GLOSSARY for Orbital Mechanics: Companion to forthcoming "Discovering Orbits"

A B C D E F G H I J K L M
N O P Q R S T U V W x y z

-A-

Acceleration signifies the change in the rate of speed. Gravitational attractors in the solar system have well-known masses and satellites have negligible mass, so it's often convenient to disregard the mass components when dealing with gravitational forces. The metric units for acceleration are kiloms per second-squared. (km / sec^2)

AGA is an acronym for Adjusted Graphic Angle. The AGA is the angle between the minRAY and the spacecraft. It uses the geometric center of orbit for the its origin or angular fulcrum.

Altitude is the shortest distance from the spacecraft to earth or lunar surface.

Angles depict the sweeping motion around a central origin. Orbital mechanics parse angles in the counter-clockwise direction from the minRAY point of orbit. Angles are then measured in degrees, where 360° makes a full circle.

Angular momentum measures the area swept by the satellite's current radius around its gravity center. Momentum for orbital mechanics has units of kiloms per second-squared. (km / sec^2)

Anomaly is the astronomer's term for *angle*. In nonastronomical parlance, anomaly means quirk or strange or unexpected.

Aphelion marks a satellite's far-point of orbit around the sun.

Apoasis marks a satellite's far-point of orbit around a gravitational attractor.

Apogee marks a satellite's far-point of orbit around the earth.

Asteroids are smaller than planets and often called planetoids. A majority of the larger asteroids are found between the orbits of Mars and Jupiter.

AU is the acronym for Astronomical Unit or average distance between earth and sun.

Autumnal Equinox is the moment of equal daylight and darkness at the end of summer. At this time the earth is passing into the psign *Seeing* in its orbit around the sun.

Average Speed marks the rate of distance covered during a full orbit. In other words, the average speed is the orbit's perimeter divided by its period. It has units of kiloms per second. (km / sec)

Away angle refers to spacecraft in LEO traveling toward a lunar capture. The away angle represents the diversionary path away from the straight line between earth and moon.

Azimuth marks an object's horizontal direction. The azimuth angle sweeps clockwise from zero degrees north. 90° points east; 180° points south, and 270° points west.

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-B-

BAL is short-form for *Balance,* which marks the 180° (-180°) angle from the minRAY point. With old-style clocks, BAL points to the six o'clock position. *See* minRAY.

Bode's Law is a formula that calculates the average distances of planetary orbits from closest to furthest away from the sun. The

formula uses a variation of the binomial power expansion: 2^0, 2^1, 2^2, 2^3, 2^4 ...

BTH is short-form for *Breathing,* which marks the 330° (-30°) angle from the minRAY point. With old-style clocks, BTH points to the one o'clock position. *See* minRAY.

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-C-

Cartesian (x, y) coordinate system is a rectangular based reference which the origin signifies (0, 0) and positive X-values extend to the right of the origin, and positive Y-values extend upwards from the origin. Negative values from X and Y extend left and down respectively.

Celestial equator is the imaginary great circle around the earth, which lies on level with the earth's orbit around the sun i.e. the plane of the ecliptic.

Celsius scale is a measurement of temperature where 0° Celsius equals the freezing point of water and 100° Celsius equals the boiling point of water. 20° Celsius is comfortable; 30° Celsius of balmy hot; 10° Celsius is chilly cool.

Center of gravity is the gravitational center of a massive object, such as a star or planet. Center of gravity represents the origin (the prime focus point) of an orbiting satellite. By ignoring gravitational influences from other massive objects, you may simplify orbital calculations to the "Two-Body" problem, which is relatively simple.

NOTE: All calculations in *Discovering Orbits* and/or *TryOrbit Lunar* assume the earth or moon are perfectly spherical with a homogeneous distribution of mass therein.

Centrifugal Force pushes against outer frame of a spinning disk. Centrifugal force acts away from the center of spin.

Centripetal force counterbalances the speed of a spacecraft, which wants to continue moving in a straight line. Centripetal force acts toward the gravitational attractor.

Cislunar signifies the volume in and around the sun-moon system.

Combined Speed refers to noncircular orbits where the satellite's speed has two components: Dynamic Circular Speed (DCS) and Dynamic Stretch Speed (DSS). The ratios of DCS and DSS vary during the course of an orbit.

Comets originate in the outer solar system and fall towards the sun where they move rapidly, making sharp U-turns, before they retreat back to whence they came. Comets consist of significant portions of frozen waterlike volatiles that heat up and vaporize as the comets near the sun. This phenomenon creates spectacular comet tails for observers on earth.

Constellations signify special groups of stars which have been given fanciful names by skywatchers thousands of years ago. Constellations may also refer to groups of satellites that orbit in a complex pattern or in staggered fashion along the self-same orbital path.

Coordinate systems are of two kinds: the Cartesian coordinate system and the polar coordinate system. Each system will nail down an object in two- or three-dimensional space. Polar spherical coordinates are more familiar to folks. 3-D positions coincide with angular values on two perpendicular great circles, plus a distance from the origin to the direction implied. Orbital mechanics find (X, Y, Z) spherical coordinates are easier to manipulate, but the values rendered are more difficult to grasp.

