AEROSPACE PALACE ACADEMY, NIGERIA
(A subsidiary of Aerospace Palace International, Nigeria)

LESSON 33: NAVIGATING THE SKIES

It's easy for us to take air travel for granted–millions of people fly every day on flights both long and short and in all manner of airplanes. But how can pilots get from one city to another without any roads or signs telling them where to go? Aerial navigation has been a challenging part of flight since aviation began, and pilots throughout the years have used many different techniques to find their way through the skies, including dead reckoning, celestial navigation, radionavigation, and GPS. This online activity demonstrates how different techniques can be combined to complete a journey.

Next Generation Science Standards (NGSS):

- Discipline: Earth and Space Sciences; Physical Science.
- Crosscutting Concept: Scale, proportion, and quantity.
- Science & Engineering Practice: Using mathematics and computational thinking.

Common Core State Standards (CCSS):

- The Number System: Apply and extend previous understandings of numbers to the system of rational numbers.

GRADES K-2

NGSS: Earth's Systems: Develop a model to represent the shapes and kinds of land and ~~bodies of water in an area.~~

If you had to get from one place to another, how might you find your way? If you were in a car, you might be able to follow road signs–but what if you were a flying a plane? There are no road signs in the sky–there aren't even any roads! For this reason, pilots use special maps to navigate. A pilot's map, called a sectional chart (or just a "sectional") shows all the things which a pilot could see from the air. What kinds of things do you think you would see if you were high in the sky? Lakes? Rivers? Mountains? Cities? Sectional charts show all of these things. By recognizing what features they are flying over, pilots can figure out where they are and point their planes in the right direction.

To help them navigate better, pilots also have compasses mounted in their planes. The compass tells the pilot if the plane is flying north, south, east, west, or any direction in between. Since the pilot can figure out the plane's position on the map and the direction the plane is going, he or she can make sure that the plane will get to its destination.

GRADES K-2 (CONTINUED)

You can see examples of the equipment which early pilots used for dead reckoning at this website published by the Smithsonian Institution. (Incidentally, the term "dead reckoning" is derived from the abbreviation "ded. reckoning," which stood for "deduced reckoning.")

Activity Suggestion

Out on the playground or a field, point out the directions north, south, east, and west. (Would northeast, northwest, southeast, and southwest be appropriate?) Give the students a way to measure distances—a 100-foot measuring tape, or a ten-foot-long piece of rope, for example—and then read off a series of navigation instructions. For example, you could instruct them to navigate 20 feet north, 30 feet west, 10 feet south, 20 feet west, and so on. It may be an advantage to have them end up at a specific point like a flagpole, the corner of a field house, or a tree. Navigating around an intermediate obstacle would be a bonus.

GRADES 3-5

NGSS: Earth's Place in the Universe: Represent data in graphical displays to reveal patterns of daily changes in length and direction of shadows, day and night, and the seasonal appearance of some stars in the night sky.

You can read above about a type of navigation called "dead reckoning," in which pilots use maps and compasses to get to their destination. This is similar to the way in which ships used to navigate when sail- and steamships were the only way to cross the oceans. When pilots first took to the skies, they adopted these techniques for the new practice of aviation.

Another form of navigating which pilots borrowed from mariners is celestial navigation, or navigation using the stars. At nighttime, it's possible to use the stars in the night sky to fly (or sail) in the right direction. How? It's simple! Navigators learn where certain stars are–usually bright ones which are part of constellations (like Orion or the Big Dipper), and by seeing which stars they are pointed towards they can figure out what direction they're flying in. An easy example would be Polaris–the north star. If you are flying towards Polaris, you are heading due north because Polaris is always aligned with the north pole.

GRADES 3-5 (CONTINUED)

Celestial navigation is most useful at night, when the sky is clear and stars are visible. Pilots and navigators can use a special tool called a sextant (see the picture) to take star sightings. The sextant lets them measure the angle between a specific star and the horizon; once the navigator has taken a few sightings, he or she can determine the plane's position by referring to a star chart.

