APPENDIX A: ORBITAL FUNDAMENTALS

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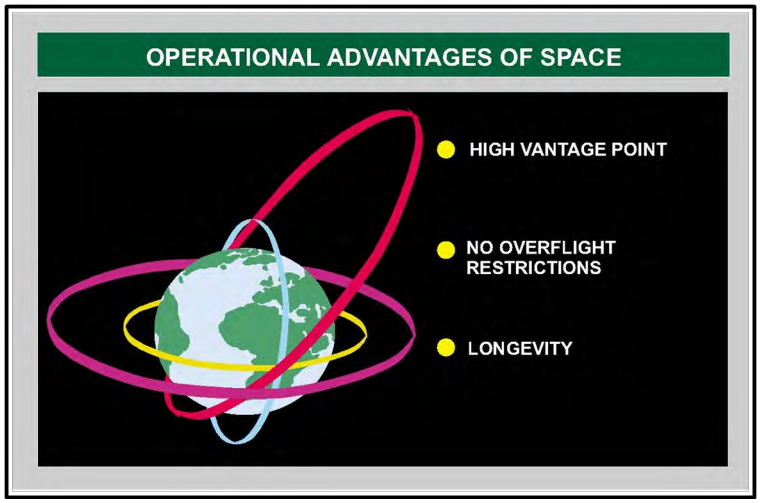
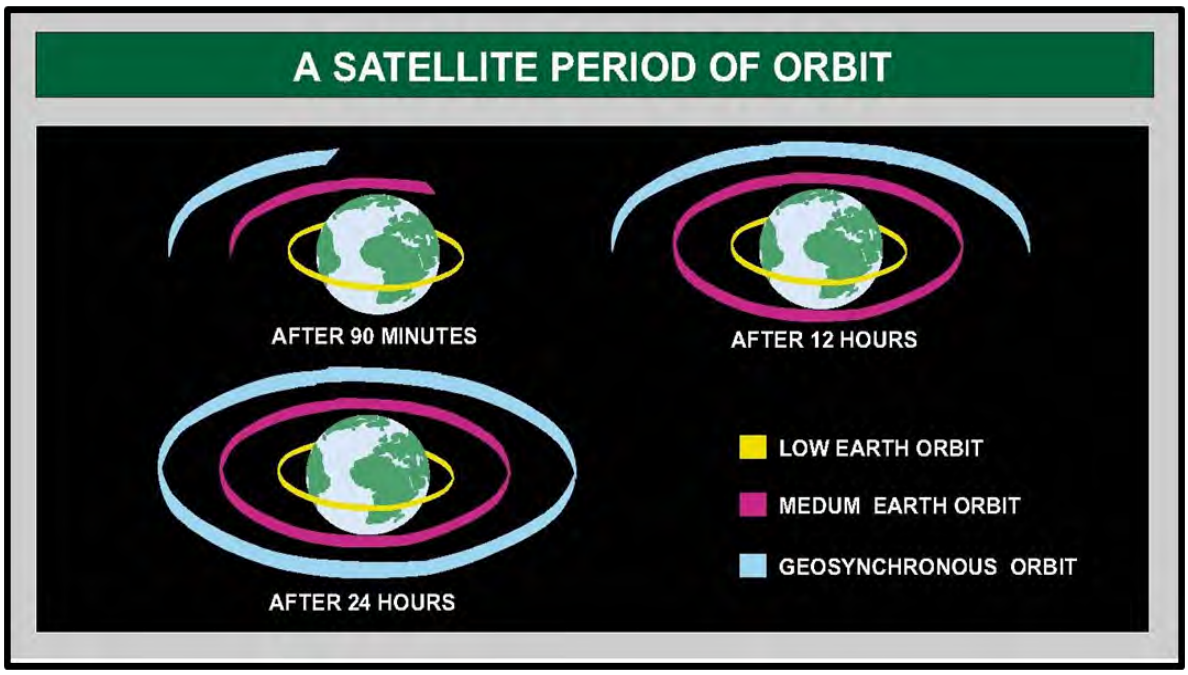
Because the constellation design and orbital characteristics of a space system can vary greatly, space operations' strengths and limitations must be considered. In general, space systems provide the ultimate high ground without overflight restrictions. The absence of significant drag and other natural opposing forces also allows space systems to have increased longevity, sometimes limited only by the reliability of the systems themselves (see figure Operational Advantages of Space). However, there are several forces at work that slowly degrade the accuracy of a satellite's location: atmospheric drag (air particles and atoms exist even at very high altitudes); gravitational attractions of the sun, moon, and other planets; the fact that the Earth is not a perfect sphere and the force of gravity varies; gentle pressure from solar radiation; and the interaction of solar radiation and the Earth's geomagnetic environment.