Coriolis effect arises from a spinning environment. The faster the spin, the more pronounced the effect. The earth spins very slow, once around every 24 hours, hence the effect is barely noticeable. Hurricanes spin clockwise in the northern hemisphere, and they spin

counter-clockwise in the southern hemisphere. Undisturbed water going down a drain will create a clockwise vortex in the northern hemisphere and a counterclockwise vortex in the southern hemisphere.

Space stations that spin to simulate gravity will experience more pronounced Coriolis effects if the period of spin is less than a minute. Someone who has never thrown a curve ball will find the trajectories of normal throws curving like crazy. Even cats will have to adapt to novel conditions before they can land on their feet.

Coriolis force derives from the Coriolis effect. *See* Coriolis effect.

COS is short-form for cosine, which functions only for right triangles where the hypotenuse equals one. The cosine of an angle is the ratio of the X-side over the hypotenuse.

Cosmic rays are highly charged elemental particles arriving from deep space. Cosmic rays are unhealthy for biological species, but the rays arrive too infrequently to cause undue concern.

CRD is short-form for *Coordinating,* which is the 240° (-120°) angle from the minRAY point. With old-style clocks, CRD points to the four o'clock position.

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-D-

Day length is the time elapsed from midnight to midnight—how we normally reckon a day. Astronomers call this the mean solar day, which is how days are counted in *Discovering Orbits*. However, in the Show-Picture window of *TryOrbit Lunar*, the radial lines drawn inside the earth signify sidereal time. The mean solar day is longer than one rotation of earth (or sidereal day) because the earth travels on its orbit (as it rotates) and faces the sun at an advanced angle. Thus the earth must rotate a small amount extra to catch the sun at sunrise.

- Sidereal day in mean solar time = 23h/ 56m/ 4.09s
- Mean solar day in sidereal time = 24h/ 3m/ 56.56s

DCS is an acronym for Dynamic Circular Speed. DCS is a speed component 90° to the current radius of the satellite in the direction the satellite is orbiting. If DCS signifies 100% of the orbiting speed, the orbit will be circular. *See* **Diagram**.

Deceleration marks the slowing down of a speeding object. Its units are negative km / sec^2.

Degree is a unit of angular measure. 360° represents a full circle.

Delta-V is the energy required to change a spacecraft onto a new orbit. Delta-V also represents the energy required to lift off from earth or moon and achieve orbital speed. Delta-V has the following units: kiloms-squared /over/ seconds-squared. (km^2 / sec^2) For minor accelerations or decelerations, orbital mechanics may use meters-squared /over/ seconds-squared. (m^2 / sec^2)

diameter is the straight-line that passes through the center of a circle and extends from edge to edge. For ellipses, the diameter length will vary depending on where the diameter is drawn.

dimensions apply to geometric environments. A point has no dimensions. A line has one dimension. A plane has two dimensions. A volume or space has three dimensions. Spacetime has four dimensions. Fortunately, orbits occupy two dimensions only, which simplify many problems of orbital mechanics.

Diurnal motion covers the observed travel of a satellite or planet over a 24-hour period.

DSS is an acronym for Dynamic Stretch Speed. DSS is the speed component that causes circular orbits to stretch into elliptic orbits. DSS extends along the current radius of a satellite either inward or outward from the gravitational center of attraction. *See* **Diagram**.

Dynamic means motion or changeable activity.

-E-

Earth is the 3rd-planet of the solar system.

- Earth has a radius of 6378.15 kiloms.
- Earth masses at —> $597 * 10^{22}$ kilograms. Where 10^{22} kilograms equals the mass of 377-billion Three Gorges Dams, the heftiest structure built by humans to date.
- Earth's majA distance from the sun = one AU.
- Earth's mean orbiting speed = 29.785 km/sec

Eccentric anomaly is an intermediary angle sweeping from the geometric center of orbit. *Discovering Orbits* uses the term midE angle for the eccentric anomaly. *See* midE angle.

Eccentricity gauges the elliptic stretch of an orbit. *Discovering Orbits* uses the term Exp (expander) for the eccentricity. *See* Exp.

Ecliptic is the plane of earth's orbit around the sun.

Ellipses are the locus of points on a plane where sum of distances from a satellite to each focus point returns a constant value. An ellipse includes circular orbits as well as elongated cometary orbits. The algebraic formula for an ellipse is... $(x/a)^2 + (y/b)^2 = one$

Elliptic theorem states that $A^2 = B^2 + C^2$. This is a classic right triangle where

- A = majA (semi-major axis);
- B = minB (semi-minor axis);
- C = hfdC (half of the distance between focal points).

Energy moves an object from its inertial state. The energy of orbit is proportional to the majA of orbit. Energy has units of kiloms-squared /over/ seconds-squared. (km^2 / sec^2)

Equatorial orbit means a satellite tracks above the earth's equator and stays on the equatorial plane.

Equatorial plane is a great circle that extends as far as needed on the plane of the earth's equator.

Exp is short-form for Expander, which is measured from zero to almost one for elliptic orbits. The Exp equals one for parabolic flightpaths and greater than one from hyperbolic flightpaths. The Exp has no units per se.

