UNITED STATES MARINE CORPS

LESSON PLAN

ROTATION AND CIRCULAR MOTION OF THE EARTH

INTRODUCTION:

1. Gain Attention. Marcel Proust once said, "In theory one is aware that the earth revolves, but in practice one does not perceive it; the ground upon which one treads seems not to move, and one can live undisturbed." Can anyone state how fast the Earth is currently revolving? Although unbelievable, at this moment we are being carried about 18 miles a second by the Earth's orbital motion!

2. Overview. During this class the student will learn about the Earth's movement around the sun, its rate of movement, and the consequential influence on the seasons.

3. Introduce Learning Objectives.

a. Terminal Learning Objective. With the aid of references, the student shall have a fundamental understanding of the Earth's rotation and circular motion.

b. Enabling Learning Objective(s). Without the aid of references,

(1) Define the effect that the rotation of the Earth has on the surface of the Earth.

(2) State the dates when the Earth is closest and farthest away from the sun.

(3) Explain the relationship between angular and linear velocity.

(5) Describe how angular momentum affects a moving parcel within the atmosphere.

4. Method/Media. This period of instruction will be taught using the lecture method with aid of QMMCBT-001 "Introduction to the Dynamics of the Atmosphere".

5. Evaluation. You will not be evaluated at the end of this period of instruction.

TRANSITION. All life on earth is dependant on solar energy. Because of this one might determine that the relationship between the Earth and the sun is vitally important. This relationship is not static because the Earth is consistently in motion. The Earth has two (2) basic movements – its daily rotation on its axis and its annual revolution around the Sun.

BODY:

1. Rotation of the Earth.

a. The Earth rotates towards the east on its axis, requiring 24-hours for one complete rotation. The apparent motion of the Sun, the Moon, and all of the stars is just the opposite of the true direction of the Earth's rotation. These celestial bodies all appear to rise in the east and set in the west. This is actually an illusion created by the steady spin of the Earth to the east.

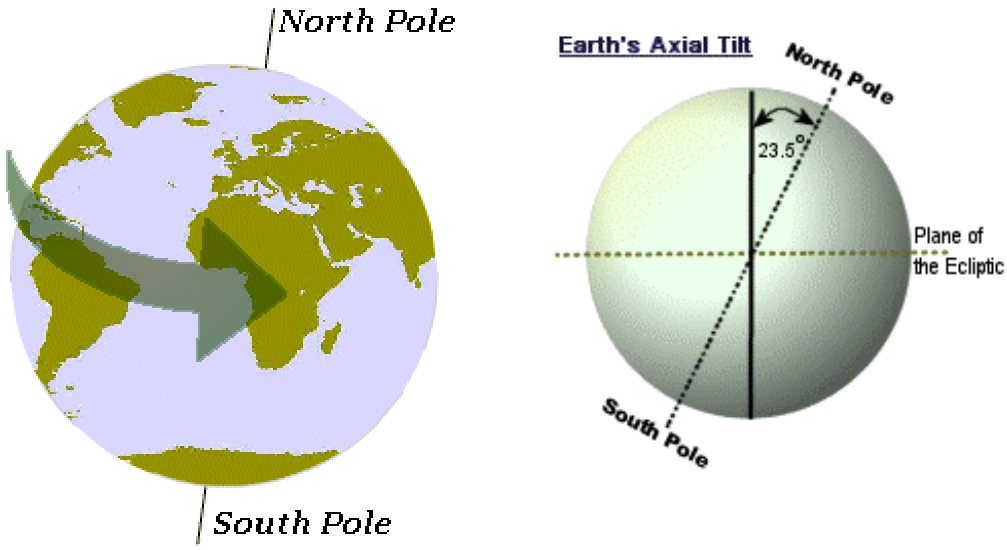

Figure 1 – Earth's rotation on its axis.

b. Rotation causes all objects on the surface of the Earth, except the poles, to rotate in a circle about the axis of the Earth. The table below shows the speed of this motion at various latitudes. Although the speed of rotation varies at various latitudes, it can also remain constant at any given place. This is the main reason why we don't experience any sense of motion. An example of how this may happen, is to use the experience of flying in an aircraft, where a smooth flight at a constant cruising speed feels much like sitting on our living room sofa. We only experience the sense of motion during take-offs and landings where the aircraft speed is changing consistently. With a direct comparison to the Earth, we would only feel the rotation of the Earth if there was a sudden increase or decrease in its rotation speed.

Table 1 -- Earth's latitudinal rotation speed.