Operational Advantages of Space

SATELLITE ORBITAL PERIOD

The size of a satellite's orbit determines its period, or the time it takes to complete one revolution. The lower the orbital altitude, the shorter the period (see figure A Satellite Period of Orbit). Common orbits have periods ranging from about 90 minutes (low orbits just above the atmosphere) to 24 hours (geosynchronous orbits approximately 22,300 statute miles above the Earth's surface).



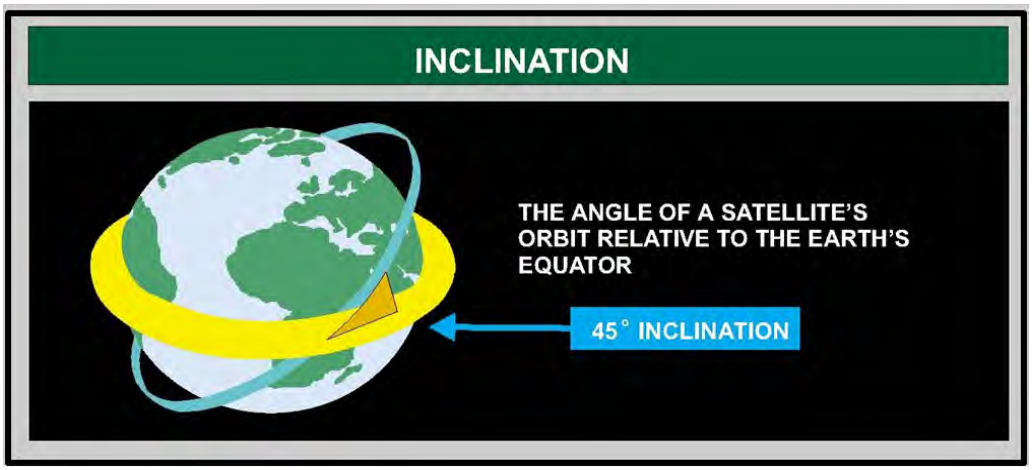
A Satellite Orbital Period

ECCENTRICITY

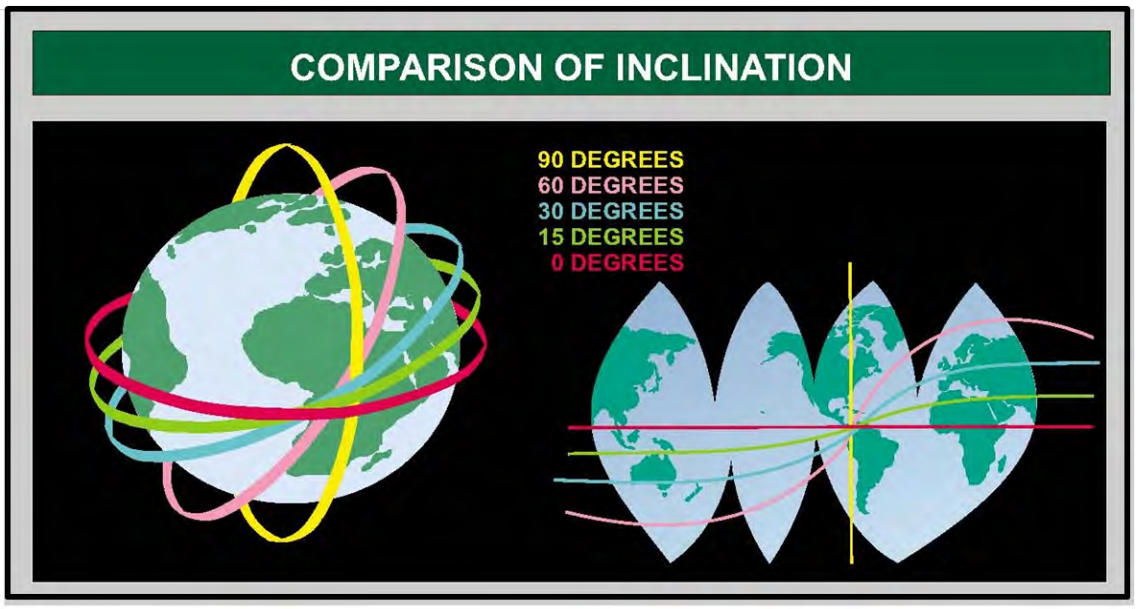
Eccentricity is used to describe how much an orbit's shape deviates from a circle. The figure ranges from 0 to 1 with a value of 0 for a circular orbit.

INCLINATION

A satellite's inclination is the angle between the Earth's equatorial plane and the satellite's orbital plane (see figure Inclination). The angle of inclination is measured counterclockwise from the equatorial plane to the orbital plane at the ascending node. The ascending node is the point where the satellite's path crosses the equatorial plane from the southern to the northern hemisphere. The angle of inclination determines the maximum north and south latitude a satellite will orbit over and, therefore, what part of the Earth's surface will pass directly beneath the satellite—a critical consideration in accomplishing its mission. See figure, Comparison of Inclinations, for a comparison of inclinations. Depending on the inclination, a single satellite may not provide coverage of a specific point on or region of the Earth. Other space assets in different orbital planes—civil, commercial, international, and foreign military—may be used to supplement the satellite's capability and provide continuous, non-intrusive coverage.