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-F-

Flightpath is the tangent to the orbital arc of the satellite in the direction of motion. It is the angle between the DSS and the Speed arrow.

Flightpath angle equals 90° minus the angle of the velocity vector. For geometers the flightpath angle is "complimentary" to the velocity angle.

Focus points are two for every elliptic orbit. The prime focus point is the gravitational center, which lies on the major axis. The secondary focus point lies also on the major axis at an equal and opposite direction from the geometric center. For circular orbits, the focus points and geometric center converge to same place.

Force equates with gravity or rocket boost. It changes the static momentum of spacecraft in orbit. Since satellite mass is very small compared to its gravitational attractor, the mass component can be ignored. The effect of force is then described in units of kiloms /over/ seconds-squared.

FPA is the acronym for FlightPath Angle.

Frame-of-reference for orbital mechanics is a flat plane surrounding a gravitational attractor. The center of gravity marks the prime focus point. For some orbital calculations, it is often necessary to move the origin from the geometric center of orbit to the gravitational center

of orbit and vice versa. To do this, you add or subtract the hfdC to the orbital parameters.

Freefloat is a term coined by John A. Wheeler. The speed of spacecraft in orbit balances the force of gravity so that astronauts feel weightless. Likewise a person falling from a tall building experiences weightlessness. If it would be possible to stand at the exact center of earth, one would experience the same weightlessness. Freefloat describes the same thing a scuba diver feels when he has adjusted his ballast to evoke weightlessness in water.

Friction causes earthside vehicles to slow down. Friction of the wheel bearings, friction of the tires and friction of air molecules in the atmosphere require constant force to maintain the speed of moving vehicles, otherwise the fuel in your gas tank would stay topped-up for years and years. In outer space, friction is negligible so that a spacecraft will circle earth almost indefinitely.

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-G-

GEO is short-form for geosynchronous orbit—a flightpath where the satellite orbits at the same speed as the earth spins. Comsats are often placed in geosynchronous orbits so that ground stations can open continuous relay channels with the satellite.

Geometric center is at the center of the ellipse. The point lies midway between the elliptic focus points, if they are separated. The geometric center is the origin and fulcrum for the midE angle.

Geocentric means earth-centered. Some telescopes include real-time maps that set all planets and planetoids in the solar system to a geocentric frame-of-reference, so that amateur astronomers can aim automatically to their points of interest. If humans inhabit permanent colonies away from earth, the geocentric view may well

be replaced with other frames-of-reference.

GP is the acronym for Gravitational Parameter. GP has been calculated accurately for all major bodies of the solar system, so orbital mechanics know from the speed, direction and radius of a spacecraft what sort of orbit it will assume.

GPS is the acronym for Global Positioning Satellites. Three satellites triangulate transponder signals for a hiker in the outback. In this way, they can nail the hiker's location with remarkable accuracy. Commercial airplane pilots use GPS to guide their aircraft through the mid-portions of their flights.

Gravitational attractor is any massive body that exerts gravity and causes a speeding spacecraft to curve around its attraction.

Gravitational center resides at the center of mass of the gravitational attractor. For orbiting satellites, this origin equates with the prime focus point.

Gravitational parameter tells an orbital mechanic how a spacecraft will react around a gravitational attractor. Scientists believe gravity acts the same anywhere in the universe. Thus gravity is a constant that varies only according to the mass of the gravitational attractor. Since the masses of major bodies of the solar system have been calculated to remarkable accuracy, you can ignore the amount of mass in the equation and describe the gravitational parameter for earth or moon in terms of volume contortion /over/ the rate of time elapsed. Thus, the gravitational parameter has units of kilometers-cubed /over/ seconds-squared.

- Mercury GP = 21,680 km^3 / sec^2
- Venus GP = 325,000 km^3 / sec^2
- Earth GP = 398,600 km^3 / sec^2
- Mars GP = 42,970 km^3 / sec^2
- Jupiter GP = 126,700,000 km^3 / sec^2
- Saturn GP = 37,900,000 km^3 / sec^2
- Uranus GP = 5,790,000 km^3 / sec^2

- Neptune GP = 6,805,000 km^3 / sec^2

Gravity-well is a descriptive term that illustrates how an orbiting satellite has a great amount of potential energy, which must be forfeited when a spacecraft deorbits to earth or lunar surface. A spacecraft in minimum earth orbit has acquired half the Delta-V needed to travel anywhere in the solar system.

GVT is short-form for *Gravity,* which marks the 270° (-90°) angle from the minRAY point. With old-style clocks, GVT points to the three o'clock position.

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-H-

Hectare is a measure of area.

- One hectare equals 2.471 acres.
- One hectare equals 107,639.1 square feet.
- One hectare equals 11,959.9 square yards.
- One hectare equals 10,000 square meters.
- One hectare equals .01 square kilometers.

HEO is an acronym for High Earth Orbit. It means any orbit beyond GEO. The moon is an example of HEO as well as L4 or L5.

hfdC is short-form for half of the distance between elliptic focus points. hfdC forms one of the sides of the elliptic triangle.

HRG is short-form for *Hearing,* which signifies the 30° (-330°) angle from the minRAY point of orbit. With old-style clocks, HRG points at the eleven o'clock position.