Earth's Rotation Speed at Various Latitudes		
Latitude	**Miles**	**Kilometers**

	Per Hour	Per Hour
0	1037.6	1669.9
10	1021.9	1642.0
20	975.4	1569.7
30	899.3	1447.3
40	795.9	1280.9
50	668.3	1075.5
60	520.1	837.0
70	355.9	572.8
80	180.8	291.0
90	0	0

c. The rotation of the Earth has several effects on the physical aspects of the Earth's surface.

(1) The Earth's consistent rotation in the same direction causes an apparent deflection in the flow path of water and air. The deflection is to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. This deflection is known as the *Coriolis Effect*.

(2) The rotation of the Earth causes every point on the surface to be affected by the increasing then decreasing gravitational pull of the Sun and the Moon. Land covered areas of the Earth are too rigid to experience any of these pulls, however, the oceanic waters move onshore then offshore in a rhythmic pattern on a daily basis in direct correspondence to the gravitational forces. The rise and fall of the oceanic water levels are known as "*tides*".

(3) The most noticeable effect of the Earth's rotation would be the daily (diurnal) of light and darkness, as portions of the Earth's surface are directed first toward then away from the light of the Sun. This alternation between light and dark has a great influence to temperature, humidity and winds.

INSTRUCTOR NOTE: For specific information on the effects of the Sun, refer to TMI "QMMPH1-007 - Sun Angle".

TRANSITION. As we have just discussed, the Earth's rotation is responsible for three major entities that affect the entire planet. The Earth's second process of motion is just as significant.

2. Earth's Revolution.

a. It takes slightly over 365 days for the earth to revolve around the sun. Each revolution takes 365 days, 5 hours, 48 minutes, and 46 seconds (or 365.242199 days). This is officially known as the *"tropical year"* and is simplified to 365.25 days.

b. The path that the Earth follows around the Sun is not a true circular pattern, but elliptical. Because of this elliptical orbit, the distance from the Earth to the Sun is not constant. It varies from its closest point, *the perihelion*, at approximately 91,455,000 miles on or about January 3rd to its farthest point, the aphelion, at approximately 94,555,000 miles on or about July 4th. The Earth is 3.3% closer to the Sun during the Northern hemisphere

winter than during the Northern Hemisphere summer. This indicates that the distance between the Sun and the Earth plays a minimal part in the determination of the seasons.

INSTRUCTOR NOTE: Ask the student(s): "If the Sun is at its closest point to the Earth on January 3rd, why is it our coldest time of the year?" The answer should be associated with the Earth's axis always pointing towards the North Star, and the location of the most intense Sun's rays are located in the Southern Hemisphere at this time. This topic is covered in detailed in TMI "QMMPH1-008 – Seasons of the Earth".

TRANSITION. We have discussed that because the Earth rotates about its axis, it causes different portions of the Earth to rotate at different speeds. The next topic explains why this happens.

4. Angular & Linear Velocity.

a. Angular velocity. Angular velocity is defined as the rate of rotation of a particle about the axis of rotation, with magnitude equal to the time rate of angular displacement of any point of the body. Angular velocity is a vector oriented in accordance with a right-hand rotation (i.e. when the fingers of the right hand are curved in the sense of rotation, the thumb points in the direction of the angular velocity vector).

(1) Angular speed is a scalar (dimensionless) quantity, while angular velocity is a vector quantity consisting of angular speed and direction in the form of a rotational sense (clockwise or counterclockwise). We might say the earth rotates at 7.272×10^{-5} radian per second (rad/s), and this tells us its angular speed. Or we might say the earth rotates at 0.00007272 (7.272×10^{-5}) rad/s counterclockwise relative to the sun as viewed from above the north geographic pole. This tells us the earth's angular velocity. An example of an object that has angular velocity would be the second hand of a clock, where it rotates 360 degrees every 60 seconds (π2 rad/24hrs). As with angular speed, we might specify either the average angular velocity over a period of time, or the instantaneous angular velocity at an exact moment in time.

(2) In the case of the earth, the instantaneous angular velocity is essentially constant. In the case of a moving car or truck, the angular speeds of the wheels, axles, and drive shaft often change, and therefore angular velocity is not constant.

b. Linear Velocity. Velocity is a measure of both the speed and direction that an object is traveling in a straight-line. Using an example of two (2) racing cars can clearly identify this concept. For the first example (Figure 1-XXX), 2 cars begin the race at the same time and finish at the same time. The cars both traveled the same distance in the same direction in the same amount of time. Their linear velocities are identical. For the second example, both cars start the race at the same time and still cover the same

distance, however car #2 traveled twice as fast as car #1. Car #2 has twice the linear velocity of car #1. For example #3, two cars begin and end the race at the same, however they traveled different directions. Even though the speed of both cars was the same, the direction was not, therefore the linear velocities are different.

c. Angular & Linear Velocity Relationships.