Inclination



Comparison of Inclination

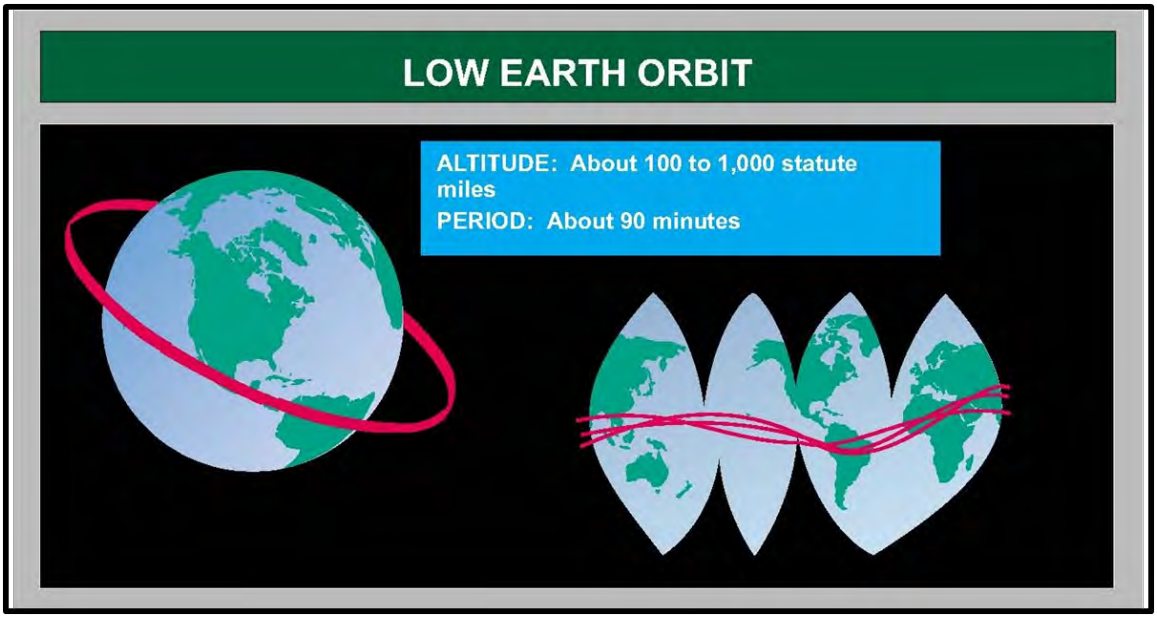
TYPES OF ORBITS

There are five types of orbits: Low Earth Orbit; Polar Orbit; Medium Earth Orbit; Highly Elliptical Orbit; and Geosynchronous Earth Orbit.

Low Earth Orbit

Low Earth Orbit (LEO) is the easiest type of orbit to reach, and the satellite's proximity to the Earth's surface provides the best potential for high-resolution imagery (see figure Low Earth Orbit). However, satellites in these orbits can only view a smaller portion of

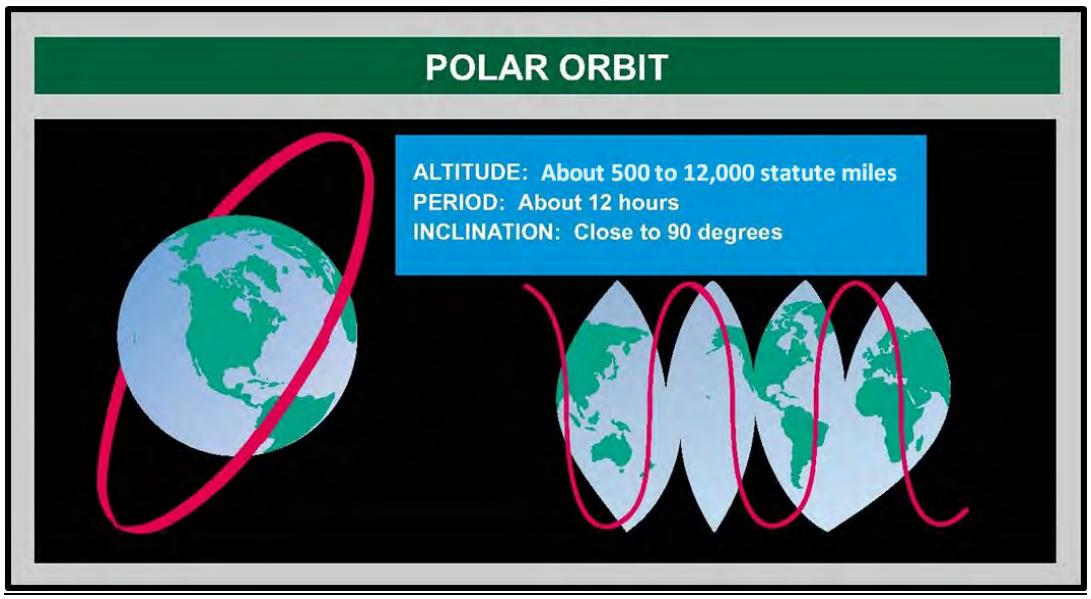
the surface of the Earth at any one time than those at higher altitudes. Atmospheric drag can shorten mission duration. LEO applications include manned flight, environmental monitoring and other ISR, and communication missions.



