).
- The military rely heavily on satellites for communications with forces abroad, making it possible to:
  - Direct operations from 1000s of km away.
  - Co-ordinate widely scattered land, air and sea forces.

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Radiodetermination

- *Global Navigation Satellite Systems* (GNSS) provide 3-dimensional *position, navigation and timing* (PNT) information to receivers on the land, sea and in the air.
- They enable anyone with a receiver to determine their location to within a few metres.
- GNSS are used intensively in military, industrial, commercial, public safety and consumer applications replacing existing conventional methods of navigation.
- There are currently three major GNSS systems in operation with more in development:
  - *GPS* – United States.
  - *GLONASS* – Russia.
  - *GALILEO* – Europe.

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Reconnaissance

- *Reconnaissance* satellites are used by governments and militaries to:
  - Provide intelligence on foreign military activities.
  - Detect missile launches or nuclear explosions.
  - Monitor electromagnetic transmissions while passing over a country.
- There are three main types of reconnaissance satellites in use:
  - Optical and infrared imaging – these detect missile launches and observe enemy weapon systems on the ground
  - Radar imaging – these are able to observe the Earth using radar, even through cloud cover
  - Signals intelligence (SIGINT) - satellites with sensitive receivers to capture radio transmissions
    - Wireless communications (Communications Intelligence - COMINT).
    - Other types of electronic emissions, such as radar (Electronic Intelligence - ELINT).

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Remote Sensing

- *Remote sensing* is the process of detecting the physical characteristics of the Earth from a distance by measuring its reflected and emitted radiation.
- Special sensors on-board satellites can make different types of images of the earth using various electromagnetic frequency bands such as:
  - Visible light.
  - Infra-red.
  - Microwave.
- Used to:
  - Map and monitor resources, such as locating mineral deposits and monitoring crops.
  - Observe areas where the climate is harsh or which are hard to reach by land.
  - Monitor environmental changes that are difficult to measure on the ground, such as deforestation, wild fires, ice cap shrinkage, spreading deserts and other large scale phenomena.

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Meteorology

- Most data used by weather forecasters now comes from *meteorology* satellites, which monitor the Earth's weather and climate, and assist in making weather predictions.
- Typically, five sensors operating in different frequency bands take images of the same scene:
  - Visual imaging identifies cloud locations and weather fronts
  - Infra-red and microwave sensors measure surface and atmospheric radiation to estimate the amount of heat and energy being released, the amount of water vapour and the sea temperature.
- Weather satellites can also be used to:
  - Monitor the movements hot or cold air masses, the amount of snow, the movement of ice fields and the depth of the ocean.
  - Examine crop conditions, areas of deforestation and drought.
  - Detect volcanic eruptions and the motion of ash clouds.
  - Relay environmental data from remote collection platforms.

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Search and Rescue

- *Search and Rescue* (SAR) satellites can be used to detect and locate emergency beacons activated on ships, aircraft, or individuals in remote or dangerous places.
- COSPAS-SARSAT (Search and Rescue Satellite Aided Tracking) is a satellite-based international, humanitarian search and rescue system.
- The system consists of a network of SAR instruments flown on remote sensing and navigation satellites, ground stations, mission control centres, and rescue coordination centres.
- When an emergency radio beacon is activated, the signal is received by a satellite then relayed via the nearest ground station to a local user terminal.
- The ground system identifies the beacon, calculates its position using Doppler techniques, and alerts the appropriate rescue coordination centre.
- A distress message can then be sent to the appropriate authorities from anywhere on Earth, 24 hours a day, 365 days a year, to instigate a rescue mission.

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Astronomy

- An *astronomy* satellite is a large telescope located in Earth orbit.
- Satellites can see into space up to ten times better than a telescope of similar strength on Earth, as:
  - Optical sensors are not impaired by the Earth's atmosphere.
  - Infrared imaging equipment is less confused by the heat of the Earth.
- Astronomy satellites are used to:
  - Map the stars in the universe
  - Take images of other planets and assess their composition (or that of their atmospheres).
  - Study unusual phenomena such as black holes and quasars.
- The *Hubble Telescope* is perhaps the best known example.

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Summary of Lesson 1

- A *satellite* is an *object* that goes round a larger *body* in space. The path it takes is its *orbit*.
- Satellites can be *natural* (e.g. moons) or *artificial* (man-made). They don't have to orbit Earth.
- Arthur C Clarke, a RAF radar pioneer, wrote about *Extra-Terrestrial Relays* in 1945.
- The first satellite was *Sputnik*, launched by the Soviet Union in 1957. It just beeped.
- A *space race* ensued between the US & USSR. Satellites were *commercially viable* by 1965.
- Satellites typically have a *specialist role,* due to orbit and weight limitations. E.g.:
  - **Communications** (Broadcasting, Telecommunications, Data Distribution and Exchange).
  - **Radiodetermination** (Positioning, Navigation, Timing).
  - **Surveillance** (Reconnaissance, Remote Sensing, Meteorology, Search And Rescue).
  - **Space Science** (Astronomy).
- There must be some *benefit* to using a satellite over doing it on land; e.g. global coverage.

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Satellite & Data Communications

Lesson 2:

Orbits

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Orbits

- In this lesson you will learn about the principles of satellite orbits including:
  - Kepler's laws of planetary motion.
  - How satellites stay in orbit.
  - Definition of orbits.
  - Popular operational orbits.
  - Orbital slots.
  - Space debris.

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Kepler's Laws of Planetary Motion

- An *orbit* is a regular, repeating path that one object in space takes around another.
- In the 17th century *Johannes Kepler*, a German astronomer, used accurate records of planetary observations over many years to arrive at an understanding of how planets orbit the sun.
- He described the behaviour of a satellite in Earth orbit by his three *laws of planetary motion:*
    1. The orbit of each planet is an ellipse, with the sun at one focus.
    2. The line joining each planet to the Sun sweeps out equal areas in equal times.
    3. The square of the period of the planet's orbit is proportional to the cube of its mean distance from the sun.

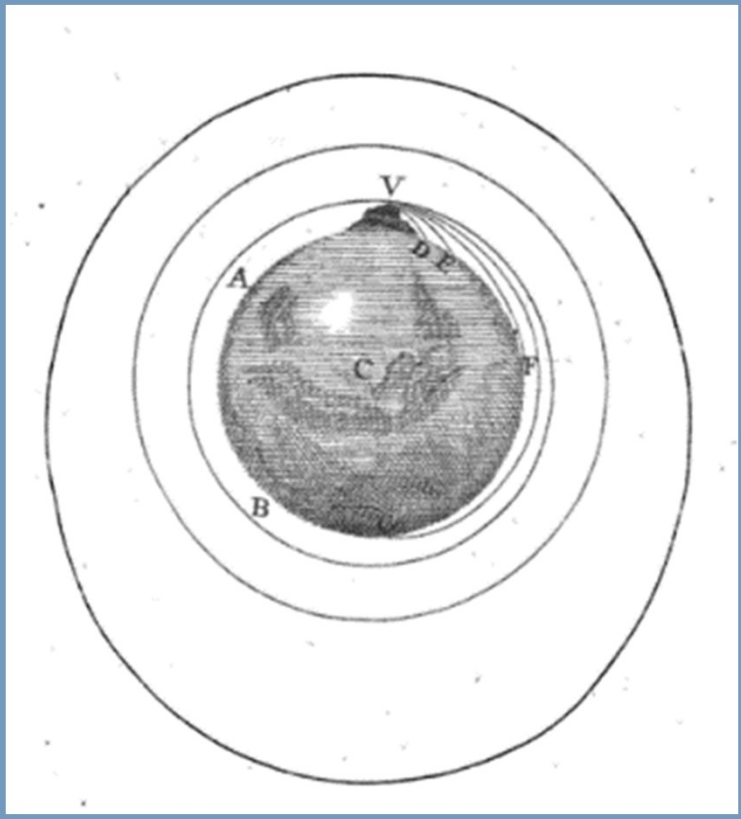


Johannes Kepler

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How Satellites Stay in Orbit

- About 70 years after Kepler, *Isaac Newton* used the newly formed principles of physics to prove that not only was Kepler correct, but to derive the physical basis of a satellite's behaviour through the *laws of motion*.
- In 1687, he devised a thought experiment known as *Newton's Cannon* to explain the nature of orbital motion.
- Newton created this diagram to explain his concept.

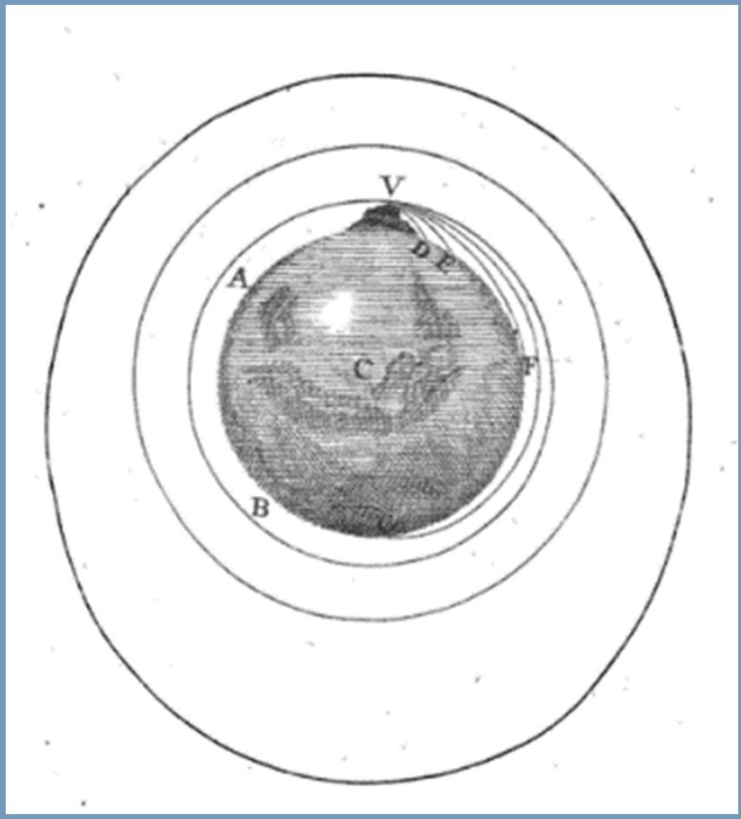


Newton's Cannon

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Newton’s Cannon

- Newton considered that if an object at a very high altitude were to be accelerated to a sufficiently high speed, that it could travel around the earth before it hit the ground.
- He imagined firing a large canon from a very high mountain top and increasing the power of the cannon each time it is fired.
  - Initially the shell falls to the ground.
  - Each time the power is increased, the shell travels a longer distance over the earth.
  - Eventually the cannon is so powerful that the shell makes a full circuit of the earth.
  - In the absence of air resistance, the shell would continue in orbit for ever.

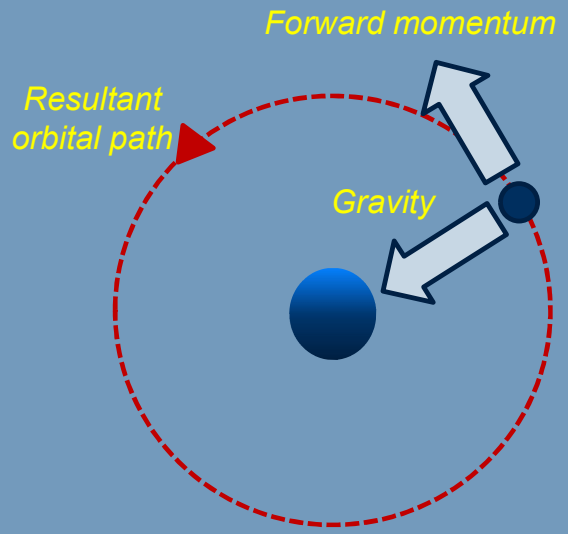


Newton’s Cannon

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Newton's Laws and Orbits

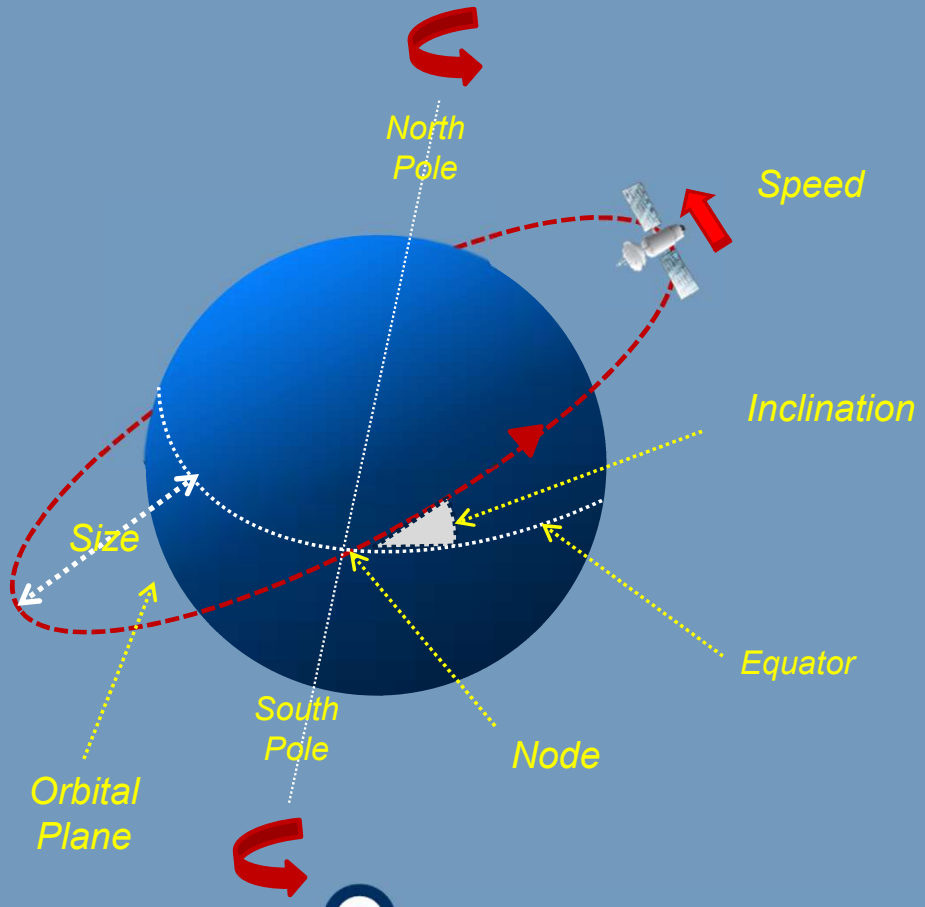
- Newton's 1st Law of Motion states that *an object in motion will stay in motion unless something pushes or pulls on it*.
  - Without gravity, an Earth-orbiting satellite would continue into space along a straight line.
  - With gravity, it is pulled back towards the Earth.
- There is an ongoing tug-of-war between a satellite's *momentum*, or tendency to move in a straight line, and *gravity* pulling it down.
- Both must be equal for a satellite to remain in orbit.
  - If the momentum of one object is too great, it will fly past the other object without entering into orbit.
  - If the momentum is too small, the object will crash into the other.
  - When the forces are balanced, the object falls towards the body, but is moving 'sideways' fast enough to continually miss it.



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Definition of Orbits

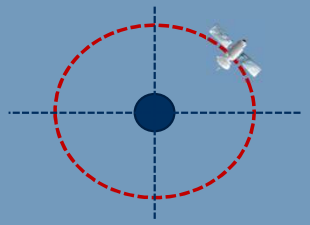
- Satellites move predictably, in accordance with the fundamental laws of physics.
- An orbit can be defined mathematically and has a set of key *parameters*, such as:
  - Shape.
  - Size.
  - Inclination.
  - Speed.
  - Period.
- These are each covered in turn on the next few slides.