Celestial navigation is rarely used nowadays because planes are equipped with more advanced technology. But for thousands of years, it was one of the primary methods navigators used to get from point A to point B, from the days of Viking longboats to the first airliners. Celestial navigation was also a key skill for early astronauts, who aligned their spacecraft's guidance systems using celestial sightings. You can see images of a wide range of celestial navigation equipment here.

Activity Suggestion

As an exercise, try having your students triangulate their positions in the classroom by measuring the angles to different objects. Give them a map of the room with key features (doors, windows, the clock, etc.) marked to scale. Then, give them protractors and have them estimate the angles to some of these fixes–if they draw lines radiating outward from each one (say, 120 degrees east from the door, 160 degrees west from the clock, 80 degrees west from the windows), they should meet at roughly the location of each student's seat. Note that the angle from the student's seat to an object is 180 degrees away from the angle from the object to the student's seat.

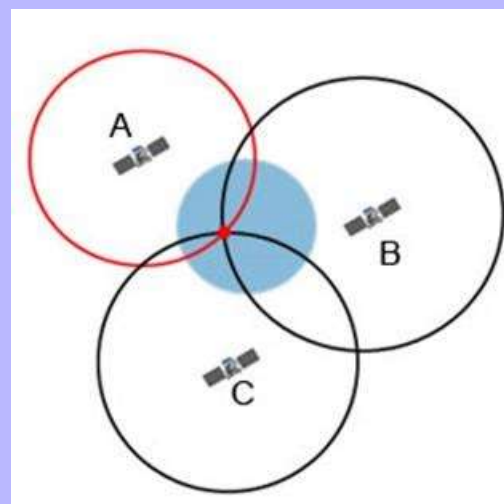
Another possible activity is to expand the K-2 activity into a full-blown orienteering exercise. Set out waypoints on an athletic field; each waypoint is simply a small piece of paper, weighted down with something, giving the direction and distance to the next waypoint. The waypoints should be small enough that you cannot see them easily from more than several feet away. Give the kids compasses and start them at a starting point with the direction and distance to the first waypoint. At the end of the trail have some prize.

The Smithsonian's online "Navigate the Skies!" activity mentioned at the beginning of the lesson is appropriate for this age group.

GRADES 6-8

CCSS: The Number System: Solve real-world and mathematical problems by graphing points in all four quadrants of the coordinate plane. Include use of coordinates and absolute value to find distances between points with the same first coordinate or the same second coordinate.

In addition to the methods of dead reckoning and celestial navigation outlined above (Grades K-2 and 3-5, respectively), modern pilots often rely upon GPS to navigate. As you probably know, "GPS" stands for Global Positioning System. It works based on a system of 24 satellites which orbit the earth about 20,000 kilometers (that's 12,500 miles) above our heads. Each satellite transmits a unique radio signal back to Earth; GPS receivers on the ground pick up several of these signals and use them to measure the distance to each satellite. With these known distances, it is possible to determine the location of the receiver with pinpoint accuracy through a process known as *trilateration* (see picture).



All GPS systems work on this principle. However, the systems which pilots use in airplanes are different than what you might find in a car or a handheld units. Pilots use special high-precision GPS receivers which have special routes and maneuvers programmed into them. GPS technology makes it possible to draw out three dimensional paths for pilots to follow–kind of like highways in the sky! Of course there is no physical "road", but a pilot can use his or her GPS unit to determine whether the plane is flying along the right course.

Several radio-navigation systems were used during the Second World War over Europe. These included the British "Gee" and "Oboe" and a variety of German systems.