Low Earth Orbit

Polar Orbit

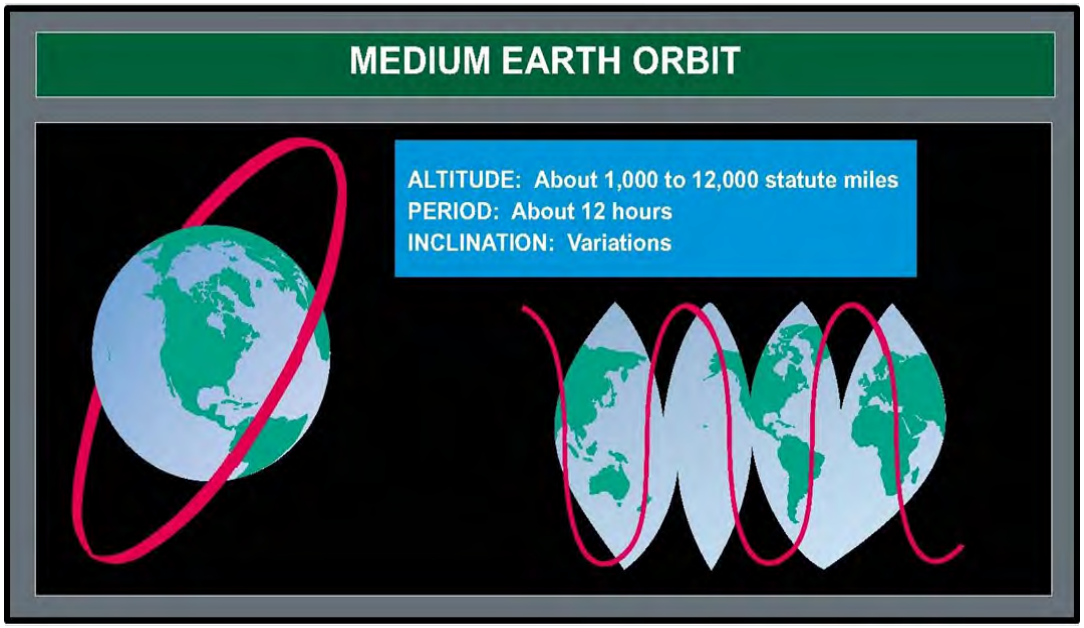
A polar orbit is one with an inclination near 90 degrees (see figure Polar Orbit). A satellite in a polar orbit will travel pole to pole, covering all or almost all the surface of the Earth in 12 to 24 hours, making this type of orbit very useful for environmental monitoring and other intelligence, surveillance, reconnaissance (ISR) missions. A particular type of near polar orbit is a sun synchronous orbit. It has an inclination of 90 to 120 degrees and maintains a constant orientation towards the sun throughout the year, resulting in similar lighting conditions every orbit and making it very useful to detect changes in environmental conditions or surface features of the Earth over time.



Polar Orbit

Medium Earth Orbit

Medium Earth Orbit (MEO) provides a satellite with a view of a larger portion of the Earth at any one time than LEO (see figure Medium Earth Orbit). While atmospheric drag is negligible, a lot more energy is required to place a satellite in these orbits. Current applications include navigation systems (e.g., GPS).

