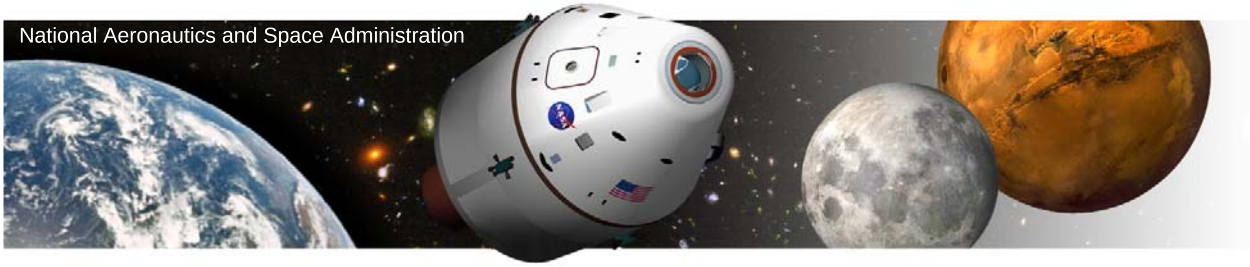

Launching From Florida: Life in the Fast Lane!

9-12 National Science Standards - Key Concept(s):
Physical Science, Earth and Space Science - Rotation, Geometry, Angular Velocity

Purpose:
Having trouble competing with the Winter Olympics for your students' attention? Use the accompanying Olympic-related video and information on launch velocity assists to give your lesson, much like a bobsled, a running start! In addition to explaining how NASA gets a free boost each time a spacecraft launches from Florida, these calculations show how NASA scientists and engineers accurately calculate the best time to launch using *sidereal (si-de-re-al)* time (Physics, Geometry).

Featured Imagery Component:
http://brainbites.nasa.gov/nasalaunch/

Educator Insights:

Geometry / Angular Velocity:

1. In much the same way that Olympic bobsledders take full advantage of a running start at the beginning of their runs, NASA takes advantage of Earth's natural rotation by launching towards the east from Kennedy Space Center (KSC). While the benefits of a *prograde* launch (in the direction of the Earth's rotation) from Florida might not be apparent to the average spectator, it will be apparent to those who study the following information.

   The west-to-east rotation of the Earth causes all points on Earth (except the poles themselves) to move eastward with some tangential velocity. Tangential velocity can be illustrated with an old phonograph turntable and two small weights, one placed near the center of the spinning turntable and one near the outside edge. It is the distance from the center of rotation, or the *radius* of rotation, that affects the instantaneous tangential velocity of an object with a constant *angular velocity*. The weight farthest from the phonograph's center (larger radius of rotation) has a greater tangential velocity than the weight near the center, even though the entire turntable is spinning with the same angular velocity. This relationship is expressed as $\mathbf{V} = \mathbf{R}*\omega$ where $\mathbf{V}$ = instantaneous tangential velocity (m/s), $\mathbf{R}$ = radius of rotation (m), and ω = angular velocity (rad/s).

   If the Earth is viewed as a three dimensional turntable, the greatest tangential velocity occurs at the equator and decreases with increasing latitude. The ideal location for a prograde launch, therefore, would be anywhere on the equator. The tangential velocity at the equator can be calculated using $\mathbf{V}_{\mathbf{equator}} = \mathbf{R}_{\mathbf{equator}}*\omega_{\mathbf{Earth}}$. Substituting the appropriate values for $\mathbf{R}_{\mathbf{equator}}$ (the Earth's equatorial radius) and $\omega_{\mathbf{Earth}}$ (the Earth's sidereal angular rate, as explained and calculated on the next page) yields:

$$\mathbf{V}_{\mathbf{equator}} = (6378.1 \text{ km})*(7.292124 \times 10^{-5} \text{ rad/s})$$
$$= 0.46510 \text{ km/s} = \underline{1674.4 \text{ km/hr } (1040.4 \text{ mph})}$$

   Since the tangential velocity of a point on Earth's surface is a function of its *latitude*, the equation $\mathbf{V} = \mathbf{R}*\omega$ can be rewritten as $\mathbf{V} = \mathbf{R}*\omega*\mathbf{cosL}$, where **cosL** is the cosine of the latitude for a point on Earth. (CosL is 1.0 at the equator and decreases with increasing latitude to a value of 0 at the poles). This equation quantifies the effect of latitude on initial velocities for any location on Earth, and it works well, despite the slight oblateness (being compressed or flattened at the poles) of Earth.

For any launch site at latitude, **L**:

$$\mathbf{V_{launch\ site} = (R_{equator} * \omega_{Earth}) * cosL}$$
$$\mathbf{= V_{equator} * cosL}$$

The latitude of KSC in Cape Canaveral, FL is 28.5° and the tangential velocity, therefore, is:

$$\mathbf{V_{KSC}} = 1674.4 \text{ km/hr} * (\cos 28.5°)$$
$$= \underline{1471.5 \text{ km/hr } (914.3 \text{ mph})}$$

Thus, all spacecraft launched from KSC into prograde orbit get an initial assist of **1471.5 km/hr (914.3 mph.)** That is faster than an Olympic bobsled and cooler than its track of ice!

Sidereal Time:

2. For Olympic athletes, timing is everything. The same is true for NASA's Flight Controllers in Mission Control. A *mean solar day* is the average time it takes the Sun to make successive *apparent* passages over a given Earth meridian (longitude) and is the familiar 24-hour period measured by our clocks. However, the Sun appears to move an average of (360° per year / 365.25 days per year) or 0.98563° among the stars during a mean solar day as Earth also revolves around the Sun.

   Because the Earth's rotation and the Sun's apparent daily motion among the stars are both eastward, the time required for a star to pass over a given meridian as Earth rotates under it can be solved using the following proportion:

$$\frac{24 \text{ hrs}}{360.98563^{o}} = \frac{\text{one sidereal day}}{360^{o}}$$

   Solving for one sidereal day gives (24 * 360º / 360.98563º) = 23 hours 56 minutes and 4 seconds.

   Because this *sidereal day* is only related to Earth's rotation, without any influence from the Sun, it is fundamental to the "head start" spacecraft receive when they are launched.

3. Based on the sidereal day, Earth's true angular velocity, $\omega_{\mathbf{Earth}}$, is equal to 15.04108°/mean solar hour (360°/23 hours 56 minutes 4 seconds). $\omega_{\mathbf{Earth}}$ can also be expressed in radians/second (rad/s) using the relationship $\omega_{Earth} \mathbf{= 2 * \pi / T}$, where **T** is Earth's sidereal period (23 hours 56 minutes 4 seconds). This method produces a result of $\omega_{\mathbf{Earth}} = 7.292124 \times 10^{-5}$ rad/s.

   Sidereal time is the most accurate time when it comes to launching and landing spacecraft on the continually spinning Earth. It lets NASA's mission planners know at all times where the spacecraft is with respect to the Earth. Calculations involving sidereal time are converted into Greenwich Mean Time for more practical use by Flight Controllers.

www.nasa.gov