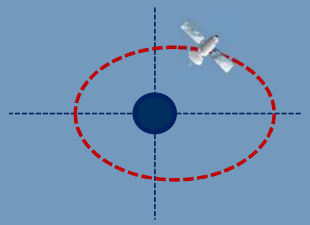
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Orbit Shape

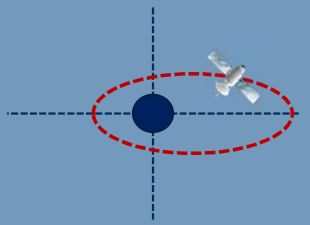
- Orbit shape is defined by Kepler's 1st Law.
- *Eccentricity* is a measure of how circular an orbit is, relative to a perfect circle.
  - In other words, how much the circle is 'squashed'.
  - It is represented by a number between 0 and 1.
  - A perfectly circular orbit has an eccentricity of 0.
  - The more elliptical ('squashed') the orbit, the closer the eccentricity is to 1.
- The most common satellite orbit is *circular*.
- *Elliptical* orbits are often used when only a particular part of the Earth needs to be in view of a satellite for infrequent periods of time.



Circular orbit (zero eccentricity)



Elliptical orbit with low eccentricity

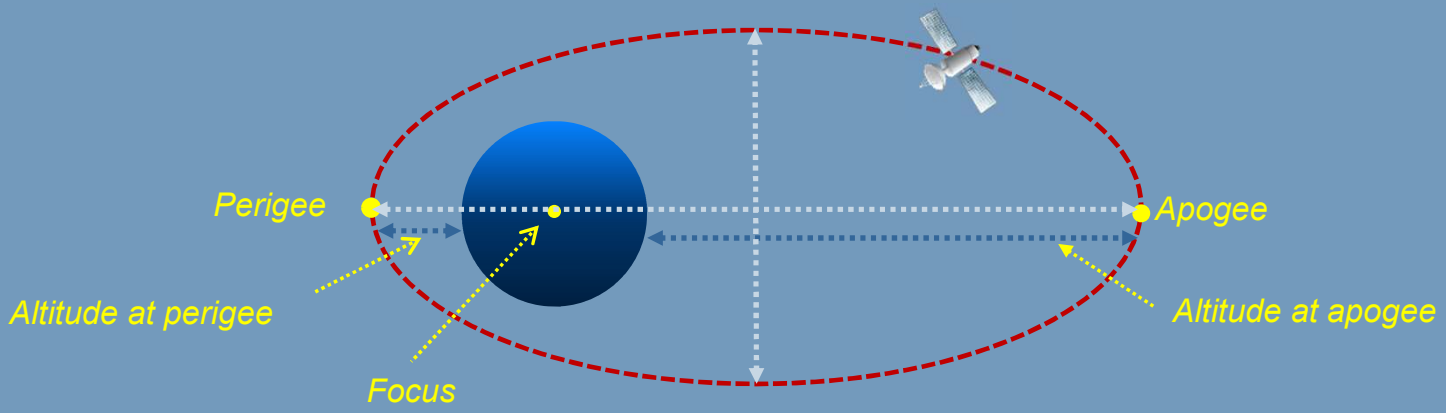


Elliptical orbit with high eccentricity

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Orbit Size

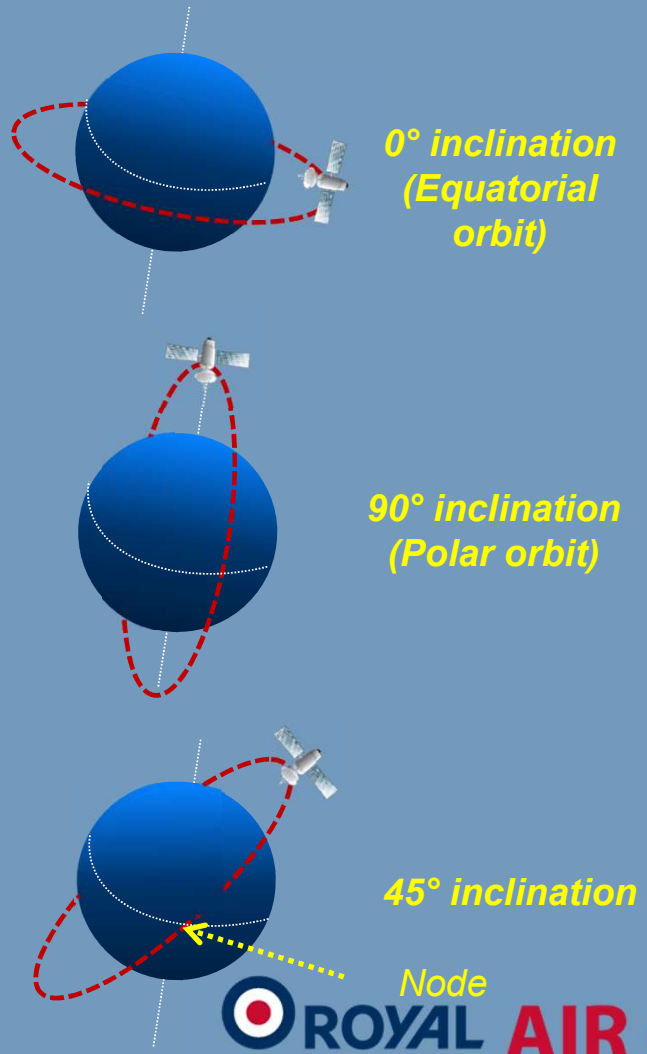
- The size of an orbit is defined by the orbit height or altitude, which is the distance between the satellite and Earth's surface.
- For elliptical orbits, the overall size of the orbit can be defined in terms of the distance between *perigee* and *apogee*:
  - The perigee is the orbit point nearest to the earth's surface.
  - The apogee is the orbit point farthest away from the earth's surface.



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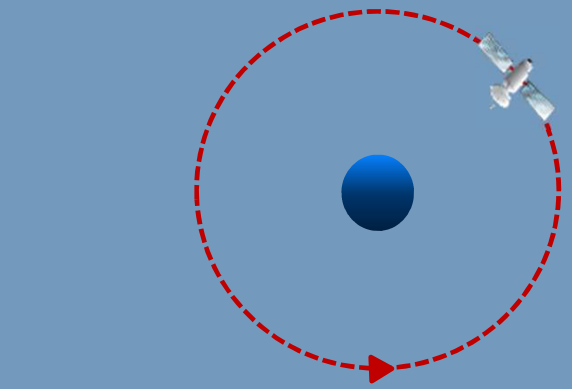
Orbital Inclination

- *Inclination* is the angle at which an orbit crosses the Earth's equator.
- By convention, it is measured anticlockwise from the equator to the orbital plane at the point where the satellite crosses from south to north.
- An *equatorial orbit* is directly above the equator, with a 0° inclination.
- A *polar orbit* travels directly over the north and south poles, with a 90° inclination.
- Other inclined orbits make an angle of greater than 0° and less than 90° to the equator.
- The point at which the spacecraft crosses the equator is called a *node.*

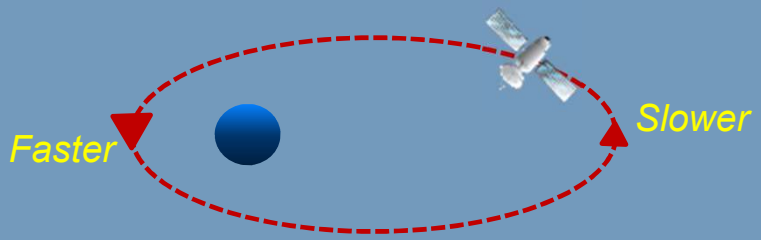


Orbital Speed

- *Orbital speed* is the speed needed to stay in orbit.
- This is determined by the shape and size of the orbit, and is defined by Kepler's 2nd Law.
- An object in a circular orbit at a particular height will travel at a constant speed throughout its orbit.
  - The higher the orbit, the slower the speed.
- An object in an elliptical orbit will travel at different speeds at different points in its orbit.
  - As orbit height increases (travelling from perigee to apogee), the orbit speed decreases.
  - As orbit height decreases (travelling from apogee to perigee), the orbit speed increases.



Circular Orbit
Constant Speed

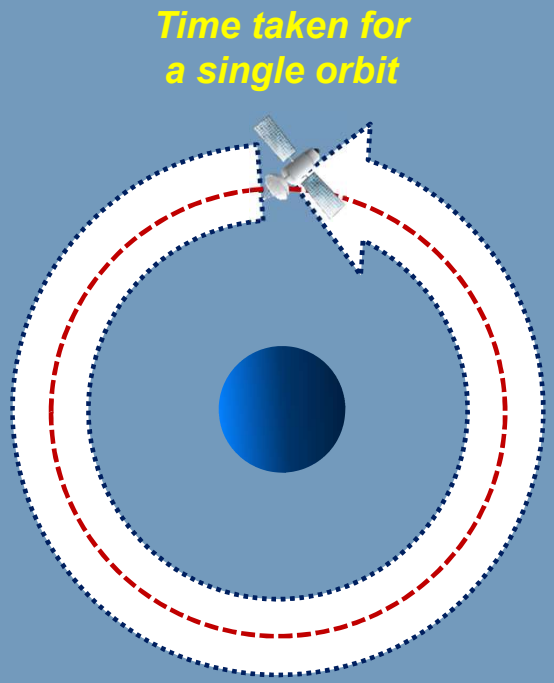


Elliptical Orbit
Variable speed

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Orbital Period

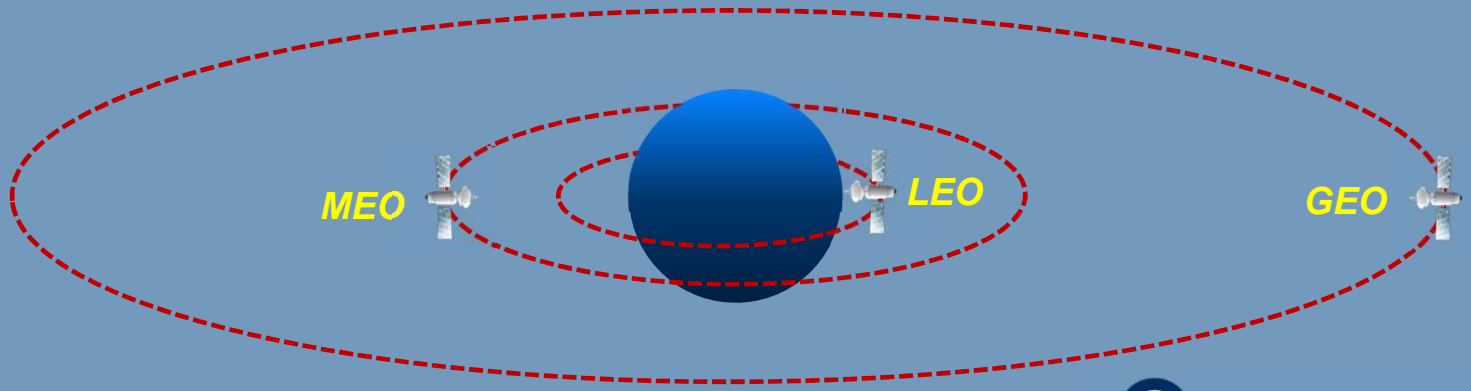
- *Orbital period* is the time it takes a satellite to make one full orbit.
  - Similar to the period of a wave, which is the time to complete one cycle (1 over its frequency).
- It is defined by Kepler's 3rd law.
- Only the height of the orbit determines the period, not the size or mass of the object.
- As the height of the orbit increases, the time taken for the satellite to orbit increases.
- At a height of 35,786km, the orbital period is exactly 24 hours – which is synchronised with the earth's rotation. This is known as a *geosynchronous orbit.*



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Popular Operational Orbits

- There are many different types of orbits used by satellites.
- The choice of orbit is determined by the function the satellite needs to perform.
- The most common circular earth orbit schemes are:
  - Low Earth Orbit (LEO).
  - Medium Earth Orbit (MEO).
  - Geostationary Earth Orbit (GEO).



Not to scale

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Low Earth Orbit

- LEO is restricted to the first 150km to 2,000km of space, just above the earth's atmosphere.
- It is the easiest orbit to reach and maintain.
- The orbital period is between 90 and 120 minutes, with the satellite travelling at over 27,000kph.
- A LEO satellite is in view from only a small percentage of the Earth's surface.
- With a near-polar inclination close to 90°, a LEO can over time provide worldwide long term coverage due to the combined motion of the satellite and the Earth's rotation.
- A constellation of several tens of satellites in LEO orbits, such as the *Iridium* system, can provide real-time worldwide personal communications.
- Most scientific satellites and many weather satellites are in a nearly circular, Low Earth Orbit.
- In 2017 over 60% of satellites were in LEO.

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Medium Earth Orbit

- MEO satellites have an altitude above 2,000km and below 35,786km.
- Their orbital period is between 2 and nearly 24 hours.
- 5% to 15% of the Earth's surface is visible from a MEO satellite.
- Most operational MEOs have an inclination of about 50°.
- With constellations of 10 to 15 satellites, continuous global coverage is possible.
- MEO is used by satellites requiring slow sweeps of large areas of the Earth such as search and rescue, navigation and mobile communications satellites.
- Constellations of satellites in MEO at various inclinations, in which at least one will be in view of any point on the earth, are used for global mobile communications.
- The most common altitude is around 20,000km which has an orbital period of about 12 hours and is used by the Global Positioning System.
- In 2017 nearly 6% of operational satellites were in MEO.

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Geostationary Earth Orbit

- GEO is a circular geosynchronous orbit with zero inclination – i.e. above the equator.
- All GEO satellites are at an orbital height of 35,786km.
- A GEO satellite orbits once every 24 hours at a speed of 11,100kph, from west to east maintaining precise synchronisation with the Earth's rotation.
- From Earth the satellite appears to be stationary, since it is always above the same location.
- 44% of the Earth's surface is visible from a GEO.
- Three satellites separated by 120° of longitude can communicate with almost all inhabited portions of the Earth (just not the poles).
- GEOs are mostly used for communications, scientific and earth observation.
- They are ideal for telecommunications and broadcasting because the ground station does not need to track the satellite and they can provide large areas of coverage of the earth.
- In 2017 over 30% of operational satellites were in GEO.

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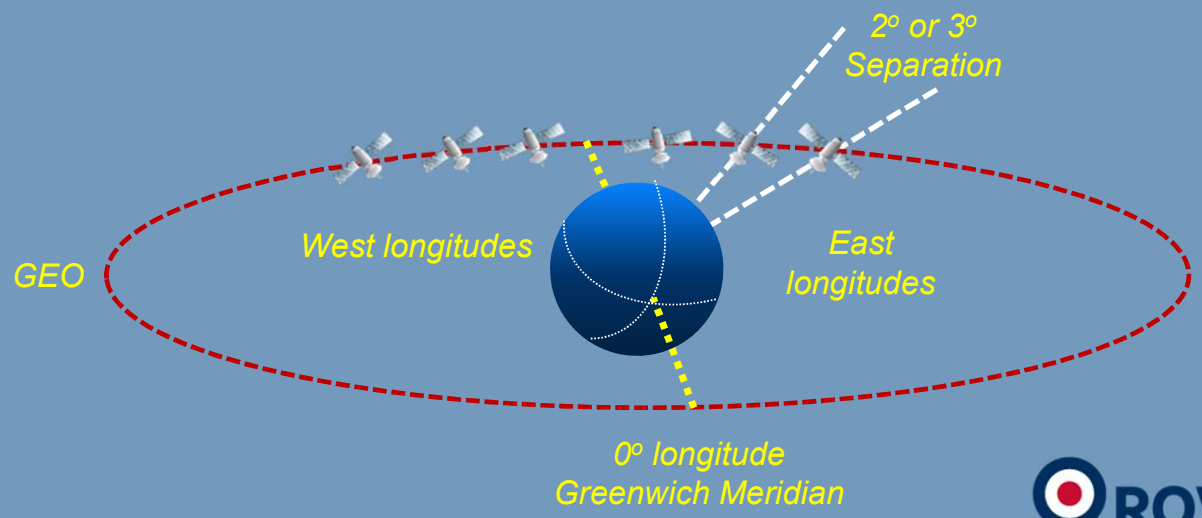
Choice of Operational Orbit

- A COMSAT's orbit is determined by the *mission objectives*, typically the communications capacity and coverage based on the operator's markets, customers and user needs.
  - Essentially: the right satellite needs to be in the right place at the correct time.
- Choice of orbital characteristics is a compromise between:
  - The power required for transmission, versus coverage of the Earth's surface.
  - How long a point on the Earth's surface remains in view of the satellite.
  - The interval between repeat visits to specific points on the Earth.
- The orbital altitude and inclination of the satellite controls the coverage and the elevation angles of the satellite and ultimately determines the satellite's orbit position.
  - 0° inclination orbits provide good equatorial coverage, but no polar coverage.
  - 90° inclination orbits provide global coverage. With the earth spinning below them, they will eventually return over the same point after several orbits.