Hypotenuse is the side of right triangle opposite the 90° angle. It is the longest side but shorter than X-side plus the Y-side. The hypotenuse-squared equals the X-side-squared plus the Y-side-squared.

- $H^2 = X^2 + Y^2$

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-I-

Inclination refers to the slant of the orbital plane. The Inclination angle gauges how far the orbital plane slants away from the ecliptic or earth equator.

Inertia is the crux of Newton's 1st-law of motion: A body will continue in its present state of motion until an outside force acts to change it.

Interval of thrust measures the duration of rocket boost needed to achieve the desired delta-V. If the rocket boost delivers 5% of the delta-V per second, astronauts will have to fire their rocket for 20 seconds.

Intercept angle signifies the optimal angle to approach a gravity-well. If you want a spacecraft to go into quasi-circular orbit around Mars or Venus, you must dip lightly into its atmosphere several times to burn off the excess approach speed. Eventually the spacecraft will match the proper orbiting speed for the gravity-well. Since the moon has no atmosphere, the spacecraft can only achieve a capture orbit, which will probably be highly elliptic. Then you fire reverse thrusters at the minRAY point to circularize the orbit. If the intercept angle is too steep, the spacecraft will crash into the gravitational attractor. If the intercept angle is too wide, the spacecraft will hook around the gravity-well and zoom off elsewhere.

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-J-

Jupiter is the 5th-planet of the solar system.

- Jupiter radius = 71,398 kiloms.
- Jupiter masses at —> 190,000 * 10^{22} kilograms. Where 10^{22} kilograms equals the mass of 377-billion Three Gorges Dams, the heftiest structure built by humans to date.

- Jupiter majA distance from the sun = 5.203 AU.
- Jupiter mean orbiting speed = 13 kiloms / second.

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-K-

Kilogram is a unit mass that equals 2.2 pounds, like hefting a quart of milk.

- One kilogram equals 1,000 grams.
- 1,000 kilograms equal one metric tonne.

Kilom(s) is short-form for kilometer(s).

Kinetic is the dynamic form of energy. Gas in a vehicle's tank represents potential energy. When it's burned, it transforms into kinetic energy which sets the vehicle in motion.

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-L-

Latitude represents the spherical angle away from the earth's equator. North or positive latitude signifies the angle north of the equator. South or negative latitude signifies the angle south of the equator. Astronomers use latitude as one of the great circles that pinpoint objects in space.

Launch module is the wherewithal needed to launch a spacecraft or satellite into orbit. The launch module contains the protective outer skin, the rocket motor, the fuel stocks and the payload capsule.

LEO is an acronym for Low Earth Orbit. LEO orbits range from 250 kiloms in altitude to 800 kiloms in altitude. In this way, the spacecraft is protected from solar radiation inside earth's ionic belt.

Libration means back and forth motion due to the earth's wobble on its axis.

Longitude is the spherical angle east or west from the Greenwich prime meridian. Astronomers describe longitude as right ascension and use it as one of the great circles that pinpoint objects in space. Right ascension is measured in 360° and represents a spacial framework of sidereal time.

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-M-

Main Windows for *TryOrbit Lunar* are:

- Show-Picture Window (satellite in animation)
- Results Window (Orbital Data)
- Speed-Graph Window (two views)

majA is short-form for semi-major axis, which is half the of the longest diameter of the orbital ellipse.

Mars is the 4th-planet of the solar system.

- Mars radius = 3,380 kiloms.
- Mars masses at —> 64 * 10^{22} kilograms. Where 10^{22} kilograms equals the mass of 377-billion Three Gorges Dams, the heftiest structure built by humans to date.
- Mars majA distance from sun = 1.524 AU.

Maximum Altitude of an orbit occur at the maxRAY point.

Maximum orbiting speed occurs at the minRAY point.

Mass measures an object size and density. Whereas weight gauges an object's heft in earth's gravity, the same object will seem weightless in the freefloat environment. Mass remains the same no matter how strong gravity is. To change an object's inertia will require substantial force, even in weightless conditions.

maxRAY signifies the longest radius of an elliptic orbit.

Mean Anomaly represents the 360° angle of orbital period. *Discovering Orbits* calls the mean anomaly the TIME angle. See *TIME* Angle.

Mercury is the 1st-planet of the solar system.

- Mercury radius = 2,439 kiloms.
- Mercury masses at —> 33 * 10^{22} kilograms. Where 10^{22} kilograms equals the mass of 377-billion Three Gorges Dams, the heftiest structure built by humans to date.
- Mercury majA distance from the sun = .387 AU.

midE Angle is measured from the origin of the geometric center of orbit. It sketches a circle of radius majA and meets the actual orbital path at two places: minRAY and maxRAY. The midE angle is the go-between the TIME angle and the POSITION angle.

minB is short-form for semi-minor axis, which is half the length of the shortest diameter of the orbital ellipse.

Minimum Altitude of an orbit occurs at the minRAY point.

Minimum orbiting speed occurs at the maxRAY or far-point of orbit.

minRAY is the minimum radius of orbit. It occurs at zero degrees of the POSITION, midE and TIME angles. The minRAY crossing signals the end of one orbital cycle and the beginning of the next.