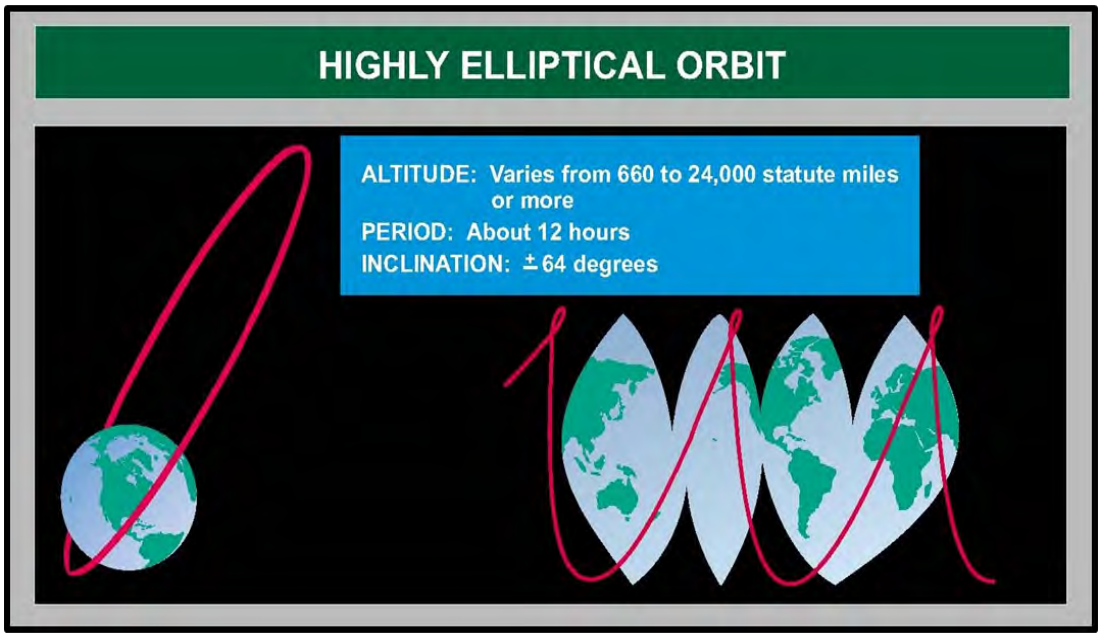


Medium Earth Orbit

Highly Elliptical Orbit

Highly Elliptical Orbit (HEO) is an orbit with a large eccentricity, and an orbit shape of an ellipse versus a circle (see figure Highly Elliptical Orbit). A useful feature of a satellite in a HEO is that the satellite travels relatively slowly when near apogee, giving a long

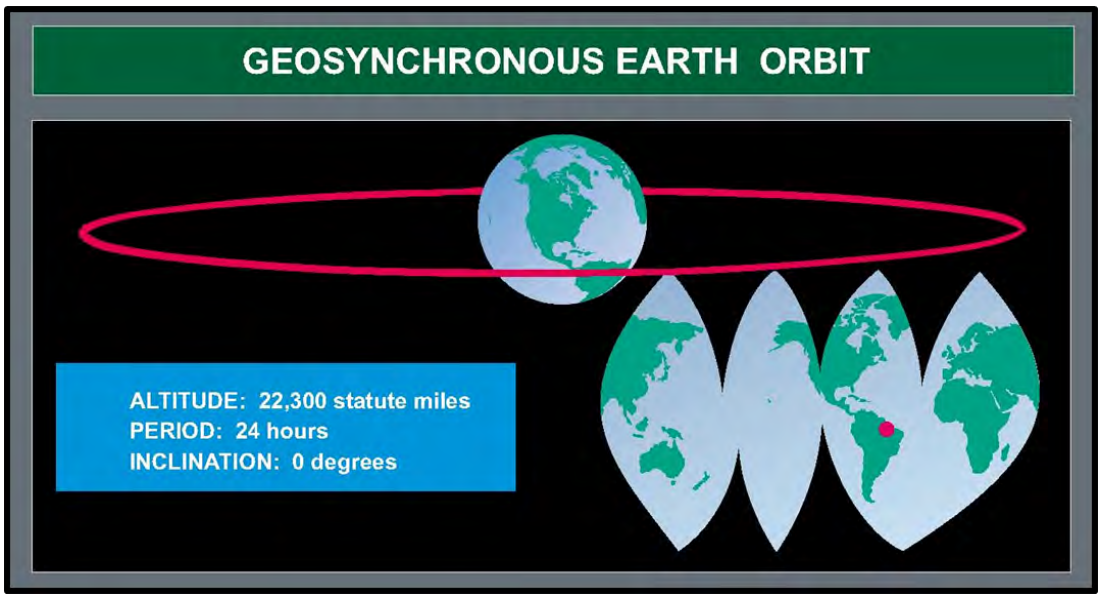
dwell time combined with visibility of a large portion of the Earth. HEO orbits are useful for communications and some ISR missions. The former Soviet Union made extensive use of a HEO called a Molniya orbit that has a period of 12 hours, an inclination of 63.4 degrees, an eccentricity of 0.7, and an apogee over the northern hemisphere. This particular HEO is very useful for providing communications or ISR coverage in the high northern latitudes, a region less well covered by satellites in geostationary orbits.