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Orbital Slots

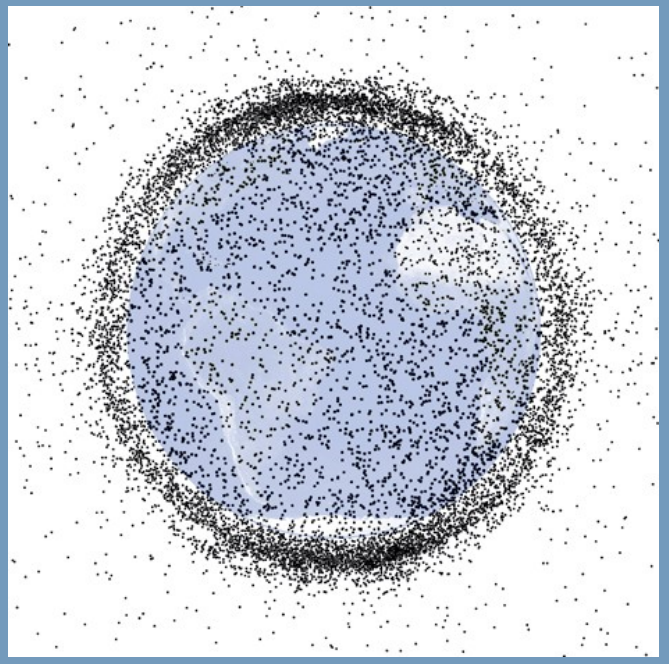
- GEO satellites are assigned a unique *orbital slot,* the position in longitude where a satellite remains stationary above Earth.
- This is to prevent unwanted radio interference occurring between satellites spaced too close together, rather than to avoid collisions.
- A slot separation of 2° or 3° of longitude is common, equating to distance between satellites of 1,500 and 2,250km at orbital height.



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Space Debris

- Space debris can be a hazard to orbiting satellites.
- *Natural debris a*re pieces of rock and dust called meteoroids mostly originating from asteroids and comet tails.
- *Man-made debris* are non-functional spacecraft, rocket parts, mission-related and fragmentation debris as a result of:
  - Launches and failures.
  - Intentional military destruction.
  - Spacecraft collision.



Each black dot is a functioning satellite, an inactive satellite, or a piece of debris.

Image source NASA

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Risk of Space Debris

- The total amount of orbiting space debris is estimated at over 100 million objects, most too small to be detected.
- Over half a million pieces are being tracked as they orbit Earth.
- There are thousands of man-made objects, many larger than 10cm, in low Earth orbit. 95% of them are “space junk”.
- Some debris is travelling at tens of thousands of kilometres per hour.
- Even very small debris can do a lot of damage at the speeds involved. (A paint fleck the size of a fingernail left a crater in a window of the International Space Station.)
- Such a relatively large amount of fast moving debris is a significant hazard to operational satellites and it is constantly increasing.
- A chain reaction could occur as debris collides, creating more debris *(Kessler Syndrome).*

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Summary of Lesson 2

- Orbits adhere to *Kepler's Laws of Planetary Motion* and *Newton's Laws of Motion*.
  - *Newton's Cannon*: a thought experiment about falling but going fast enough to miss the ground.
  - Newton's 1st law: an object in motion will stay in motion unless something pushes or pulls on it.
- Orbits can be described using 5 parameters:
  - **Shape.** The extent to which the orbit is *circular* (*eccentricity* near 0) or *elliptical* (*eccentricity* near 1).
  - **Size.** The height at which the satellite orbits above the surface of the body. Can be defined in terms of minimum orbital height (at *perigee/periapsis*) and maximum orbital height (at *apogee/apoapsis*).
  - **Inclination.** The extent to which the orbit goes around the equator (near 0°) or the poles (near 90°).
  - **Speed.** Larger orbit size = lower speed. Elliptical orbits: slowest at apogee, fastest at perigee.
  - **Period.** The time to complete one full orbit. Kepler's 3rd law: period^2 is proportional to (mean height)^3.
- Popular orbits:
  - LEO: Detailed imagery. Less fuel to launch. Low power. Only covers a small % of the Earth at once. Mainly polar.
  - MEO: Compromise option, between LEO and GEO. Mainly ~50° inclination. Example: GPS.
  - GEO: Satellite stays at one point in the sky. More fuel to launch. High power. Broad coverage. Equatorial, in slots.
- Space debris: lots of junk, moving very quickly. *Kessler Syndrome.*

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Satellite & Data Communications

Lesson 3:

Satellite Mission Phases

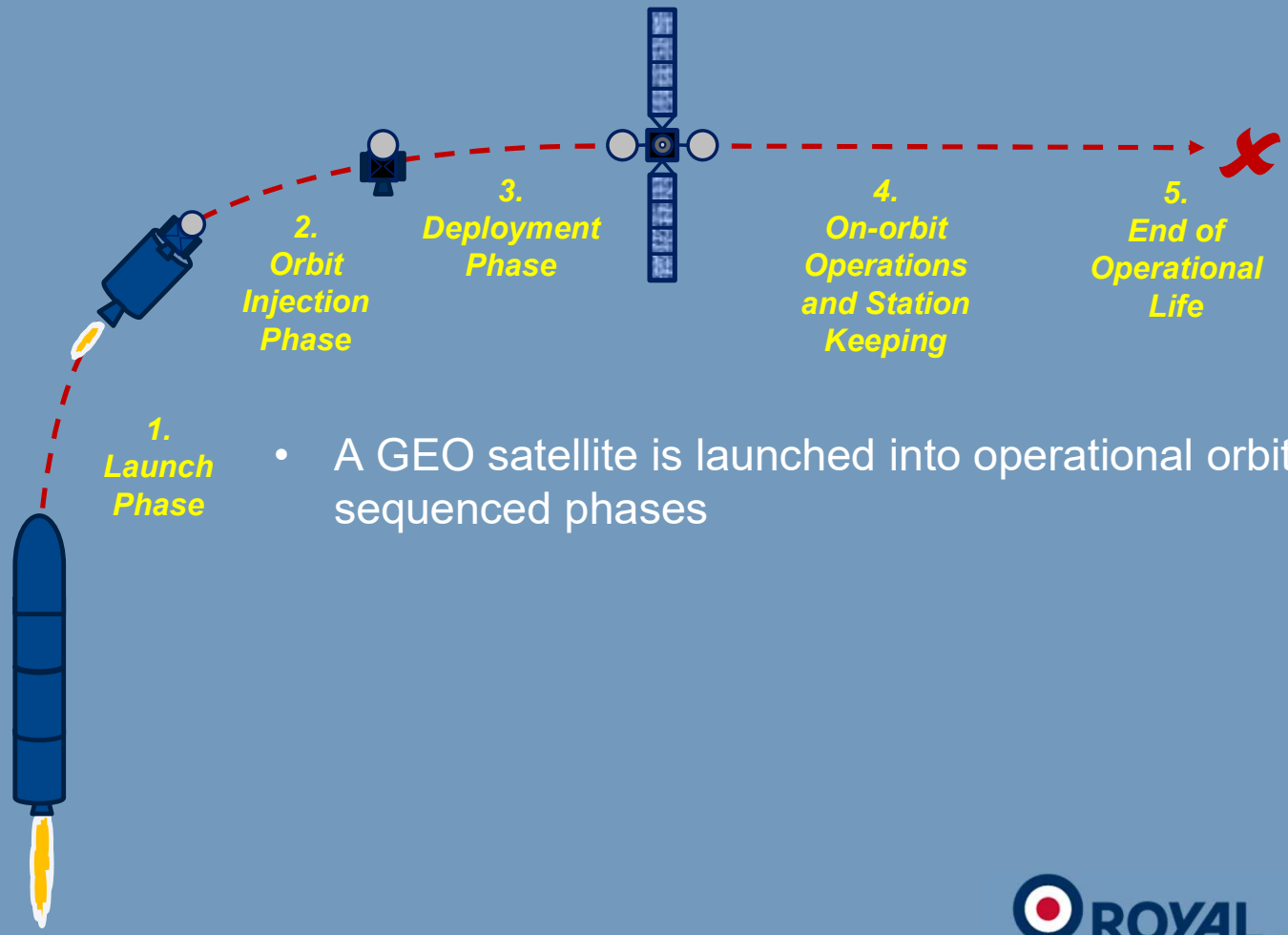
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Satellite Mission

- In this lesson you will learn about the various phases in the lifecycle of satellite's mission including:
  - Launch phase.
  - Orbit injection phase.
    - Parking orbit.
    - Hohmann transfer.
  - Deployment phase.
  - On-orbit operations.
    - Station keeping.
  - End of operational life.

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Mission Phases



- A GEO satellite is launched into operational orbit in several sequenced phases

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Launch Phase

- A satellite mission begins with the Launch Phase when a *Launch Vehicle (LV)* containing the spacecraft leaves the launch pad.
- The task of the LV is to release the satellite:
  - At the correct height; and
  - With the proper speed and direction.
- The LV is typically an expendable ballistic rocket consisting of several stages stacked on top of one another.



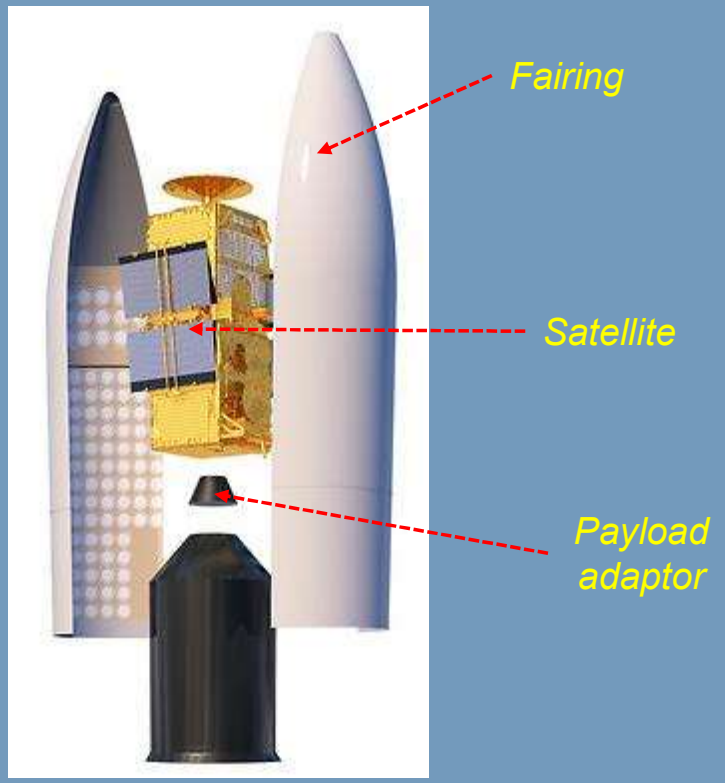
Arianne 6 Launch Vehicle

Image courtesy of Airbus

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Launch Vehicle Payload

- The satellite is located inside the launch vehicle in a protective nose cone called a *fairing* at the top of the rocket stack.
- When the atmospheric pressure is low enough for safe deployment, the fairing is *jettisoned*.
- A *payload adaptor* connects the satellite to the Launch Vehicle.



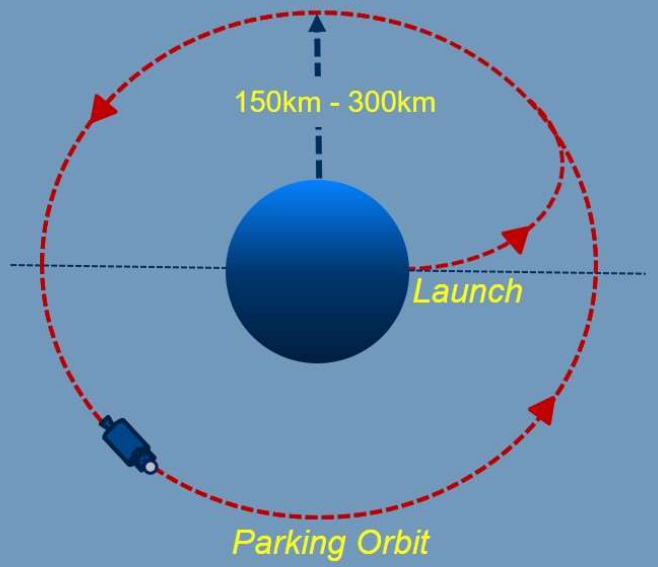
Arianne 6 Satellite Payload

Image courtesy of Airbus

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Parking Orbit

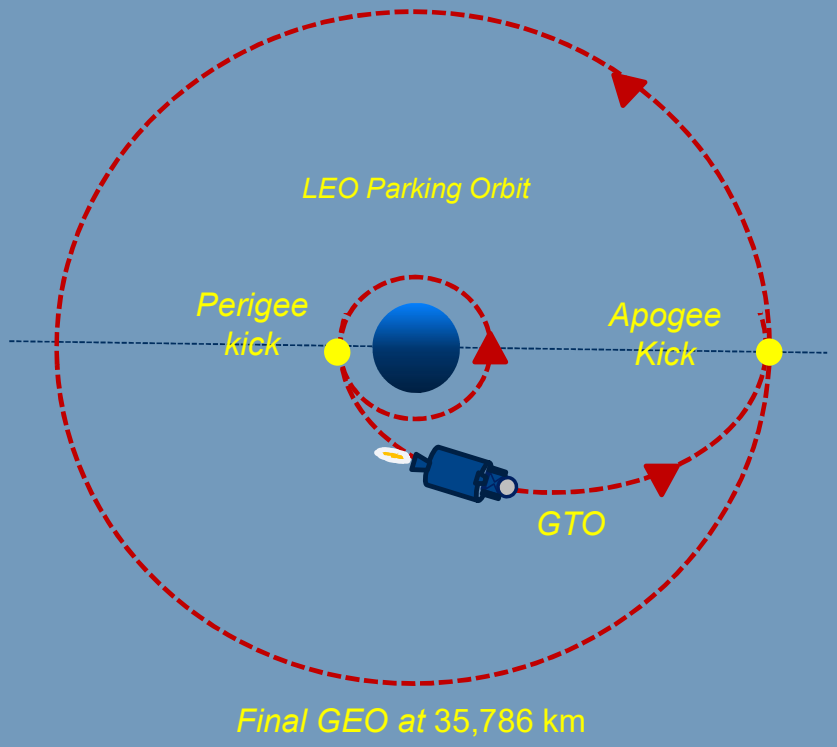
- LEO and MEO satellites are usually delivered directly into the target orbit by the LV.
- For GEO satellites:
  - The LV delivers the spacecraft to a temporary circular *parking orbit* at an altitude between 150km and 300km.
  - A LV second stage booster rocket burn pushes the spacecraft into the parking orbit.
  - The LV makes an orbit around the earth in about 1.5 hours.