Moon's orbiting speed is 1.0183 kiloms per second on average. It varies as much as 5% from norm, depending its POSITION of orbit and distance from earth.

MOV is short-form for *Moving,* which marks the 300° (-60°) angle from the minRAY point. With old-style clocks, MOV points to the two o'clock position.

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-N-

Neptune is the 8th-planet of the solar system.

- Neptune radius = 24,300 kiloms.
- Neptune masses at —> 10,200 * 10^{22} kilograms. Where 10^{22} kilograms equals the mass of 377-billion Three Gorges Dams, the

heftiest structure built by humans to date.

- Neptune majA distance from the sun = 30.11 AU.

Newton's 1st-law of motion: Objects stay in their inertial state unless acted upon by an outside force. A body at rest will stay at rest. A body in motion will stay in motion on its present course.

Newton's 2nd-law of motion: An object's momentum changes in proportion to the force acting on it. Orbital momentum is expressed in units of kilograms times kiloms-squared per second. (kg * km^2 / sec)

NOTE: *TryOrbit Lunar* uses 100 hectares in place of one kilom-squared.

Newton's 3rd-law of motion: Every action as an equal and opposite reaction. Combustive fuel that is pushed out of the rear of a spacecraft propels the spacecraft forward in directly proportion to the mass of the fuel and the speed of its exit.

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-O-

Oblate earth means the earth isn't a perfect sphere. Earth is flattened at the poles and resembles an ellipsoid. This means that gravity pulls somewhat less for satellites that pass over the poles compared to satellites that track along earth's equator. *Discovering Orbits* assumes the earth is a perfect sphere and doesn't take into account the subtle perturbations due to earth's gravitational anomalies. All orbits made with *TryOrbit Lunar* are only accurate for about ten to fifteen days beyond their initial parametric constraints. Nonetheless, you will gain a good ballpark estimate of how orbits behave, given their initial parameters. In fact, *Discovering Orbits* will give you better orbital know-how than many sci-fi authors who fudge the known laws of physics.

Operators act on the parameters of algebraic equations. The most

common operators are add, subtract, multiply and divide. Throw in elementary trig functions, and you have all the math operators you need to understand rocket science in theory and practice.

Discovering Orbits uses the following symbols:

- The symbol * means multiply.
- The symbol + means add.
- The symbol - means subtract.
- The symbol / means divide.
- The symbols ( ) mean do the calculations inside before doing the calculations outside. For example, the expression 3 * (2 + 2) means add two & two and then multiply by 3, which equals 12, which proves a sasquatch has more toes than you do.

Orbits are the closest natural phenomena to perpetual motion. Once satellites are lofted into stable orbits, they keep going around without assistance.

Orbiting energy is directly proportional to the majA of orbit. The larger the majA, the slower the orbiting speed, and the greater the energy of orbit. The more area enclosed within an orbital track, the greater portion of the energy is potential. Think of the bicycle rider who has huffed and puffed up a steep hill. He or she sits at the summit and looks forward to enjoying the gift of potential energy on the way down.

Orbital mechanics marks the way to maneuver a spacecraft to best effect, to accomplish a mission in the least time with the least fuel expended. After you read through *Discovering Orbits* you will become a competent orbital mechanic.

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-P-

Parabolic curves mark spacecraft with minimum escape speed from their local gravity-well. Some comets come close to resembling

parabolic flightpaths. After their close encounter with sun, they return to the outer solar system way beyond the orbit of Neptune. Some of them won't return to inner solar system for thousands of years. A parabolic flightpath has a Exp value equal to one. A spacecraft on collision course toward a gravitational attractor also has a Exp value of one. You need common sense to distinguish one from the other.

Parameters are variable numeric values that turn general equations into specific instances returning specific results. If a percentage of your income goes to the taxman, you have to make do with whatever remaining income remains at hand. Suppose we introduce a new parameter, such as a winning ticket in the lottery. You spending plans will suddenly find many new opportunities. Orbital equations work the same way. If you set generous initial parameters, you will have more choices of flightpaths that will fulfill your mission.

Parking orbit means a roughly circular orbit around a gravitational attractor. A parking orbit has a modest altitude enabling a possible deorbit to the attractor's surface. Likewise, the spacecraft retains enough potential energy to facilitate an escape from the gravity-well if such action is desired.

Payload includes all parts of the launch module the makes it into orbit. It includes the electronic package, the solar collector wings, the antenna, the spacecraft protective shell, maneuvering rockets and reserve fuel, extra shielding for sensitive science packages and occasionally the upper stage of the launch booster.

Periapsis marks the minRAY point or shortest altitude of orbit.

Perigee marks the closest approach of an orbit around earth.

Perihelion signifies the shortest radius of an orbit around the sun.

Period represents the time span of one complete orbit. It equates with 360° of the TIME angle. The period has units of seconds.

The period equals 2 * PI * SQR(majA * majA * majA / GP)

Where * means multiply by
and SQR means "Take the Square Root of."

Perpendicular means at 90° to a line or plane.

Perturbations represent 3rd-party intrusions on an orbital path. They included the nonspherical composition of earth, the gravitational effects of the sun, moon and Jupiter for earth-based orbits. For lunar orbits add the gravitational tides of earth.