Highly Elliptical Orbit

Geosynchronous Earth Orbit

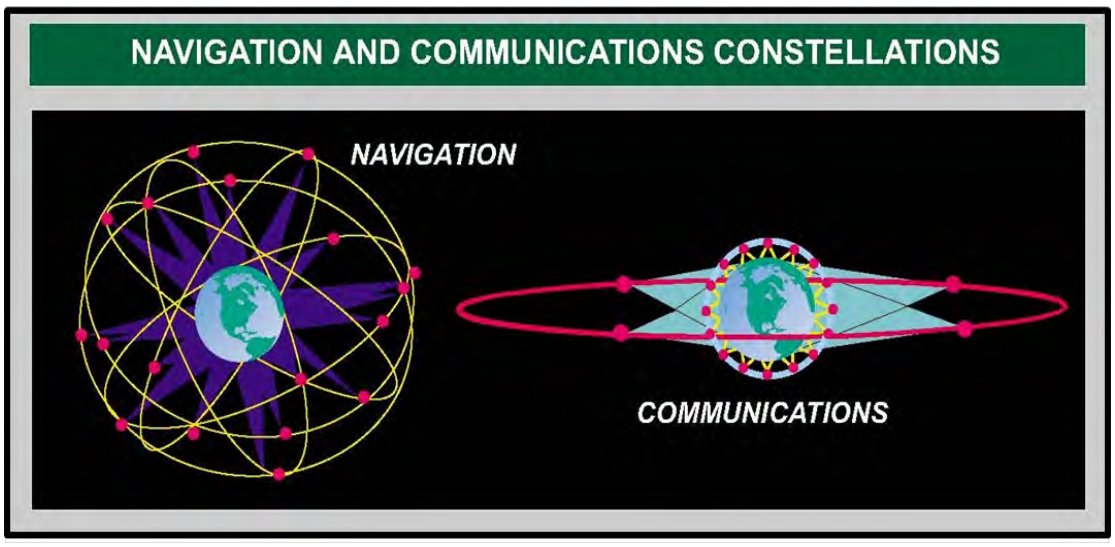
Geostationary satellites are in a near-circular, near-zero inclination orbit with periods exactly equal to the Earth's rotation of 24 hours (see figure Geosynchronous Earth Orbit). Hence, geostationary satellites remain roughly over one spot on the Earth at all times. Orbits that have a 24-hour period, but do not have a near-zero inclination or eccentricity, are called geosynchronous. All geostationary satellites are geosynchronous, but not all geosynchronous satellites are geostationary. The ground trace of a Geosynchronous Earth Orbit (GEO) satellite looks like a figure "8" pattern when traced onto a Mercator map of the Earth, which reflects the natural oscillations of the orbit as well as the degree to which the orbit is inclined to the Earth's equatorial plane. GEO orbits have an altitude of approximately 22,300 statute miles, are difficult to reach, and require launch vehicles with significant lift capability. Satellites in GEO orbit provide coverage of large areas of the surface of the globe with continuous visibility of these areas. Therefore they are very useful for persistent communications, weather monitoring, and certain ISR functions. Because of these advantages, an orbital slot in the GEO "belt" is highly desired, resulting in spatial congestion and electromagnetic interference. A specialized agency of the United Nations known as the International Telecommunication Union manages allocation of GEO orbital slots and electromagnetic spectrum.