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Orbit Injection Phase

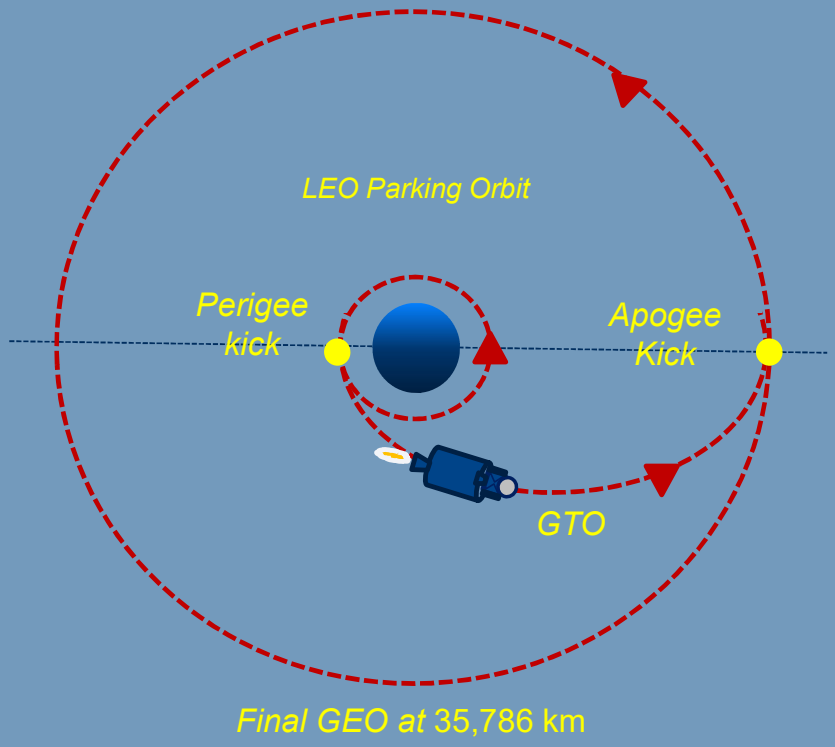
- The *Orbit Injection Phase* is when the spacecraft destined for GEO is transferred from a parking orbit into the final operational GEO.
- The simplest approach is to use a *Hohmann Transfer.*
  - Attractive because it is fuel-efficient.



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Hohmann Transfer

- A Hohmann Transfer uses an intermediate elliptical Geosynchronous Transfer Orbit (GTO) where:
  - The perigee is at the same altitude as the parking orbit.
  - The apogee is at or near the target geosynchronous altitude of 35,786km.
- A LV third stage, high thrust, solid fuel rocket provides a *perigee kick* to move the spacecraft from parking orbit into GTO.
- At the GTO apogee, *circularisation* of the orbit is achieved by reorienting the satellite and firing the on-board *Apogee Kick Motor*.



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Deployment Phase

- Having reached the target altitude, the satellite is prepared for operation.
- If a GEO satellite: the satellite drifts to its assigned *orbital slot*.
- When *on-station*, it is oriented to the correct attitude.
- External appendages such as solar panels and antennas are deployed.
- All the satellite's bus and payload systems are tested.
  - Can take from a few days to several weeks.

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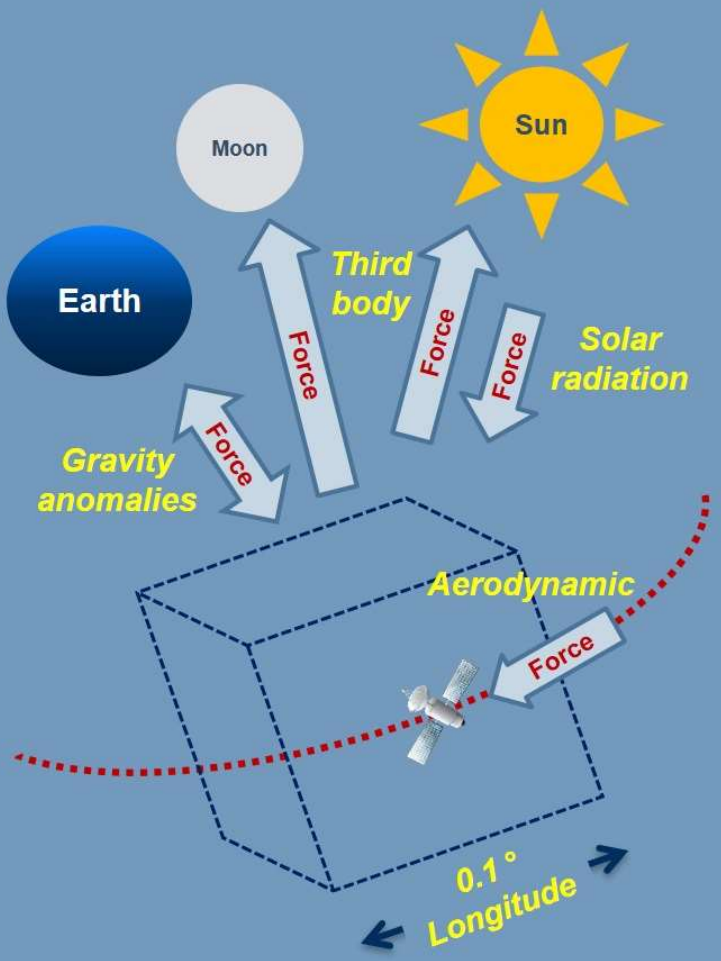
On-orbit Operations Phase

- When fully functional the satellite begins *on-orbit operations* and service can commence.
- However, while in operational orbit, a satellite can be affected by disturbing forces called *perturbations* which can take the form of:
  - *Gravity anomalies*, caused by the earth not being spherical, causing its gravitational pull to vary as the satellite orbits.
  - *Third body forces*, caused by the gravitational influence of the moon and the sun.
  - *Solar radiation pressure*, caused by the force of light particles (photons) striking the satellite.
  - *Aerodynamic forces*, caused by atmospheric drag in low earth orbits.
- These forces cause the satellite's speed to vary, moving it away from its ideal location.
  - This can compromise the satellite's ability to fulfill its mission objectives.
- Changes in orbit due to perturbations must be corrected by *station keeping* manoeuvres.

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Station Keeping

- GEO satellites are typically kept within 0.1° of their orbital slot longitude.
- *Sensors* on board the satellite measure whether the satellite is in its correct orbital position.
- The results are sent back to the *Satellite Control Station* (SCC).
- If the satellite has moved too far out of position, commands are sent from the SCC to the satellite to fire the *reaction control thrusters* and produce a small change in velocity to correct the orbit.
- Station Keeping is planned and carried out periodically over the operational lifetime of the spacecraft.



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End of Operational Life

- The *operational life* of a satellite is determined by its ability to remain at its assigned orbital slot and oriented correctly by station keeping. Thruster fuel is the limiting factor.
- When the thruster fuel has nearly run out, the satellite reaches the end of its active life, even though the satellite's other systems and payload often remain fully functional.
  - Need to avoid it becoming another piece of space debris, and to make room for new satellites.
- GEO satellites:
  - Typically have a useful lifetime of about 15 years.
  - Are usually repositioned to a *graveyard orbit,* a few hundred kilometres higher than GEO.
- LEO satellites:
  - May have even shorter lifespans, due to atmospheric drag reducing their orbital height.
  - Usually repositioned so that they will re-enter the atmosphere in a controlled descent and burn up.

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Summary of Lesson 3

- **Launch phase**: Launch Vehicle carries LEO/MEO satellite to target altitude, or GEO to parking orbit.
- **Orbit injection phase**: GEO satellite transferred from parking orbit to GEO, via Hohmann Transfer.
  - Hohmann Transfer: A 3rd stage solid fuel rocket provides a *perigee kick* to move spacecraft from parking orbit into Geosynchronous Transfer Orbit (GTO). At the GTO apogee, the orbit is circularised using an *Apogee Kick Motor*.
- **Deployment phase**: satellite oriented, appendages deployed, systems checked.
- **On-orbit operations**: station keeping manoeuvres used to correct for drift caused by perturbations.
- **End of operational life**:
  - GEO satellites moved to (higher) graveyard orbit.
  - LEO satellites burnt up in atmosphere.

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Satellite & Data Communications

Lesson 4:

Satellite Communications

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Satellite Communications

- In this lesson, you will learn about the principles of satellite communications and the concepts of:
  - Satellites in telecommunications.
  - Satellite networks.
  - Space, control and ground segments.
  - Earth stations.
  - Satellite footprint.
  - Transmission systems.
  - Uplinks and downlinks.

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Satellites in Telecommunications

- Satellites are one technology of many within the field of telecommunications.
- They provide an alternative method of transmission to terrestrial copper cable, optical fibre or microwave radio.
- Satellites may, or may not, satisfy all criteria demanded by a user for a specific telecommunications task.
- However, satellites have still prospered as they fill niche roles very cost effectively.
- Recent technology advances have led to smaller, lower cost, more sophisticated satellites with higher capacity and more capabilities, allowing operators to expand their services.



***Eutelsat** is the longest-standing COMSAT operator with a fleet of 37 GEO satellites serving Europe, Africa, Asia and the Americas.*

Image courtesy of Airbus

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Satellite Communications Benefits

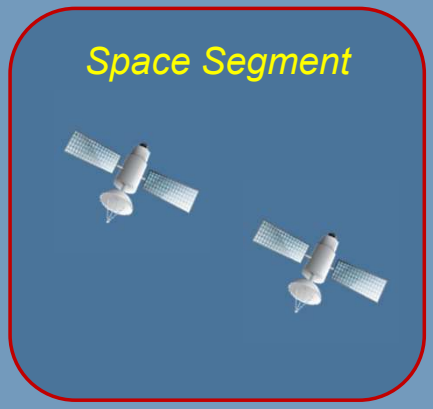
- Telecommunications is the most common use for satellites, as satellites offer benefits such as:

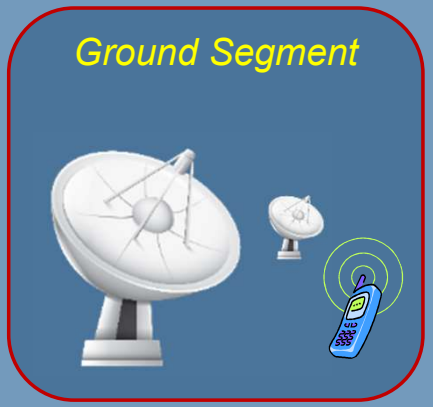
Broad coverage	• A single high altitude satellite can cover a large area of the Earth. • A single global network provider can serve a large population.
Mobility / Remote Comms	• Services are independent of location and terrestrial infrastructure.
High bandwidth and capacity	• Applications such as HDTV are feasible.
Instantaneous deployment	• Set up is rapid and reconfiguration is simple.
Resilience	• Provides an alternative to terrestrial infrastructure in case of failure or emergencies.

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Satellite Networks

- A satellite communications system is divided into three generic *segments* which are required to provide a complete operational *network*:
  - *Space* segment.
  - *Ground* segment.
  - *Control* segment.
- Typically an end-to-end satellite telecommunications network comprises:
  - A *transmitter* on the ground.
  - A *satellite payload* in orbit.
  - A *receiver* on the ground.







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Space Segment

- The *Space Segment* contains one or more operational, and sometimes spare, orbiting communications satellites, or COMSATS, arranged into a *constellation*.

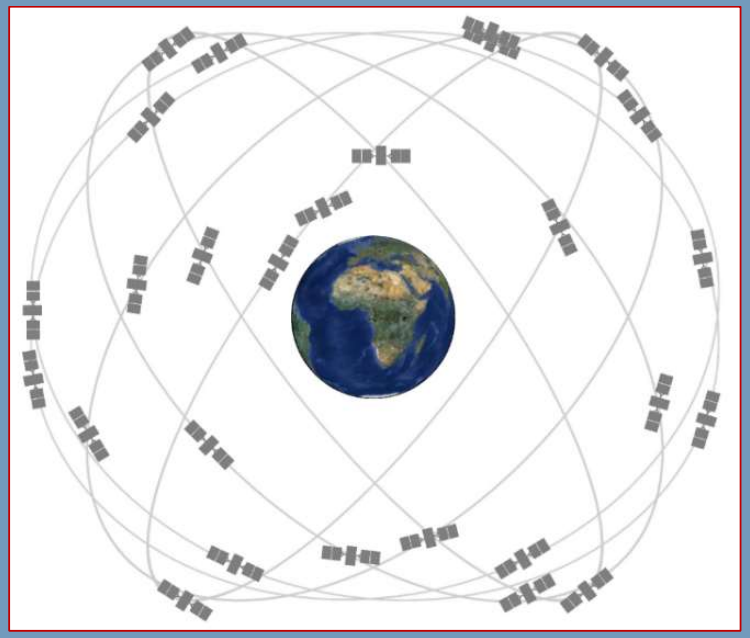


Image source US Government

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Control Segment

- The *Control Segment* consists of all the ground facilities required to:
  - Control the satellite's function and orbit.
  - Manage the satellite payload equipment.
  - Manage the telecommunications traffic.
- *Satellite Control Centres (SCC)* use *Telemetry, Tracking and Command (TT&C) Earth Stations* to:
  - monitor the health of the satellites
  - control the satellite remotely from the ground
- Often a separate *Network Operations Centre (NOC)* controls the operation of the satellite's payload handling the telecommunications traffic.

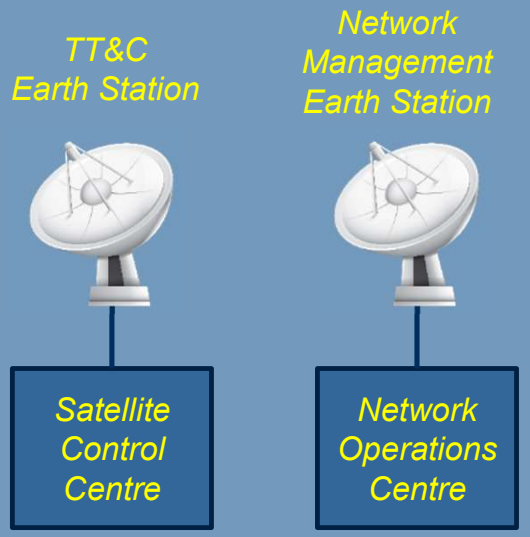




Image source MOD

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Ground Segment

- The *Ground Segment* consists of all Earth Stations which access the space segment and interconnect users.
- It is a diverse collection of facilities, users and applications that includes terminals located on land, sea and in the air.
- Earth Stations are connected to the end-user's terminal either directly or to terrestrial networks such as the public telephone network and the Internet.
- Antenna sizes differ according to traffic type and quantity:
  - Historically, the largest used 30m diameter antennas.
  - Currently, the smallest have antennas between 60cm (e.g. satellite TV receivers) and 10cm (on personal handsets).
- Some Earth Stations both transmit and receive, whilst others only receive, e.g. a satellite TV station.





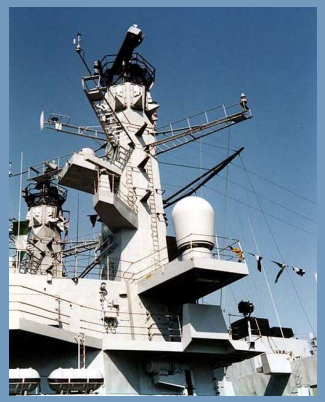
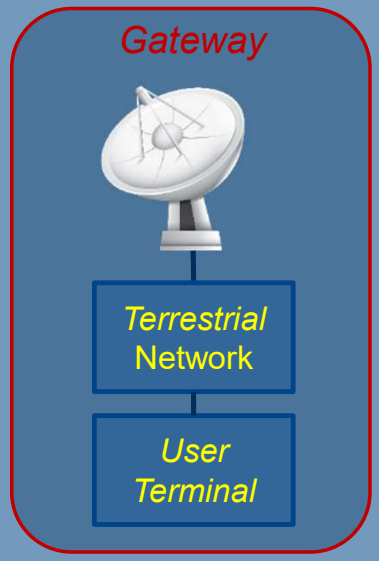


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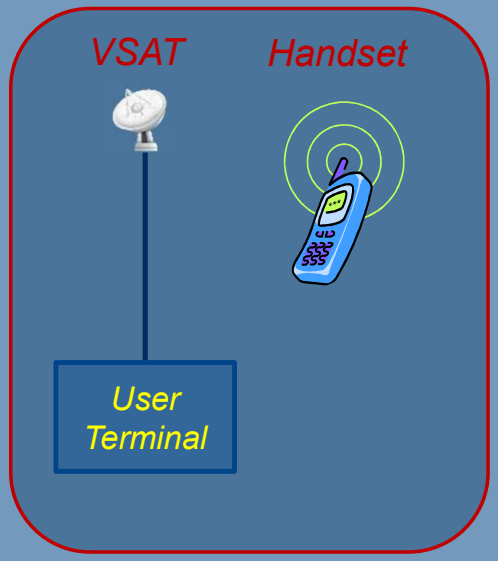
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Earth Station Types

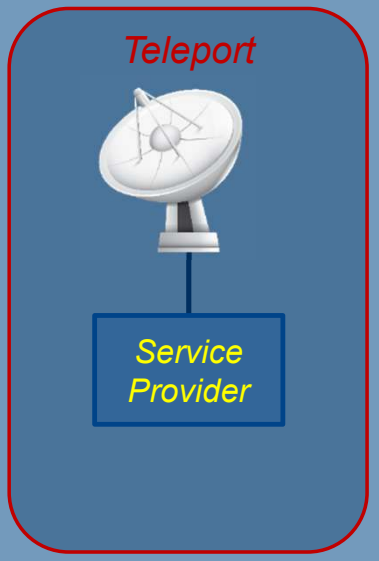
- *Interface Stations*
  - *Gateways* connecting with other terrestrial or satellite networks.