PI is a natural constant = 3.14159265358979323846264338327 9…

Polar coordinates consist of planar or spherical angles and the radius of the spacecraft.

POSITION angle advances rapidly near the minRAY and slowly near the maxRAY. It has its origin and fulcrum at the gravitational center of orbit. The POSITION angle sweeps out equal areas in equal times.

Pythagoras is the so-called originator of the right-angle theorem on which trigonometry is based. However, evidence suggests Egyptian surveyor-astrologers understood the right-angle theorem 1,000 years before Pythagoras was born. For any right triangle, the longest side is called the hypotenuse opposite the 90° angle. The hypotenuse-squared equals the X-side-squared plus the Y-side-squared.

- $H^2 = X^2 + Y^2$

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-Q-

Quadrants divide the 360° circle into four equal parts. The 1st-quadrant includes angles from zero to 90° (x-positive, y-positive). The 2nd-quandrant includes angles from 90° to 180° (x-negative, y-positive). The 3rd-quadrant includes angles from 180° to 270° (x-negative, y-negative). The 4th-quadrant includes angles from 270° to 360° (x-positive, y-negative).

Queue overflow occurs in *TryOrbit Lunar* when more than 2,047 orbits

are loaded in a current session. *TryOrbit Lunar* will automatically save these to the default file.

NOTE: If you use *TryOrbit Lunar* with 64-bit Windows systems, Windows may not let you save custom orbits to disk. If it does, you will only have access to one file called Userorb.d06. Userorb.d06 has a capacity much larger than 2,047, but it is NOT unlimited. If you fill the file to capacity, it will no longer accept custom orbits.

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-R-

Radian angles are those measured in 2 * PI radians instead of 360°. To convert degrees to radians multiply by PI / 180. To convert radians into degrees multiply by 180 / PI. Digital trigonometry is best done with radian angles. Then you convert the answers back to degrees.

Radius is the distance from the satellite to the gravitational center. For elliptic orbits, the radius will change for different positions in the orbit.

Radial velocity is the same thing as the DSS component. *See* DSS.

Retrograde motion is the side effect of observing celestial bodies from a moving, spinning earth. There are times when observers on earth will see planets and/or earth-based satellites apparently moving backward or retrograde. This backtracking is an optical illusion. Satellites or planets do NOT reverse direction, they merely appear to do so, because they are tracking slower than earth's spin or orbital motion.

Right-angle theorem works for all triangles in which one corner forms a 90° angle. The side opposite the 90° angle is the longest side and is called the hypotenuse. For convenience, trigonometric tables put the hypotenuse at one unit of length. Then the theorem holds that the X-side-squared equals the Y-side-squared equals the hypotenuse-squared.

- $X^2 + Y^2 = 1^2$ or one.

Right ascension is an astronomical term for longitude. Right ascension is both directional and time dependent. By using sidereal tables, the astronomer can orient himself or herself at the point of interest in the night sky.

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-S-

SAM is the acronym for Static Angular Momentum. SAM is a constant for all orbits. SAM is similar but not the same as energy of orbit. It has units of kiloms-squared per second.

Satellites orbit around gravitational attractors, their rotational momentum matching the inward pulls of the gravity-wells. The flightpath of a satellite is inertial. It continues to follow the laws of orbital dynamics until an external force is exerted, such as the firing of rocket engines or the drag of atmospheric friction.

Saturn is 6th-planet of the solar system.

- Saturn radius = 60,369 kiloms.
- Saturn masses at —> 56,800 * 10^{22} kilograms. Where 10^{22} kilograms equals the mass of 377-billion Three Gorges Dams, the heftiest structure built by humans to date.
- Saturn majA distance from the sun = 9.555 AU.

SEE is short-form for *Seeing,* which marks the zero (360°) angle for the minRAY point. With old-style clocks, SEE points to the twelve o'clock position.

semP is short-form for semi-parameter. The semP is the radius line from the gravitational center straight up to the satellite's orbital path.

Sidereal day is the length of time for the earth to rotate on its axis. Astronomers call this "right ascension." The sidereal day is

somewhat less than the mean solar day that we use to denote day lengths.

- Sidereal day in mean solar time = 23h/ 56m/ 4.09s
- Mean solar day in sidereal time = 24h/ 3m/ 56.56s

SIN is the acronym for sine, which functions only for right triangles where the hypotenuse equals one. The sine of an angle is the ratio of the Y-side over the hypotenuse.

SML is short-form for *Smell,* which marks the 60° (-300°) angle from the minRAY. With old-style clocks, SML points to the ten o'clock position.

Solar rays are charged particles (X-rays) blown off from the sun's fusion furnace. Solar rays are dangerous to human health. Fortunately, the earth's magnetic shield blocks most of the solar rays from reaching the biosphere where we live. However, solar rays can be hazardous to folks who live and work in outer space. Protective shielding is recommended for off-earth habitats.