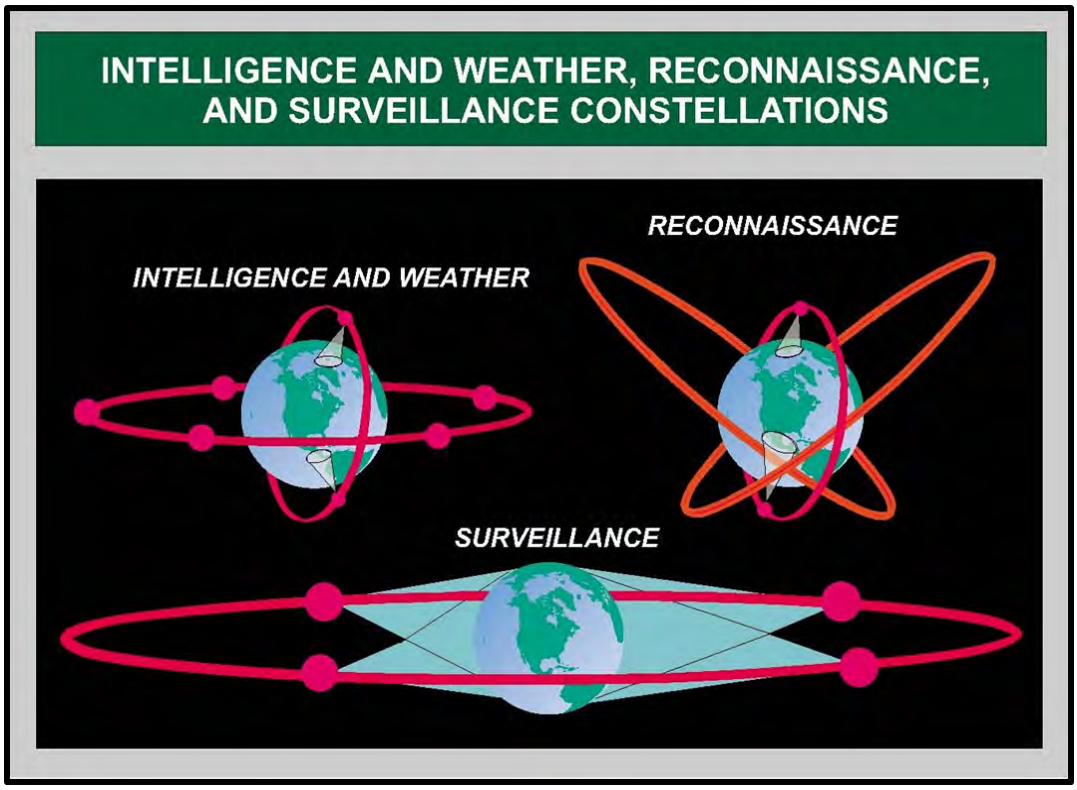
Geosynchronous Earth Orbit

CONSTELLATIONS

When a single satellite cannot provide the coverage necessary to accomplish a given mission, multiple satellites performing a single mission (a constellation) are used to provide global coverage or increase timeliness of coverage (see figure Navigation and Communications Constellations and figure Intelligence and Weather, Reconnaissance, and Surveillance Constellations). Navigation constellations (such as GPS) are designed to ensure that signals from multiple satellites can be simultaneously received at a location on the ground, improving the accuracy of the information coming from those satellites. In contrast, communications constellations are designed to ensure that at least one satellite is within line of sight of both ends of the communications link, and may include both equatorial and polar components. ISR constellations have satellites in both high and low altitude orbits, providing both wide-area coverage and high-resolution data.



Typical Constellations



Intelligence and Weather, Reconnaissance, and Surveillance Constellations

Weather and reconnaissance systems may require constellations that combine high and low altitude systems. This provides on-board sensors with the capability to acquire wide-area, low-resolution coverage and limited field of view, high-resolution coverage, respectively. Some ISR systems, on the other hand, need continuous access to the areas surveyed and usually rely on high altitude, long dwell time orbits.