- *Single-purpose User Stations*
  - *Very Small Aperture Terminals (VSAT)* located at user premises.
  - Personal *handsets*.



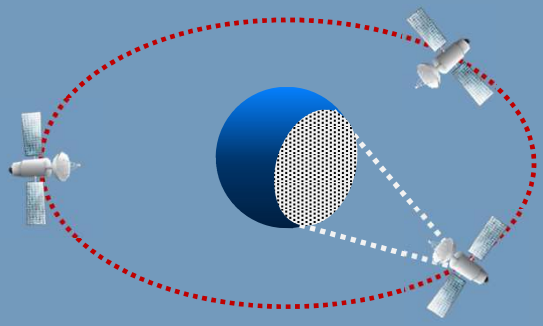
- *Service Stations*
  - *Teleport* hub and feeder stations for users requiring point-to-point communication.



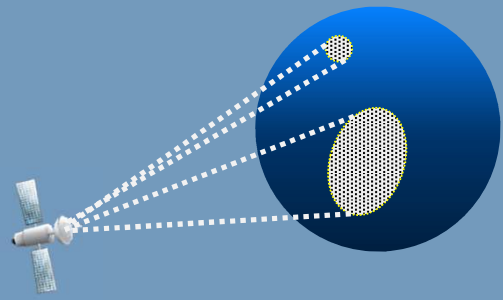
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Satellite Footprint

- The satellite's *footprint* is the ground segment signal reception area on the Earth's surface.
- An Earth station must be within the footprint and visible to the satellite to be able to communicate with it.
- The footprint shape and position depends on:
  - Distance from the satellite to the horizon.
  - Shape of the antenna beam.
  - Time of overflight (determined by orbital speed).
- Different antenna systems can create different footprints:
  - GEO satellites can cover 44% of the Earth using *a global beam* pattern.
  - A *regional beam* or *spot beam pattern* will limit the area of the Earth served.



GEO Global Beam



Spot or Regional Beam

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Transmission Systems

- Transmission of information occurs between Earth stations and the satellite, and vice-versa.
- Information is encoded digitally and combined to produce a *baseband* signal – a bit stream of 1s and 0s, which is sent to the transmitter.
- The baseband signal can convey information from:
  - A single source; or
  - Several sources, by *multiplexing* (combining) signals from different sources. E.g. it could contain a mixture of telephone, data or television signals.
- A microwave radio frequency carrier is *modulated* with the baseband signal at the Earth Station and transmitted to the satellite.
- The carrier is received at the destination satellite and the signal is retransmitted on a different carrier frequency back to the Earth Station.
- The original bit stream is recovered at the Earth Station by *demodulating* the carrier and *decoding* the digital bit stream to reveal the original information.

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Traffic Uplinks

- Transmission of baseband signals from an Earth station to a satellite is called the uplink.
- Satellite transmissions use microwave radio frequency carriers, typically between 1GHz and 45 GHz depending on their mission.
- The signal need only be just strong enough to reach the satellite in a useable form, although it may be affected by atmospheric and other interference sources.



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Traffic Downlinks

- Transmission of baseband signals from the satellite to the Earth Station is called the *downlink.*
- The downlinking transmitter sends the signal from the satellite back down to earth;
  - either to a single receiver
  - or by broadcasting to multiple receivers
- As the downlink transmitter must rely on the satellite's limited power supply, there are greater constraints on the downlink signal power than for fixed ground stations.



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Summary of Lesson 4

- Satellites **complement** ground-based comms systems, rather than replacing them entirely.
  - There is often an interface (connection) between satellite ground stations and ground networks.
- **Benefits** of using satellites for telecommunications include:

Broad coverage	Mobility / remote communications	High bandwidth and high capacity	Instantaneous deployment	Resilience

- A satellite **network** comprises a:
  - **Space segment**: a constellation of satellites in orbit.
  - **Ground segment**: the users/consumers of the service(s), which might be people and/or things.
  - **Control segment**: Satellite Control Centres (SCC) use Telemetry, Tracking and Command (TT&C) Earth stations to monitor and control satellites. Network Operations Centre (NOC) manages service.
- A satellite's **footprint** is the reception area on the Earth's surface. Global beam vs. spot beam.
- Signals from different sources are **multiplexed** together into a **baseband signal** of 1s and 0s.
- A **carrier signal**, typically of 1GHz to 45GHz, is **modulated** with the baseband signal.
- An **uplink** is the modulated signal sent from ground to satellite. A **downlink** is the reverse.

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Satellite & Data Communications

Lesson 5:

Satellite Components

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Main Components of a Satellite

- In this lesson, you will learn about the main components of a COMSAT and their uses, including:
  - Satellite bus.
    - Structural housing.
    - Propulsion system.
    - Electrical power system.
    - Tracking, telemetry and command system.
    - Attitude control system.
    - Thermal control system.
  - Communications payload.
    - Transponders.
    - Antennas.

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Main Components of a Satellite

- A satellite is a complex, interconnected, mechanical and electrical system designed and constructed to support the specific mission and functions for which it is designed.
- A COMSAT incorporates two major modules:
  - The *payload* is the most important part of the satellite and is there to fulfil the mission objective using specialised hardware.
  - The *bus* comprises 6 major subsystems which are there only to support the payload in its operation.



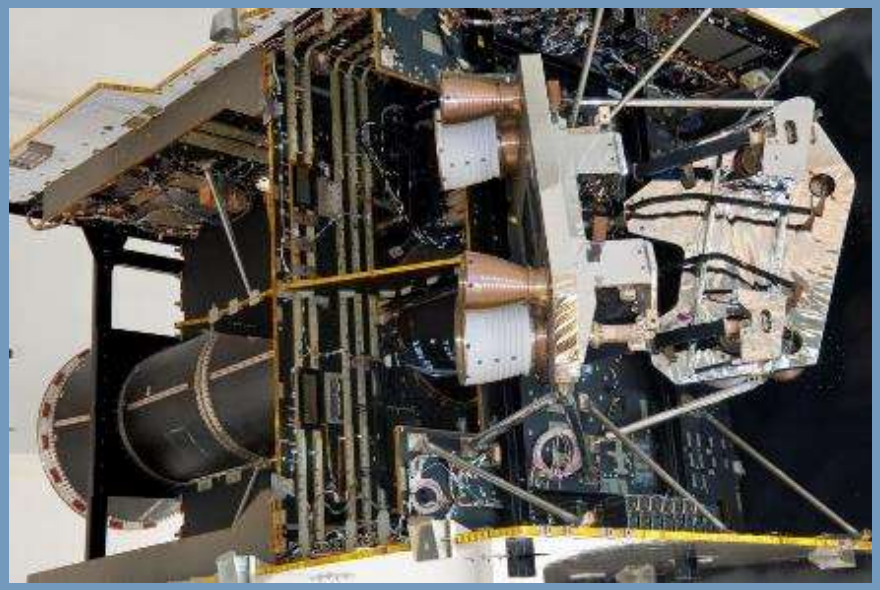
Inmarsat-4A ALPHASAT
Satellite under construction

Image Courtesy of Airbus

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Satellite Bus

- Satellite manufacturers usually have a standard bus to carry a variety of payloads.
- The bus has several different subsystems incorporating different functional components.

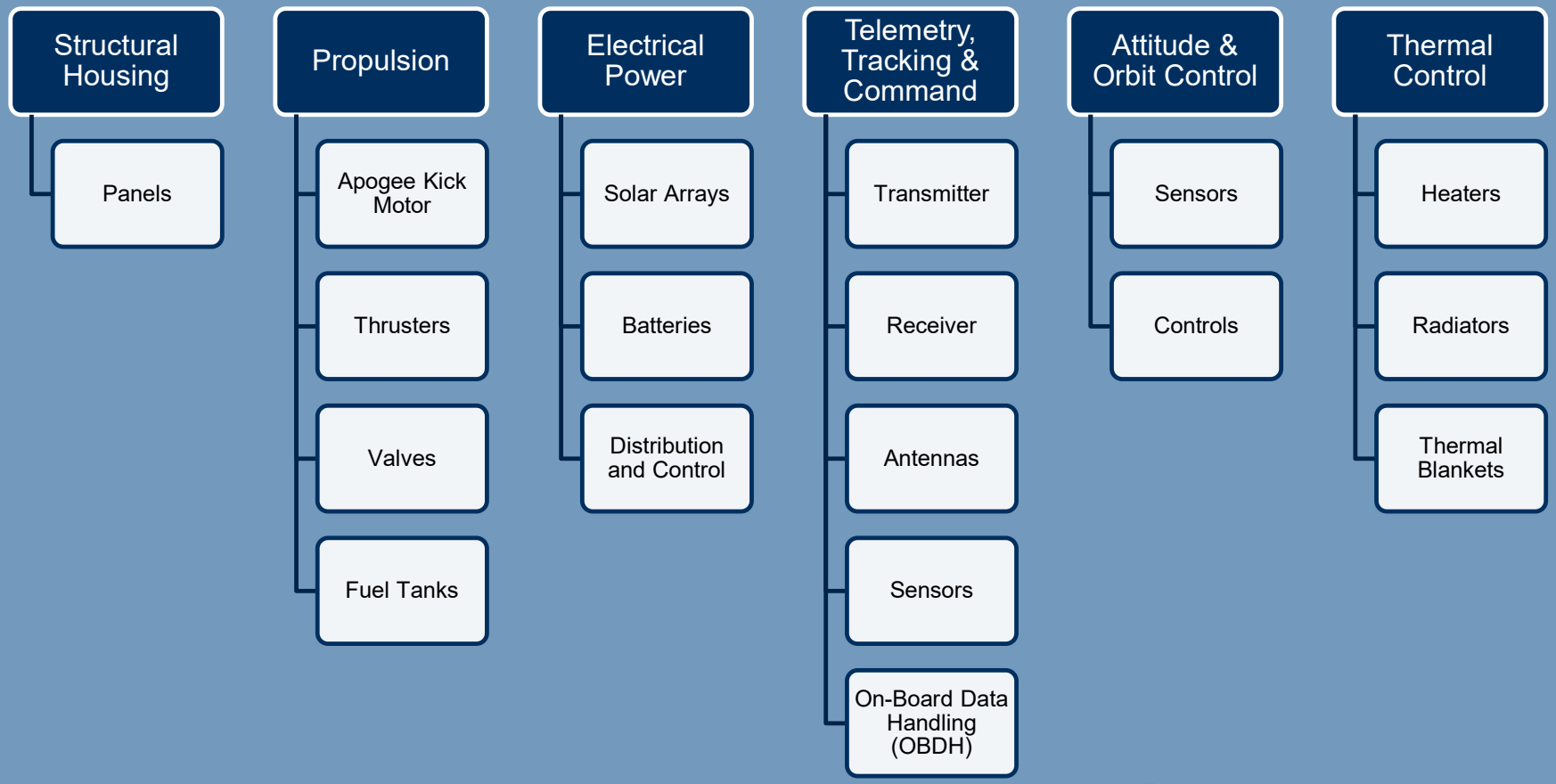


Airbus Eurostar 3000 Bus

Image courtesy of jc4i

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Satellite Bus



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Structural Housing

- The *housing* provides the base structure of the satellite, which:
  - Physically supports all the on-board payload and bus equipment.
  - Is designed to survive and operate in the harsh environments encountered from launch through to orbit.
  - Acts as a shield cage to protect the sensitive electronics from space radiation and electrostatic discharge.
- It is a rigid framework of panels usually constructed of lightweight aluminium *skins* bonded onto a sandwich filling of aluminium honeycomb – which is very light, strong and rigid.
- The form of the housing is determined by the satellite *stabilisation* mechanism.
- The size of the housing is limited by the launch vehicle.



Aluminium panels



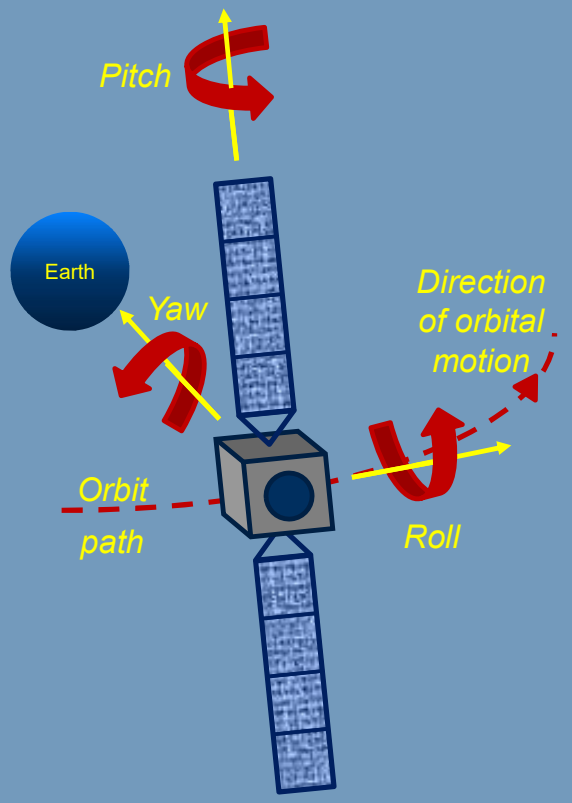
Honeycomb skin

Image Courtesy of Airbus

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Stabilisation

- The satellite's antennas, solar panels, thermal radiators and rocket engines must be correctly oriented on orbit.
- To achieve this a stabilisation mechanism is required. There are 2 main types:
  - *Spin* stabilisation.
  - *3-axis* (or *body*) stabilisation.
- 3-axis stabilisation is the most convenient form for supporting a communications payload function.
- A satellite can achieve any attitude by changing the direction of the 3-dimensional axes using the Attitude Control System.
- Attitude describes the position of a satellite in a rotational sense and changing attitude implies rotation.