Solar sails use light pressure in the same way as sailing ships use wind for propulsion. Because solar-sail craft require little or no fuel, they are excellent choices for long-range travel in the solar system. They have few moving parts, so they might be the most reliable and durable spacecraft in the universe. Solar-sail craft need extra time to get up to speed. Once they start cruising, their ETAs compare favorably with rocket-powered craft. Solar sails have one big disadvantage. They are next to useless when they venture deep into gravity-wells. It takes them months to crawl out LEO, but at HEO orbits they can gain near-escape speeds within days or weeks.

Solstices are the longest and shortest days of the year. The most daylight happens around June 21st, and least daylight happens around December 21st.

Spacecraft is any fabricated craft that is launched above earth's atmosphere. If the spacecraft settles into orbit, it becomes a satellite

of earth. If it escapes earth's gravity-well, it becomes a probe of the solar system. If it journeys outside the solar system, it becomes an inter-stellar probe. The spacecraft may or may not carry humans onboard.

Spring equinox signals the time of equal daylight and darkness. It is often called the vernal equinox. The spring equinox occurs at the moment the earth enters the psign BAL or 180° from the minRAY point.

SPS is the acronym for Solar-Powered Satellite. 75 years ago, Nikola Tesla envisioned an era of cheap and clean energy, when solar collectors in geosynchronous orbit would beam microwaves to earth and thereby power the world's electric grid. So far, no government has had the gumption to make this dream a reality.

SQR is short-form for "take the square root of." SQR is a mathematical operator. It means calculate the numerical root, which when multiplied by itself, returns the original number.

Sun is our luminous star. It contains a lion's share of the mass in the solar system. The sun orbits around the gravitational center of the Milky Way galaxy and takes all objects of the solar system in its train.

Index.

-T-

TAN is short-form for tangent, which functions only for right triangles where the hypotenuse equals one. The tangent of an angle equals the ratio of the Y-side over the X-side. (Y / X)

Tangential velocity means the same thing as the DCS component. *See* DCS.

TCH is short-form for *Touch*, which marks the 150° (-210°) angle from the minRAY point. With old-style clocks, TCH points to the seven o'clock position.

Thrust is combustive fuel that is jettisoned by a spacecraft. The exhaust from the fuel powers a spacecraft forward in the opposite direction from which the exhaust expels.

TIME angle sweeps 360° in synch with an orbit's period. For geosynchronous orbits, one degree of the TIME angle equals about four minutes gone by on your watch. Most orbits have periods far less or greater than a day. The degrees of the TIME angle adjust to whatever orbital period you may wish to examine.

Trigonometry is based on the right-angle theorem. You don't need to futz around with vectors or matrices. Just use the right-angle theorem and a morsel of common sense. This simple equation produces tables that match angular values to triangular side ratios. Most computer systems offer a calculator applet that produces sine, cosine and tangent ratios for almost any angle imaginable. When minimal parameters are known, trigonometry lets you find the unknowns of a triangle or other geometric objects. Moreover, trig functions work in three dimensions almost as well as they work in two dimensions. *See* Quadrants.

True anomaly means the same thing as POSITION angle. *See* POSITION angle.

TST is short-form for *Taste,* which marks the 120° (-240°) angle from the minRAY point. With old-style clocks, TST points to the eight o'clock position.

Turning angle results when a free-wheeling spacecraft encounters gravity-well. Three things can happen.

- The spacecraft skims the gravity-well enough for the attractor to capture it. Then the spacecraft becomes a satellite in orbit around the gravity-well
- The spacecraft dives too deeply into the gravity-well and crashes into the massive attractor.
- The spacecraft skims the gravity-well, but the attractor cannot capture it because the spacecraft is going too fast. In effect, the

spacecraft makes a hyperbolic flyby during which the attractor changes the spacecraft's directional flightpath. In other words, the spacecraft acquires the attractor's orbiting speed as it exits the system, although its intrinsic speed remains unchanged, going in and going out. This change of direction is called the turning angle.

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-U-

Units are a very important check on the accuracy of your calculations. As you crunch the numbers, do the same for the units. You should end up with distances expressed in kiloms, speeds expressed in kiloms per second and parameters like Exp expressed in no units at all. If the units match up correctly, you know you have used the right equations. If there are still errors, they must be errors of arithmetic.

Uranus is the 7th-planet of the solar system.

- Uranus radius = 25,400 kiloms.
- Uranus masses at —> 8,670 * 10^{22} kilograms. Where 10^{22} kilograms equals the mass of 377-billion Three Gorges Dams, the heftiest structure built by humans to date.
- Uranus majA distance from the sun = 19.218 AU.

URG is short-form for *Urgency,* which marks the 90° (-270°) angle from the minRAY point. With old-style clocks, URG points to the nine o'clock position.

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-V-

Van Allen belt is an ionic shroud around earth, which occurs at an altitude of about 1,000 kiloms. Earth's magnetic field causes this protective layer named after its discoverer.

Vectors are numerical values that have direction as well as magnitude, even if it just means having a plus or minus sign attached. It makes a difference if your rocket exhaust points away from the gravity attractor or toward it. If you're hungry, you want to move toward the refrigerator not away from it. Direction adds real-world significance to a numerical expression.

Venus is the 2nd-planet of the solar system.