Activity Suggestion

As an exercise, you can draw an x-y graph and mark three GPS satellites: Satellite 1 is at (1, 3), Satellite 2 is at (5, 1), and Satellite 3 is at (6, 3). One unit on the graph can be one thousand miles. Tell the students that their GPS receiver shows that Satellite 1 is two units farther from them than Satellite 2 and that Satellite 2 is one unit farther from them than Satellite 3. Where are they? (The answer is (5, 3).) You can come up with similar exercises with different satellite and receiver positions rather easily. If the students have learned the Pythagorean Theorem, you can make the problem more general. For example, you can place Satellite 1 at (1, 1), Satellite 2 at (5, 1), and Satellite 3 at (9, 5). Then if

GRADES 6-8 (CONTINUED)

Satellite 1 is 1.08 units farther from your GPS receiver than Satellite 2 and Satellite 2 is 1.94 units closer to your GPS receiver than Satellite 3, a little trial and error will reveal your position as (4, 4). Again, you can make similar exercises with different positions quite easily.

GRADES 9-12

NGSS: Waves and their Applications in Technologies for Information Transfer: Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

Long before pilots had GPS to rely on, engineers and airmen found other ways of navigating long distances. In the late 1930s and throughout World War II, several technologies were developed to allow pilots to fly without visual cues to the outside world–allowing them to still fly if they couldn't see the ground or the stars for dead reckoning or celestial navigation. Today, we collectively refer to these techniques as "instrument flight". Pilots have within their cockpits a suite of gyroscopic, magnetic, and barometric instruments which tell them everything they need to know about the orientation and velocity of the plane–however, this is a broad and complex topic and so for now we will focus on navigational systems.

The first big breakthrough in aerial navigation came with the Automatic Direction-Finder (ADF) system, which consisted of a series of non-directional radio beacons dotted across the country. A rotating antenna mounted onboard an aircraft can determine which the direction gives the strongest signal; using this information, an instrument in the cockpit points towards the ground station. ADF technology allowed pilots to reliably navigate the skies by moving from beacon to beacon along "airways" defined between each station.

Near the end of the 1930s, a new navigation system was developed–the Very High Frequency Omnidirectional Rangefinder (VOR). The VOR was an improvement on the earlier ADF system because it used directional beacons on the ground–each facility broadcasts a different signal in each direction (360 signals for the 360 degrees of a circle). The result of this is that instead of merely pointing towards a ground station, the VOR receiver could track along a specific course (called a radial) to or from a station and

GRADES 9-12 (CONTINUED)

measure how far off of a particular radial it was. The VOR system was so revolutionary that it quickly became standard on all aircraft–in fact, it still is today. The skies above our heads are crisscrossed by a network of airways which connect VORs. Chances are, there is a VOR ground station not too far from your school—you can look at a list of VORs around the world (including by US state) here. Planes from tiny two-seat trainers to huge airliners still rely on VORs to navigate around the world.

VORs are an excellent example of a practical use of radio waves and phase shifts. The VOR ground facility works by broadcasting a constant 30 Hz signal (much like the earlier non-directional beacons used for ADF systems). On top of that, there is a modulated 30 Hz signal–originally this signal was modulated by spinning a second antenna at 30 Hz, but today the effect is mimicked with solid-state electronics–which interferes with the reference signal. Since the frequency of the signal's rotation and its transmission are the same, the phase shift (relative to the reference signal) will be constant in a particular direction. Thus, measuring the phase difference between the two signals at any point makes it possible to calculate which radial of the VOR station an aircraft is flying along.
Here is a website with some helpful interactive tools to demonstrate this concept better.

For some interesting history and photographs of various radionavigation tools from the past century, you can look at this excellent website published by the Smithsonian Institution.

Activity Suggestion

As an exercise, have your students calculate the measured phase difference and draw the waveforms for north, south, east, and west radials–at the 0/360 radial, the reference and modulated signals are perfectly in phase; at 180, they are exactly out of phase, etc. Knowing the 30 Hz rotation speed and the 30 Hz signal frequencies, it is possible to calculate the phase differential (in percent wavelength) for any radial of the VOR, from 0 to 360 degrees.

Sixty Years Ago in the Space Race:

February 21, 1957: The Los Alamos Scientific Laboratory completed a report on the Metal Dumbo Rocket Reactor, which was designed to be a nuclear reactor to power a reusable single-stage-to-orbit vehicle.