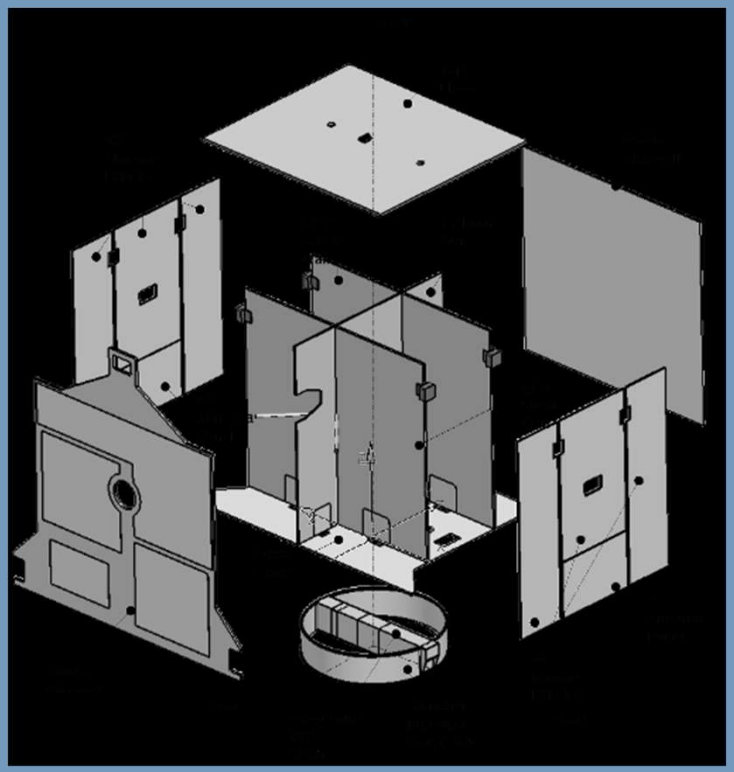


3-D rotational movement of a satellite in space

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Configuration

- 3-axis stabilised satellites do not have to have a particular shape.
- The most common shape is a box, with major equipment attached directly to the exterior panels of the housing, including:
  - Solar Arrays.
  - Communications Antennas.
  - Propulsion System.
- Batteries, fuel tanks and the payload are usually contained within the box.



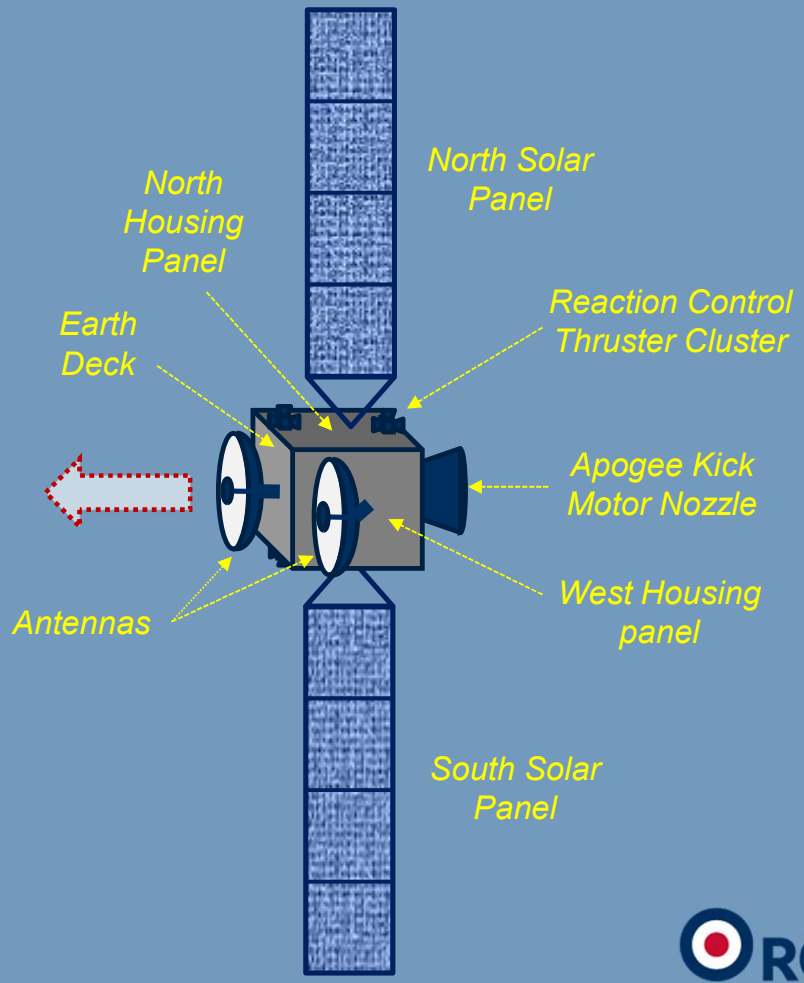
Exploded view of structural housing panels on a typical modular 3-axis satellite

Image Courtesy of Airbus

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Design Features





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Propulsion System

- Satellites are equipped with two types of propulsion systems:
  - A *Primary propulsion system,* used for GEO orbit transfer using a larger rocket engine.
  - A *Secondary propulsion system,* used for controlling orientation and operational orbit position using smaller rocket engines.
- A commonly used combination is:
  - A primary *Apogee Kick Motor* (AKM).
  - Secondary *Reaction Control Thrusters.*
- This approach is relatively simple and remis common for small satellites.



A Primary Propulsion Nozzle



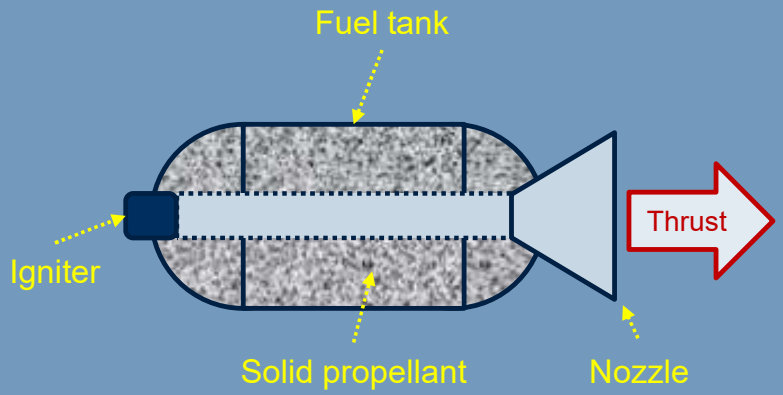
A Secondary Propulsion Nozzle

Image courtesy of jc⁴i

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Apogee Kick Motor

- The AKM is installed in the *central thrust cone* within the housing.
- One type of AKM uses a *solid propellant rocket motor* which when ignited produces thrust.
- The shape of the AKM's external *nozzle cone* is critical to producing thrust.
- It is designed to expand and accelerate the gases to supersonic speeds.
- The nozzle is made from mixtures of carbon and other materials capable of surviving the heat and erosion by the particles in the combustion products.



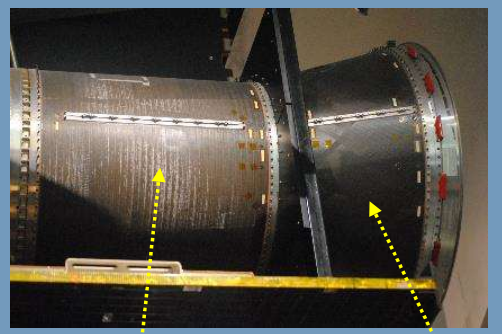


Image courtesy of jc⁴i

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Reaction Control Thrusters

- Small *Reaction Control Thrusters* are located around the satellite housing in *clusters*.
- When fired, the thrusters work together to maintain the satellite in the correct orientation and orbital position.

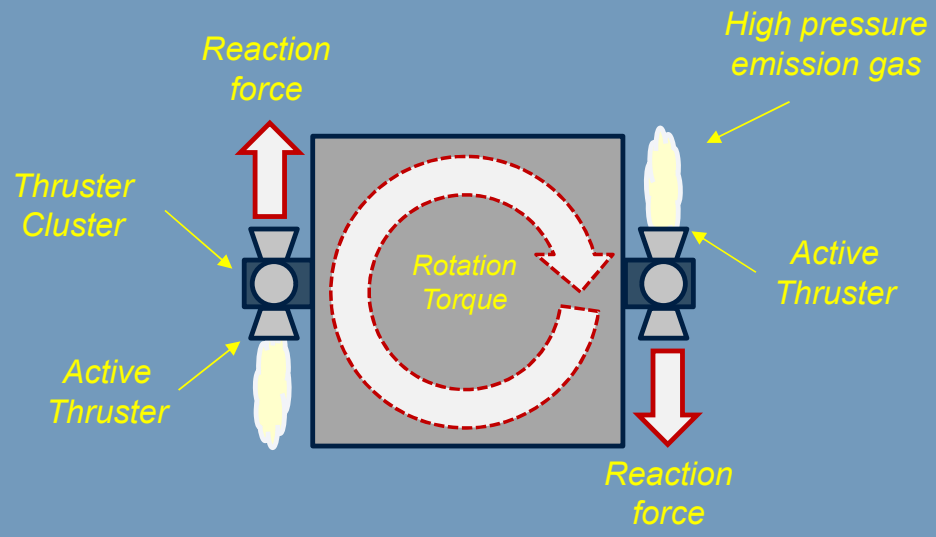


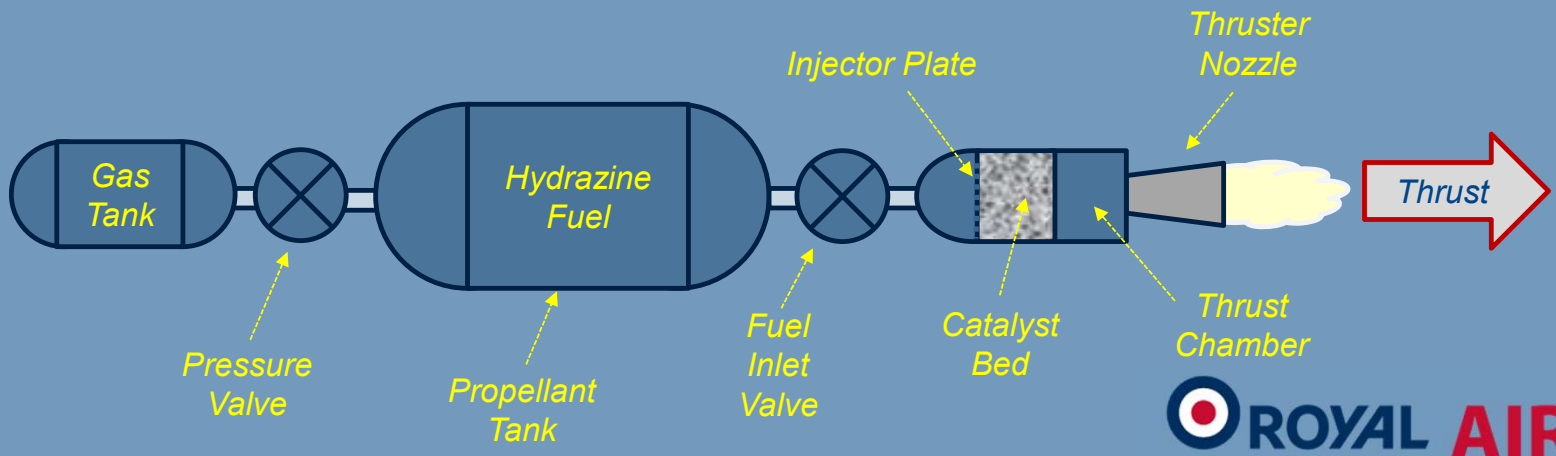


Image courtesy of jc⁴i

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Liquid Mono-propellant Thrusters

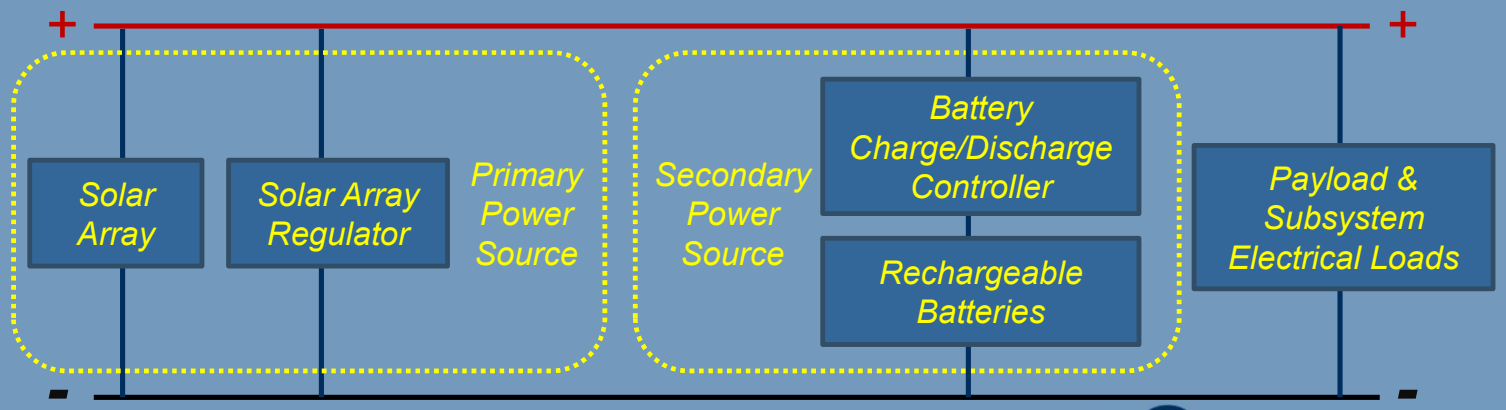
- One type of thruster uses liquid mono-propellant *hydrazine* fuel.
- Fuel is stored in a cylindrical, pressurised, sealed tank with rounded ends, typically made from welded titanium.
- To fire a specific thruster, the fuel inlet valve is opened and high pressure gas forces hydrazine through a bed of chemicals, causing a heat-producing *exothermic* chemical reaction.
- The hydrazine decomposes into hot, high pressure hydrogen, nitrogen and ammonia gasses which are exited at supersonic speed through the nozzle to produce thrust.



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Electrical Power System

- The electrical power subsystem provides *generation*, *storage* and *conditioning* of a reliable electricity source to operate the payload and bus.
- The only feasible external *primary* source of energy for an Earth orbiting COMSAT is from the conversion of sunlight into electricity.
- When the *primary* solar power source is unavailable, a *secondary* power source is required.
- The most common arrangement is a solar array and battery combination.



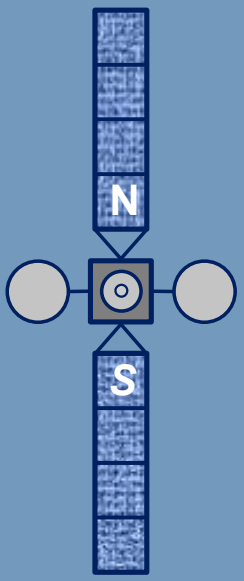
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Solar Array

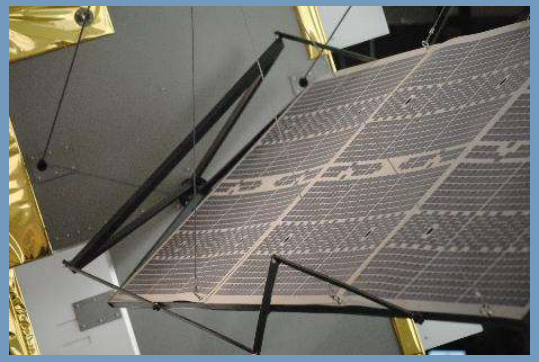
- *Solar arrays* are attached to the north and south panels of the housing.
- A typical array consists of semi-rigid hinged panels.
- As room on the launch vehicle is limited, the arrays are folded up against the sides of the satellite during the launch phase.
- Once in orbit, the arrays are extended by a deployable mast until flat and positioned above and below the housing.
- The arrays are rotated in orbit to point towards the sun regardless of the direction the spacecraft is facing.