- Venus radius = 6,052 kiloms.
- Venus masses at —> 4,87 * 10^{22} kilograms. Where 10^{22} kilograms equals the mass of 377-billion Three Gorges Dams, the heftiest structure built by humans to date.
- Venus majA distance from the sun = .728 AU.

Index.

-W-

WRM is short-form for Warmth, which marks the 210° (-150°) angle away from the minRAY point. With old-style clocks, WRM points to the five o'clock position.

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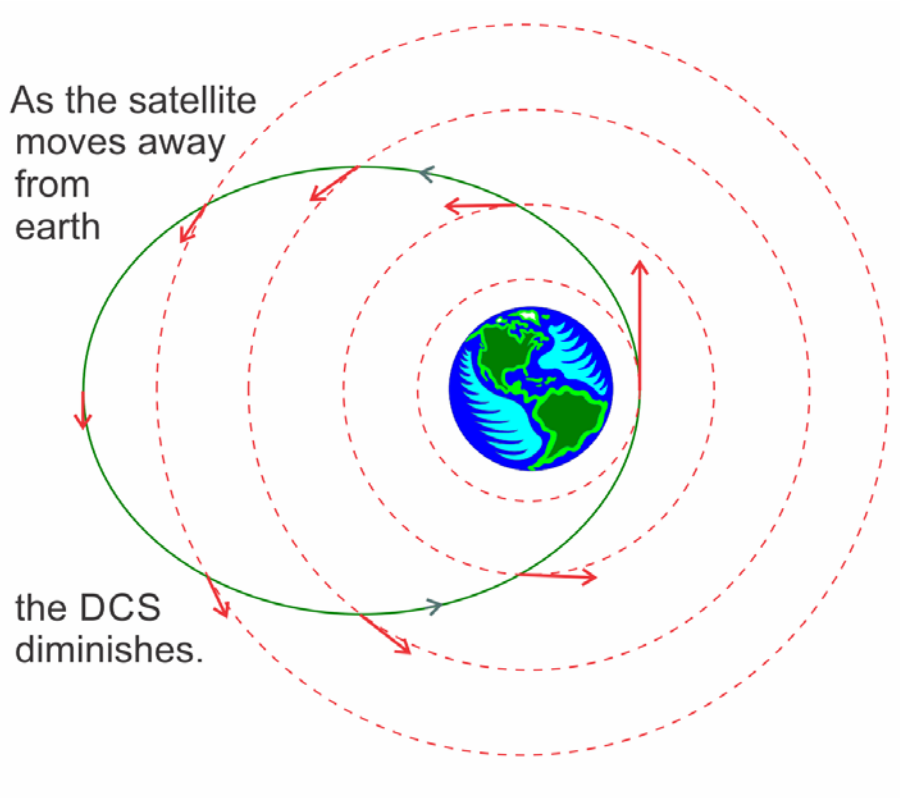

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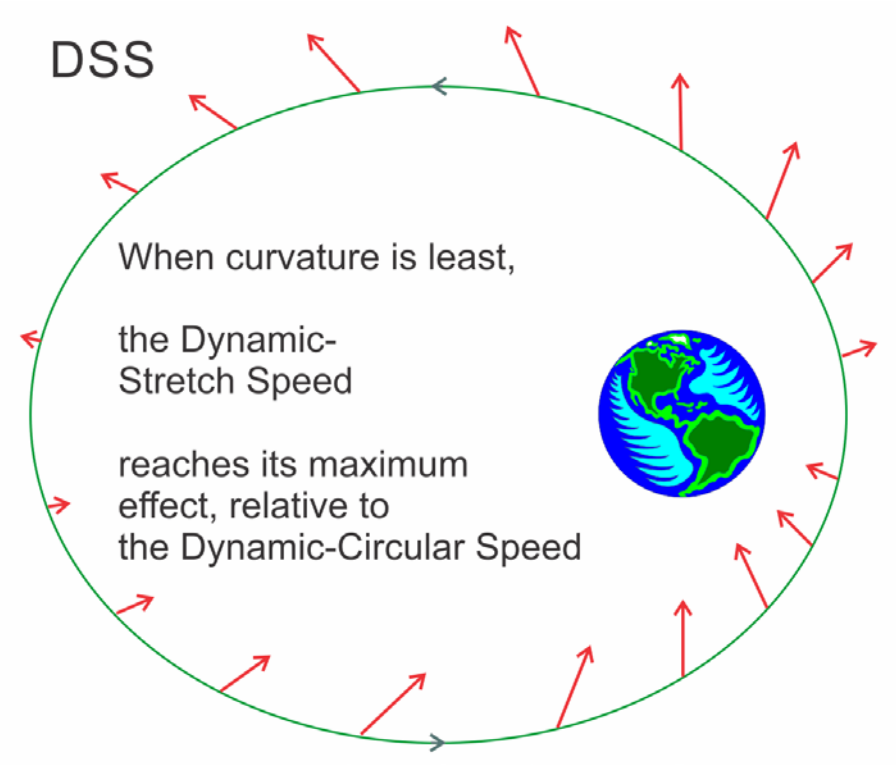
DSS
When curvature is least,
the Dynamic-
Stretch Speed
reaches its maximum
effect, relative to
the Dynamic-Circular Speed

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