(1) Angular velocity for the Earth is a constant because it is a solid. Reference Figure 1-XXX and note that points "C" and "D" will both complete 1 revolution around the Earth's axis in 24 hours.

(2) Use the same figure to notice that points "C" and "D" are at different latitudes. Point "C" is poleward of point "D" and therefore has to cover a smaller radius. Point "D" has to travel faster in order for it to complete a revolution about the Earth's axis at the same time as point "C".

(3) This concept can be mathematically stated as $V = \Omega r$, where "V" is equal to the linear velocity, "Ω" is equal to the angular velocity of the earth (held constant because the Earth is a solid at 7.292×10^{-5}, and "r" is the radius of the Earth. If the angular velocity remains constant, linear velocity becomes directly proportional to the radius. Point "C" is more poleward than point "D"; therefore it has a smaller radius. If linear velocity is directly proportional to radius, the linear velocity will decrease with decreasing radii. Simply stated, as you move poleward, linear velocity (speeds) decreases.

(4) One point to remember is that the atmosphere acts like a fluid (the oceans) and is not solid like the Earth. Therefore, the relationship just stated is quite variable for the "fluid" atmosphere. The atmosphere does not rotate at the same speeds of the Earth. It may move faster, slower, or at the same speed.

5. <u>Angular & Linear Momentum</u>.

a. Linear Momentum. Linear momentum is a quantity associated with how a mass moves along a straight path. A force can change the linear momentum of a mass. If you hit a hockey puck with a stick, the puck will move forward and there is a linear momentum associated with it. If no forces are acting on the puck, it keeps moving in the same path with the same velocity forever or until it runs out of ice; in this case, the linear momentum stays the same.

(1) Linear momentum is defined to be equal to the mass of an object times its velocity. A 10,000 kilogram (kg) truck moving at 2 meters per second (m/s) has a linear momentum of 20,000 kilogram-meters per second (kg m/s) while a 80 kg bicyclist moving at 2 m/s has a linear momentum of 160 kg m/s. The truck has a much larger linear momentum even though both are moving at the same velocity. It is easier to bring the bicyclist to a stop than it is to bring the truck to a stop. Similarly, it is easier to stop a bicyclist moving at 2 m/s

than a bicyclist moving at 5 m/s.

(2) Another way to compare linear momentum is to consider a collision. If a large dog is running at you at full steam and hits you, you'll probably be knocked down but will still be okay. However, if a truck is coming at you at the same speed and hits you, you will be hurt badly. In this example, the dog has much less linear momentum than the larger truck.

(3) If there are no external forces acting on a system, then the linear momentum of the system is conserved. The hockey puck sliding across the ice has no forces acting on it, so its linear momentum is conserved. Two billiard balls rolling toward each other each have some linear momentum and after they hit, their total linear momentum will be the same as their total linear momentum before the collision.

(4) Linear momentum (LM) can also be mathematically represented as LM=mv, "LM" is the linear momentum, "m" is the mass of the object, and "v" is the velocity of the object. Mass and velocity will have an indirect relationship, meaning in theory, if you increase the mass of an object the velocity will decrease when determining linear velocity.

b. Angular Momentum. Angular momentum (AM) to is referred to as the momentum found in curved flow. It can be mathematically stated as AM = LM(r), where "AM" is the angular momentum, "LM" is the linear momentum, and r is the radius of the Earth. Or since LM = mv, its can also be stated AM = mvr.

(1) Angular momentum is conserved for an object when all forces are equal to each other. Using the formula above, if the mass is held constant and the radius decreases, the velocity must increase trying to conserve AM. An example of this, is if you placed a ball at the end of a string. Then place the string on your finger and spin the string. As the string's radius decreases, the velocity of the string with the ball increases.

(2) As previously stated, the atmosphere acts like a fluid and will try to conserve its angular momentum. As a parcel in the atmosphere moves poleward, the radius will decrease therefore increasing velocity when the mass of a parcel is held constant.

TRANSITION. The relationship between angular and linear velocities and momentum set the stage for a topic of discussion regarding the "Coriolis Effect". These concepts act as a basis of understanding for future topics of the study of the atmosphere.

OPPORTUNITY FOR QUESTIONS:

1. Questions from the Class. At this time are there any questions regarding any of the subject material that has just been presented to you?

2. Questions to the Class. There will be no questions asked of the student(s) at this time.

SUMMARY: This period of instruction covered a wide array of information. The two main motions of the Earth were discussed, as well as, the affects these movements have on the Earth's surface. Once rotation and revolution were defined and discussed, it allowed us to focus on the fundamental relationships of how parcel speeds change as you move poleward or equatorward.

REFERENCE.

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Physics and Biomechanics. Montana State University. April 1998. **http://btc.montana.edu/olympics/physbio/glossary/g15.html**.
Meteorology Today.