Launch configuration



On-orbit configuration



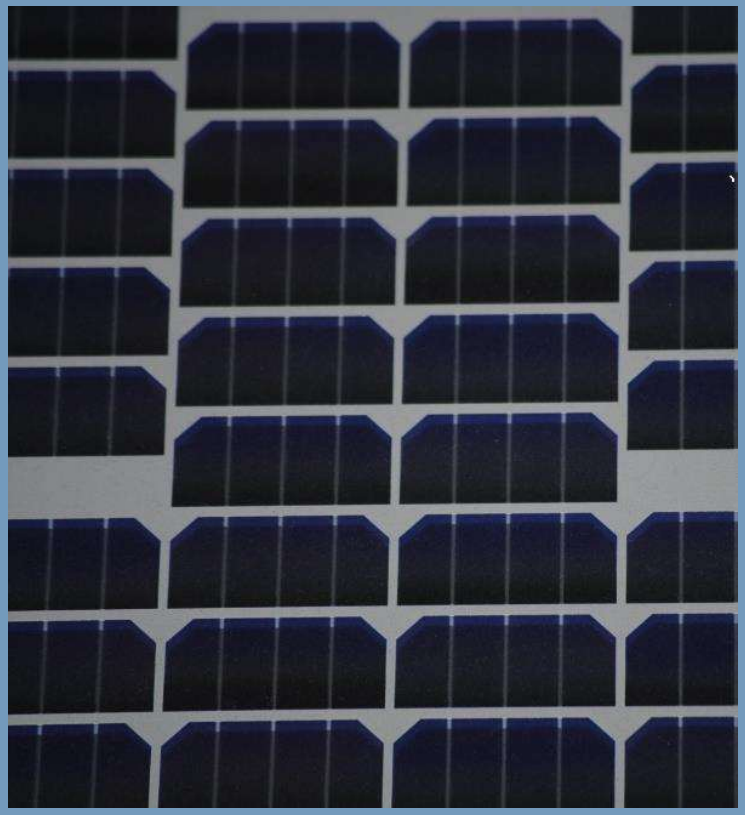
GPS Satellite Solar Array

Image courtesy of jc⁴i

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Solar Cells

- The solar arrays consist of a large number of individual *solar cells*:
  - Made from semiconductor materials, such as silicon or gallium arsenide.
  - Connected in series, in vertical *strings.*
  - Bonded to panels.
  - With a glass cover on the front surface.
- When illuminated by the sun, each cell generates electricity by a process called the *photovoltaic effect*.
- By connecting different numbers of strings together in parallel *circuits*, the amount of electricity available can be adjusted to match the needs of the satellite.



GPS Satellite Solar Cells

Image courtesy of jc⁴i

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Limitations of Solar Power

- Without batteries, a satellite would shut down entirely during eclipses of the sun by the earth and might not re-activate properly after re-entering sunlight.
  - For GEO satellites, eclipses occur on 90 days per year for up to 70 minutes.
  - For most LEO satellites, eclipses occur every day and orbit, for up to 30 minutes.
- Only about 10-20% of the sun's energy falling on a solar array is turned into electrical power.
- The output of a solar array also deteriorates over its lifetime.
- The array output and electrical load both vary over time.
- *Power distribution control* helps ensure the correct voltage and current is delivered to equipment when needed. E.g.:
  - If power generation exceeds consumption, the solar arrays can be turned away from the sun.
  - Excess electrical energy generated and not used, but which cannot be stored in the batteries, can be dissipated into space as heat.

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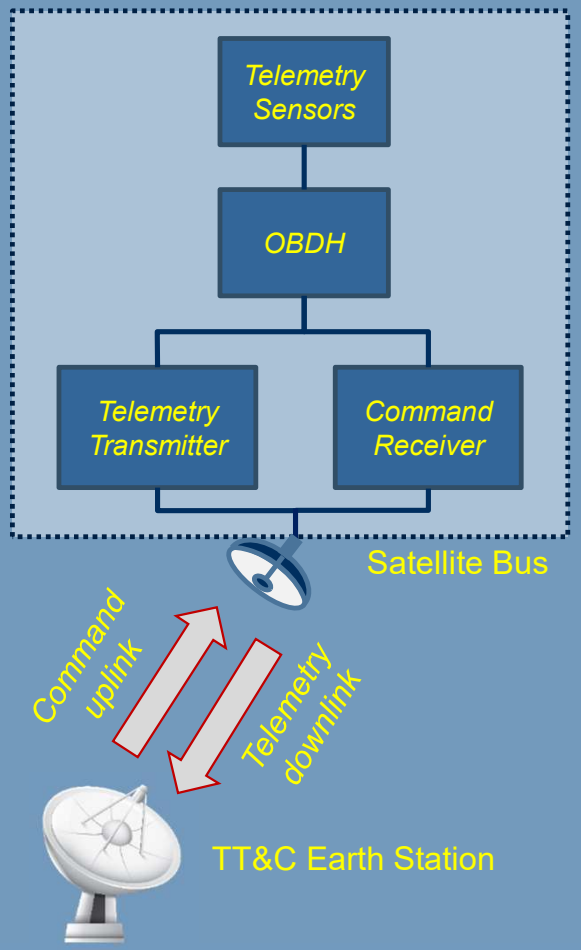
Batteries

- High performance *electrochemical* batteries are typically used as a secondary power source. They:
  - Store surplus energy from the solar array when illuminated by the sun.
  - Return the stored energy when the solar array is in the earth's shadow.
- The battery storage capacity must be adequate enough to continue to operate the satellite during an eclipse.
- Following an eclipse, the batteries need to be charged fully before the next eclipse.
- About 10% of solar power generated at a given time is used to charge the batteries.

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TT&C System

- The on-board *Telemetry, Tracking and Command (TT&C)* system allows the Satellite Control Centre to:
  - Determine the location of the satellite.
  - Determine the status of the satellite.
  - Control the various payload and bus subsystems.
- The TT&C subsystem comprises:
  - Telemetry sensors.
  - An On-Board Data Handling System (OBDH).
  - A telemetry transmitter.
  - A command receiver.
  - Antennas.



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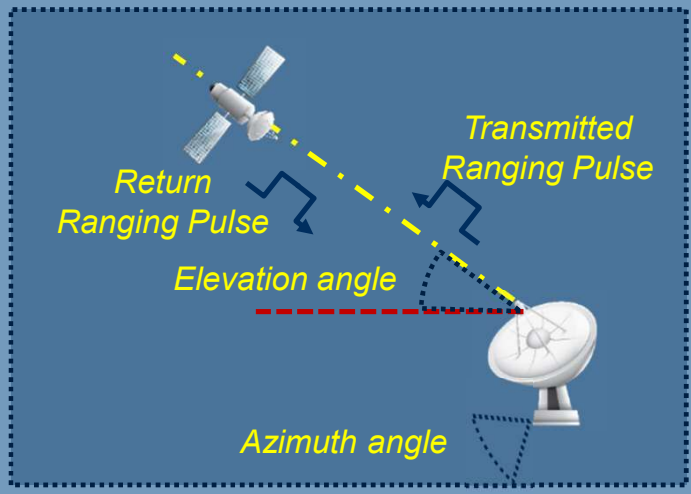
Telemetry Function

- *Sensors* placed around the spacecraft monitor the status and health of the payload and bus.
- They provide *housekeeping data* by measuring important parameters such as temperature, electrical voltage and tank pressure.
- The operational status of equipment is also monitored, as to whether it is switched on or off.
- Housekeeping data is processed by the *OBDH*, converted into a digital bit stream and transmitted to the ground segment using the telemetry downlink.
- The data is received at the *Satellite Control Centre*, processed by a computer to provide a current picture of satellite health, and displayed on computer monitors in the operations room.
- When any parameters move out of specification, warning signals alert the operations team and potential problems can be identified and corrected by the engineers.

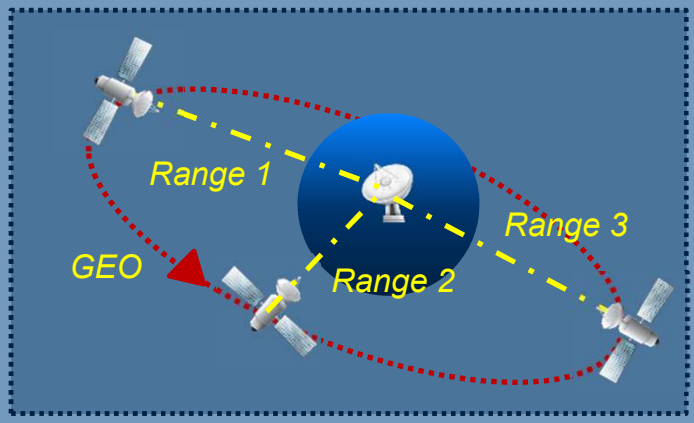
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Tracking Function

- To *track* a satellite is to know its position in space.
- The precise *range* can obtained by measuring the time delay at the TT&C station between transmission of a reference signal and its reception after being delayed by the distance and satellite.
- The *direction* can be fixed by measuring the azimuth (bearing) angle and elevation angle of the Earth station antenna when its beam is aligned to receive the maximum *telemetry beacon* signal.
- Knowing range and direction, the *position* of the satellite can be determined.



Ranging view from the ground



Ranging view from orbit

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Command Function

- The *command* function allows the Satellite Control Centre to control all aspects of the spacecraft's operation to optimise and maintain the service.
- Command functions include:
  - Powering subsystems on/off or changing operating modes.
  - Controlling spacecraft guidance and attitude control.
  - Deploying antennas and solar cell arrays.
  - Uploading updated computer software.
- Commands are received by the satellite through the command uplink, interpreted by the *On-board Data Handling System* and then passed on to the satellite subsystems.
- Commands are checked before execution to ensure that they have been received correctly.
- The OBDH confirms uplinked commands have been executed correctly via the telemetry downlink.

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Satellite Command and Control

- The OBDH is the satellite's main computer system and is distributed throughout the spacecraft.
- The function of the OBDH is to:
  - Exchange command and control data between the various subsystems.
  - Monitor and control all of the satellite's operations.
  - Provide storage and processing of payload and other data.
  - Transfer payload data to the communications system ready for download to the Satellite Control Centre.
- Overall command and control of a satellite is carried out from the SCC.
- SCC personnel monitor the health and status of onboard systems via the telemetry downlink.
- This is the only way to observe and control the spacecraft's functions and condition from the ground.

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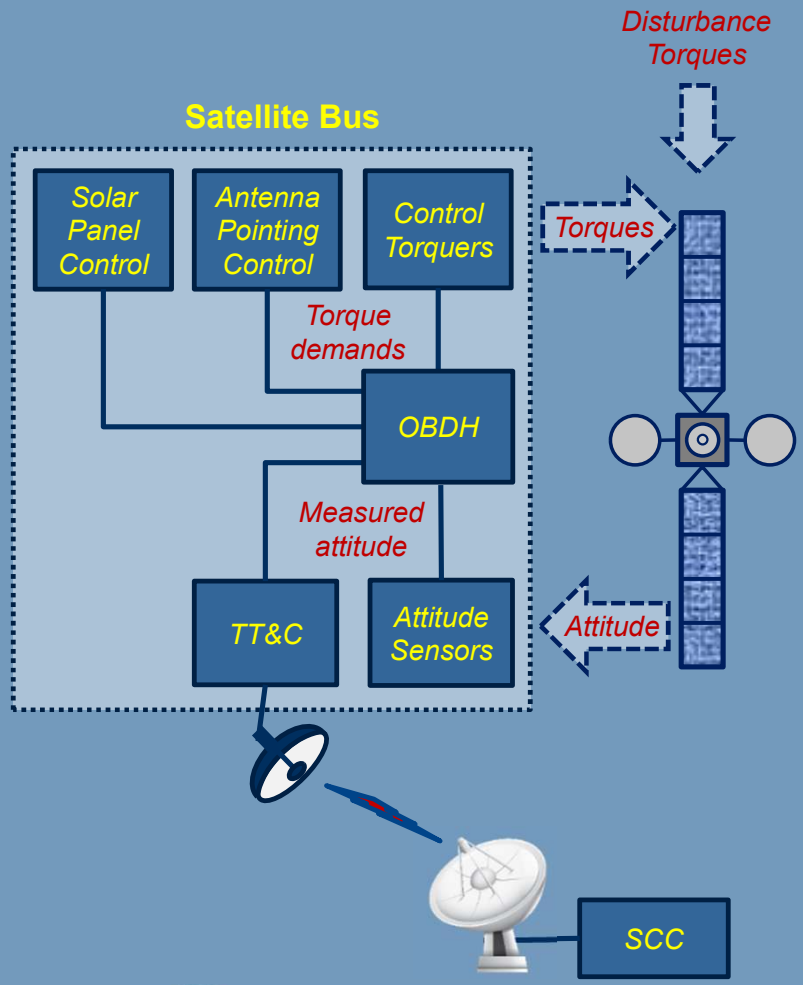
System Priority

- It is important that commands are executed at the correct time and in the correct order, or the satellite could drift out of control.
- Depending on the mode selected, commands can be handled in one of two ways:
  - The most important commands are executed immediately when received by the OBDH.
  - Alternatively the commands can be stored in memory and executed:
    - On receiving a command; or
    - A given time, determined by a signal from the ground or the OBDH.
- Built-in *failsoft* procedures control the computers in case contact between the satellite and Satellite Control Centre is lost.

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Attitude Control System

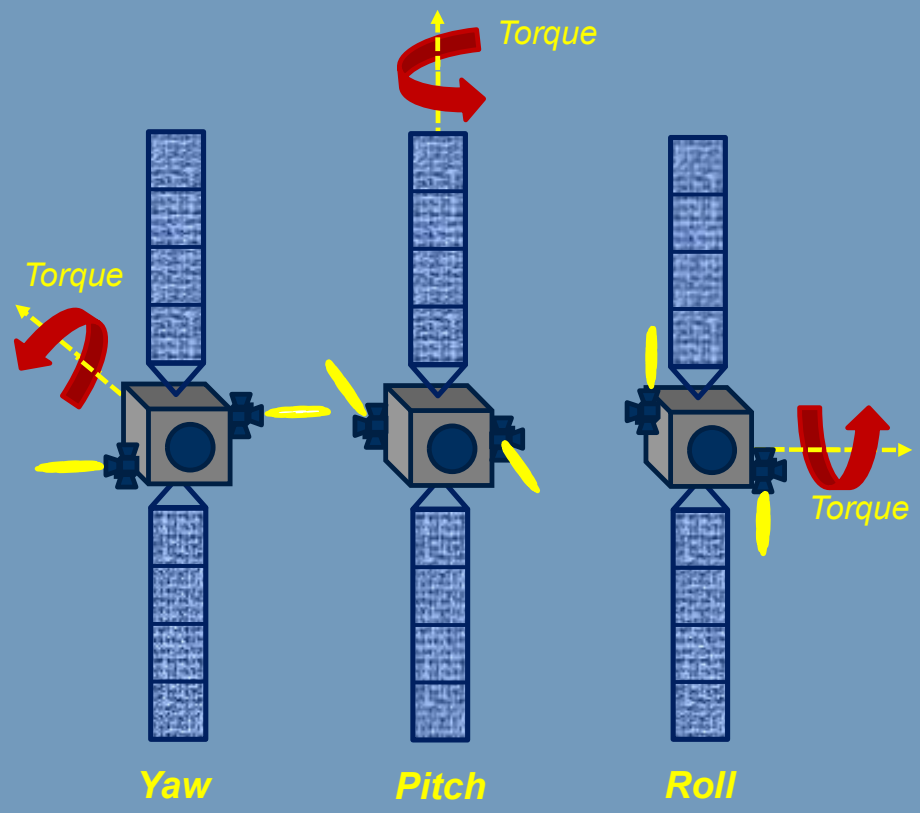
- The ACS controls the rotation of the satellite.
  - Rotation is detected and measured by *attitude sensors.*
  - OBDH control software processes sensor measurements to calculate the satellite's current attitude.
  - The estimated attitude is compared to the required attitude for the desired orientation.
  - If different, the control software determines the *torques* to correct the attitude.
  - The *Reaction Control Thrusters* are fired to act as *control torquers.*
- The ACS is also used for station keeping.



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Control Torques

- The firing of 2 thrusters in opposed pairs produces torque.
- 12 nozzles provide thrust in the 6 degrees of freedom:
  - Up-down.
  - Left-right.
  - Forwards-backwards.
  - Roll.
  - Pitch.
  - Yaw.
- The satellite can be rotated in any direction to set the spacecraft's attitude as desired.



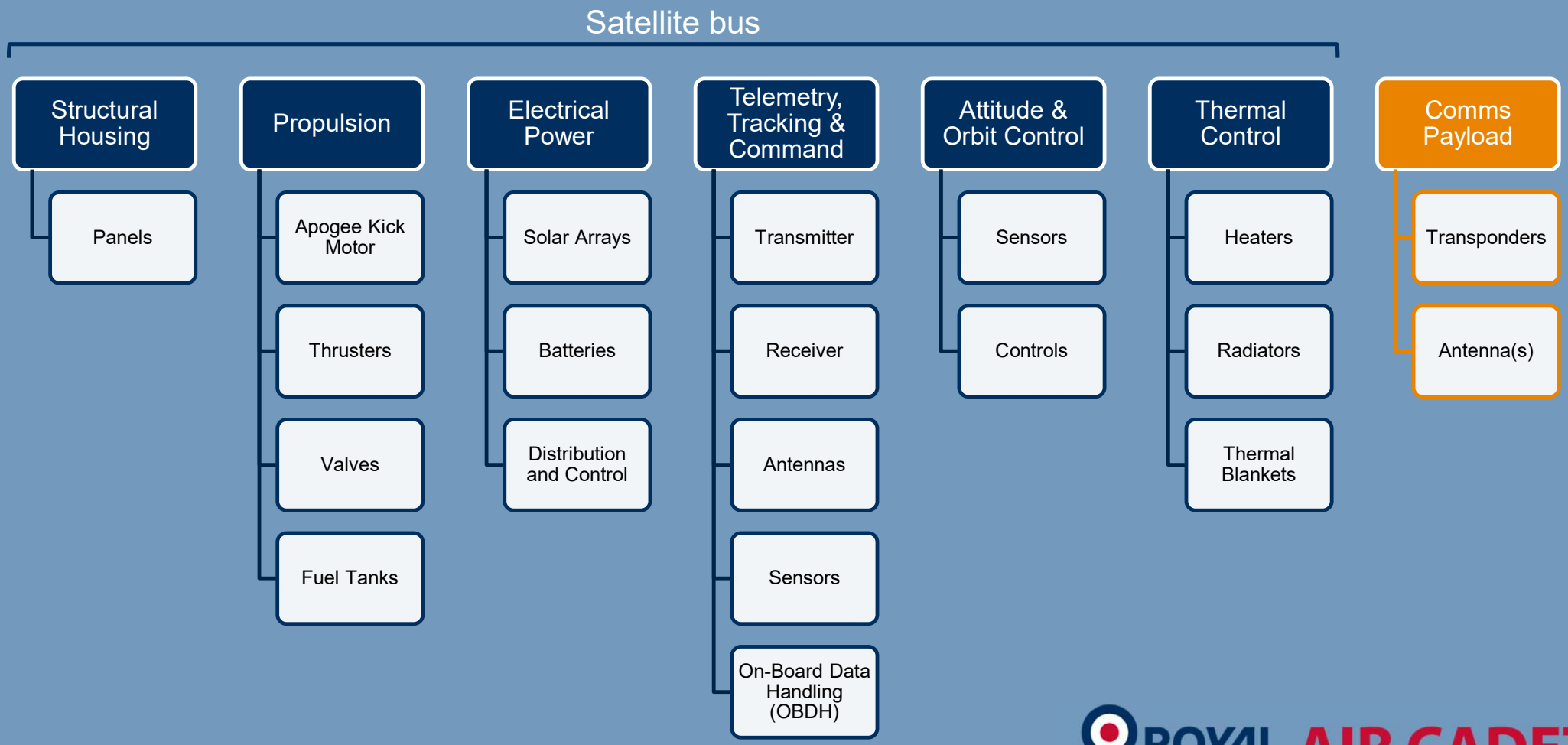
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Thermal Control System

- The Thermal Control System provides an appropriate thermal environment onboard the satellite to ensure reliable operation of the payload and subsystems.
- A satellite absorbs heat from sunlight and generates heat from internal electrical equipment and this must be radiated away into space.
- When in the Earth's shadow, the satellite must not be allowed to get too cold.
- Various techniques are used to maintain the temperature within the satellite's operating limits:
  - *Thermal blanket* composed of a multi-layered insulation of thin plastic film with a gold coating acts as a thermal barrier.
  - External mirror-like *radiator* surfaces attached to internally mounted electrical equipment encourage the escape of dissipated heat.
  - *Heat pipes* transfer heat from the interior to the outside.
  - *Heaters* prevent the batteries weakening and the onboard fuel freezing.

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Adding the Payload (COMSAT Example)



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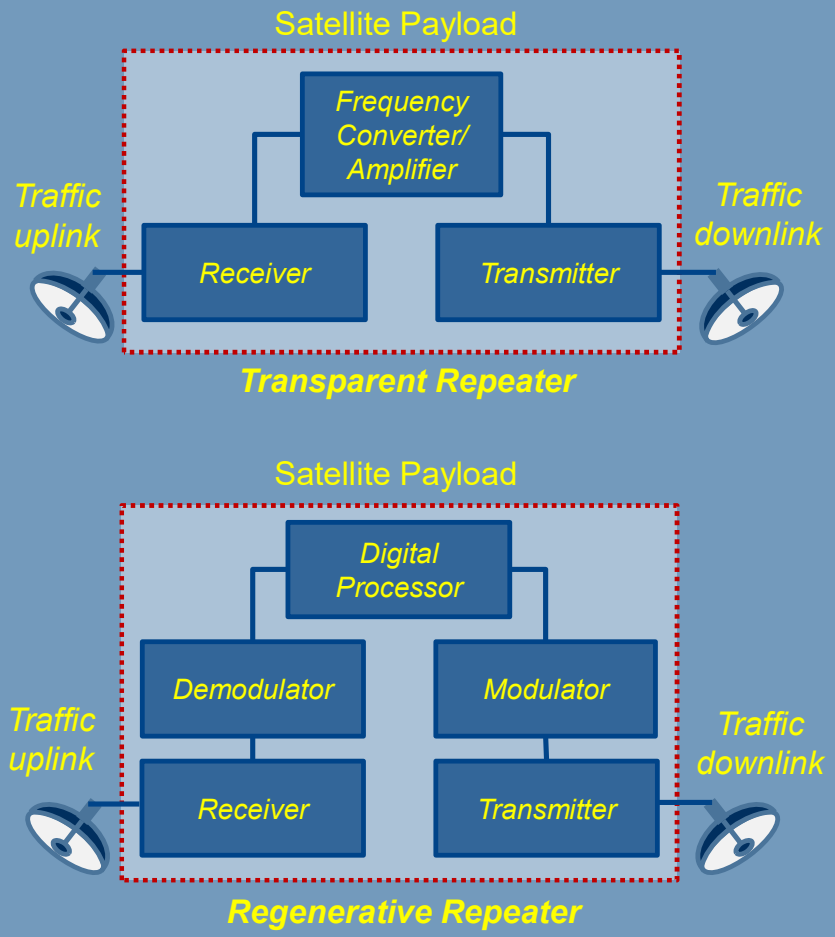
Communications Payload

- A COMSAT's communications *payload* delivers the telecommunications *services*.
- Most communications payloads are *radio relay* stations in orbit that carry on-board electronics called *transponders*.
- The term transponder is a contraction of "***trans****mitter-res****ponder****"* and is used to identify one complete microwave radio channel of transmission from a satellite.
- The basic function of the transponder is to:
  - Receive signals from an Earth Station on the uplink frequency.
  - Change the signal to another downlink frequency.
  - Amplify the signal.
  - Rebroadcast the signal back down to another Earth Station.
- Rebroadcasting on a different downlink frequency prevents the uplink receiver and downlink transmitter interfering with each other.

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Transponder Operation

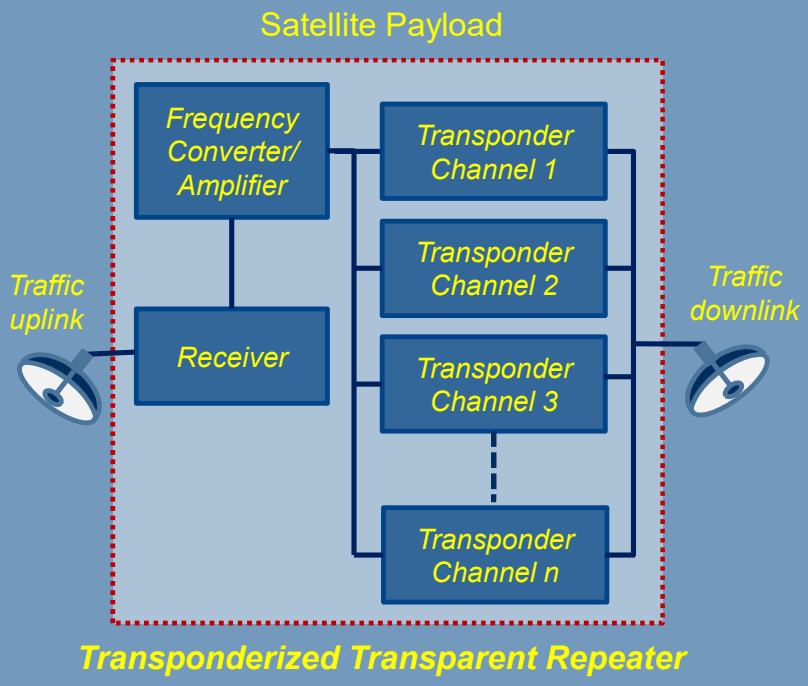
- Most COMSATs operate as a *transparent* (often called a "*bent pipe*") transponder:
  - The received uplink signal is retransmitted back to earth with amplification and frequency shift.
- Some modern satellites have more advanced *regenerative* transponders:
  - The received uplink signal is demodulated to reveal the original bitstream.
  - On-board digital processing cleans up the signal and remove noise and extracts routing information, before retransmitting the signal back to Earth.



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Number of Transponders

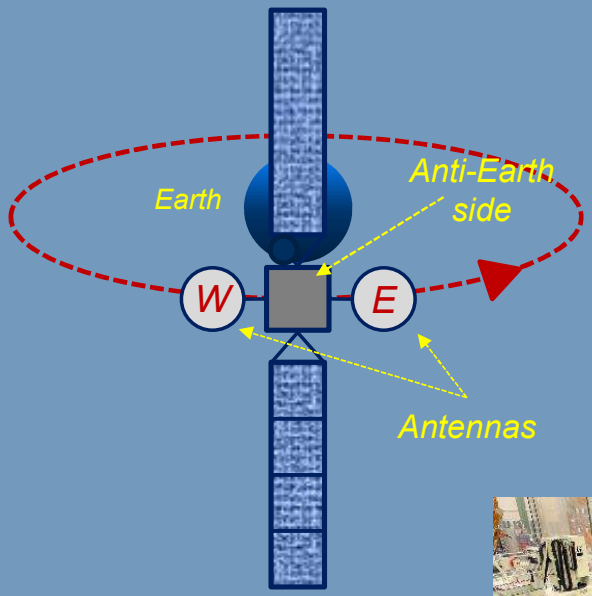
- A *transponderized* design breaks up the downlink bandwidth into a range of individual channels.
- The number of transponder channels varies greatly depending on the satellite's role.
- Depending on the mission, a satellite will often contain multiple transponders, sometimes 20 to 30 or more, to provide redundancy and increased capacity.
- Individual transponders can be assigned to different uses.



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Communications Antennas

- Antennas are used to:
  - Collect uplink telecommunications traffic and TT&C signals from earth stations.
  - Direct downlink telecommunications traffic and TT&C signals to earth stations.
- They can be mounted on the Earth-facing side and the adjacent east and west side panels of the structural housing.
- Most antennas are attached to the housing by short or long booms.
- The satellite must be continuously oriented so that the antennas point towards the Earth.





Typical Antenna Assembly

Image Courtesy of Airbus

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Antenna Types

- Different types, sizes and numbers of antennas may used depending on the communications payload requirements.
- *High gain* directional antennas are mostly used to project a narrow *beam* to create the desired footprint on the Earth.
- More sophisticated types of antennas can:
  - Form multiple individual spot beams at any one time across the surface of the Earth.
  - Be steered either physically with motors, or electronically, to point at a specific location on the Earth when required.



Parabolic reflector

Horn



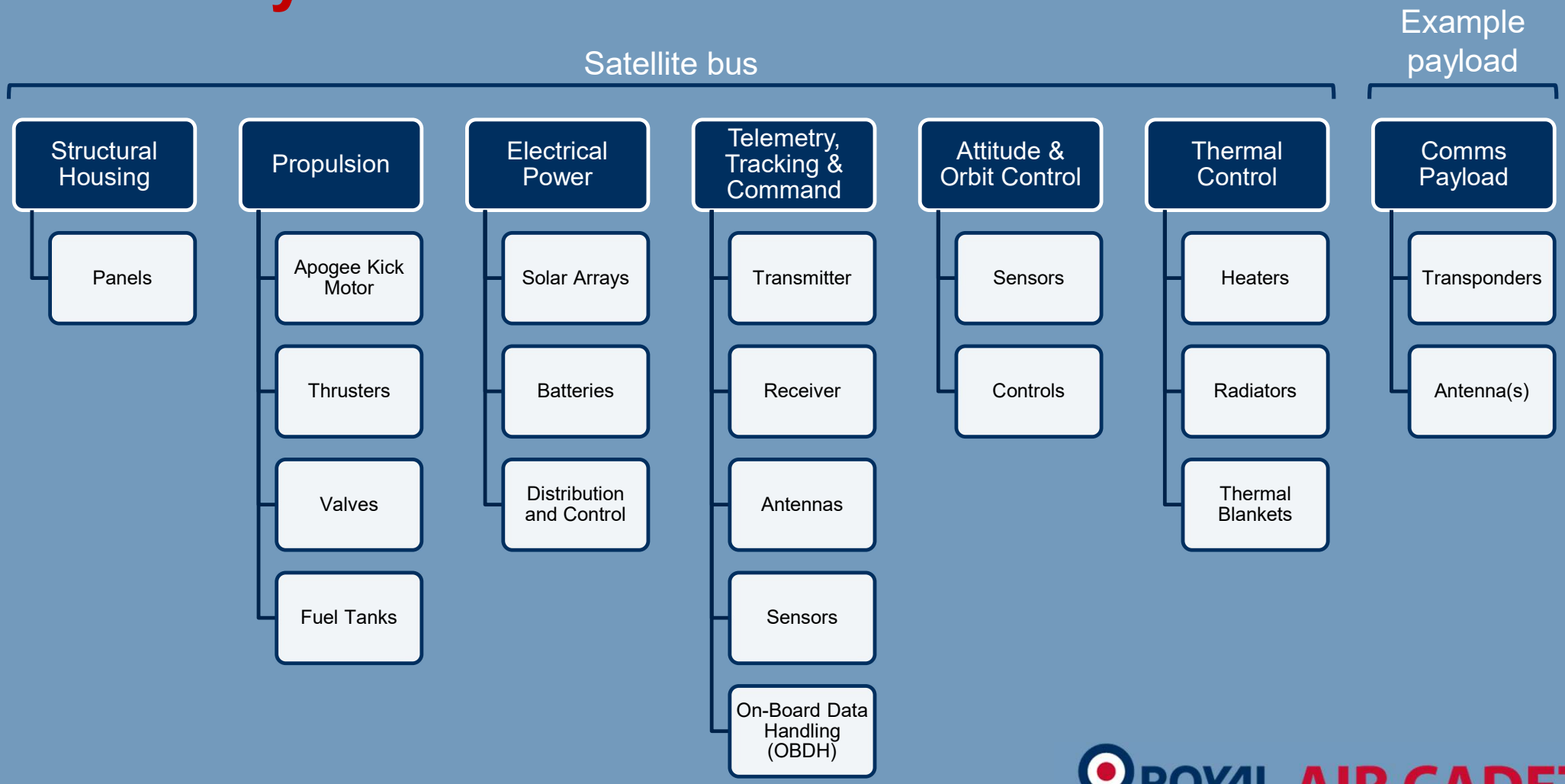


Helical

Image Courtesy of jc⁴i

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Summary of Lesson 5



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Summary of Module (Learning Outcome) 1

- You should now know the **types** and **roles** of satellites and the **principles of earth orbit** including:
  - Uses of satellites.
  - Orbits.
  - Satellite mission phases.
  - Satellite communications.
  - Satellite components.

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