

A CLASSROOM ACTIVITY: TWO APPROACHES TO FORMATION FLYING

NOTE TO TEACHER:

Anyone who has witnessed the precision formation flying of the U.S. Navy's flight demonstration squadron, the Blue Angels, has marveled at how these sleek jets can fly so close together, so fast, and, at times, so close to the ground.

In this activity, students will learn about some of the techniques used by the Blue Angels pilots to create their thrilling aerial performances. They will also learn about some new technologies being used to automate formation flying by multiple spacecraft in Earth orbit or beyond to greatly enhance their data-gathering capabilities. The article is written to be used directly as a student handout.

The National Aeronautics and Space Administration (NASA) is getting ready to launch a new spacecraft called Earth Observing-1 (EO-1) in December 1999. EO-1, managed by Goddard Space Flight Center in Greenbelt, Maryland, will test some of these new technologies by flying in formation with the new Landsat-7 Earth-imaging satellite, which was launched in April 1999. EO-1 is the first of the Earth-orbiting spacecraft of the New Millennium Program, with the primary mission of testing advanced new technologies in space for use on 21st century space missions.

This article was written by Diane Fisher, a science and technology writer at NASA's Jet Propulsion Laboratory in Pasadena, California, and Sharon Mayeux, a 5th grade teacher in La Crescenta, California. Special thanks to Lt. Commander Mark Dunleavy, a current Blue Angels pilot, for sharing some of the Blue Angels' "secrets" and for reviewing the article, and to David Folta, technology manager for the Enhanced Formation Flying system on Earth Observing 1 at Goddard Space Flight Center.

Find out more about EO-1 and other New Millennium Program missions on JPL's web site for children, The Space Place, at <http://spaceplace.jpl.nasa.gov>, and at the New Millennium Program web site at <http://nmp.jpl.nasa.gov>.

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HOW TO PUT A PRECISION-FLYING TEST PILOT INTO A SPACE-FARING ROBOT

Have you ever noticed how much people like to dance? They may not always call it dancing, but in ever so many ways, people like to move in formation, in a pre-planned—or choreographed—way.

For example, at school when your class lines up to march from one place to another, you are doing sort of a line dance. (Although you may not find this particular dance all that much fun.) Marching bands and drill teams move in more-or-less precise formation, staying a certain distance apart and keeping their rows and columns straight. Square dancers and folk dancers, synchronized swimmers, and paired skaters also practice the art of moving in formation. Can you think of others?

THE ULTIMATE FORMATION FLYERS

The U.S. Navy takes formation movement—in this case flying—to a fine art. The Blue Angels are the Navy's flight demonstration squadron. These highly skilled and experienced pilots fly six F/A-18 Hornet strike-fighter planes so close together the planes almost appear to be attached to each other by rigid, invisible beams. But then, suddenly they will all peel off in six different directions! They may also fly right in front of their audiences as low as 20 feet off the ground and going at almost the speed of sound (known among pilots as Mach [pronounced "mock"] number 1), which is about 750 miles per hour!

How do they do that? Are the planes in some sort of high-tech auto-pilot mode? Could the pilots possibly be so good that they can do these aeronautical gymnastics using



The U.S. Navy's Blue Angels flying their six F/A-18 Hornets are the ultimate formation flyers.

only their eyes, ears, and brains, with their hands and feet making the minuscule adjustments to the plane's controls that will keep them in just the right formation, at times only inches apart?

We were so curious that we phoned the Navy and asked! We got to talk with Lt. Commander Mark Dunleavy who is a current Blue Angels pilot. What we found out was even more amazing than it looks from the ground.

SKILLS HONED TO A FINE EDGE

The major ingredients to the Blue Angels success are:

- Teamwork
- Communication
- Training
- Training
- and more Training

The pilot in the lead plane is called the boss. The pilots are all in constant radio contact with each other. Like a caller singing out the steps at a square dance, the boss tells the other pilots everything he is about to do before he does it, then they all do it at precisely the same time on the boss's radio call.

How do they stay in such perfect formation? Visually! Each pilot knows exactly what part of the nearest plane is supposed to line up visually with the leading edge of the wing on his own plane. Then they just make ultra-fine adjustments to keep that relationship going.

On calm weather days, the planes may be only a soda can length apart! Can you imagine how your mother or father would react when driving down the highway at even 50 miles per hour if another car came up beside them that close?

TAKING IT EVEN HIGHER

Besides providing breath-taking entertainment, formation flying has some very practical uses, not only in military operations, but also in space exploration.

The National Aeronautics and Space Administration (NASA) is testing some new formation flying techniques that will enable two or more spacecraft to maintain very precise and stable positions relative to each other. This way, they can be made to function as one very large "virtual spacecraft," which opens many other possibilities for collecting more, better, and less expensive scientific data. The first spacecraft to put these new technologies to the test will be an Earth orbiter, called Earth Observing-1,

or EO-1. To be launched in December 1999, EO-1 will fall into step right behind the newest Landsat-7 satellite, which has been in orbit since April 1999. Landsats have been imaging and mapping Earth's surface since 1972 and have contributed much to our understanding of our planet and how it is changing.

EO-1 will have computers onboard with programs that try very hard to "think" like the Blue Angels (or any other smart people). EO-1 will always know its own position and Landsat-7's position by location and time

information it receives from the Global Positioning Satellite (GPS) system. GPS is a system of 24 satellites in *geosynchronous* Earth orbits. This means each satellite orbits the Earth once per day, always remaining above exactly the same point on Earth's surface. If you can communicate with these satellites you will never get lost, either on Earth's surface or in orbit. GPS will tell you information like "The time is 12:01:56 universal time and your location is latitude 118 degrees 8 minutes 41 seconds west and longitude 34 degrees 8 minutes 44 seconds north."

Formation flying spacecraft in deep space (beyond the range of the GPS) will keep track of their positions using other techniques, involving radar, Earth-Sun-star positions, and attitude measuring instruments.

In the case of EO-1, it wants to follow Landsat-7's orbit exactly, but 1 minute (give or take 3 seconds) behind it. Since it "knows" its own position and that of Landsat-7 for a particular instant in time, it can calculate where the two will be at some point in the future. This system does the same function for this spacecraft formation flying technology as the Blue Angels visual system does for them.



But what if EO-1 finds it is falling too far behind Landsat-7? Or getting too close? It must plan a correction maneuver (by firing its thrusters), just as a Blue Angels pilot might make a tiny adjustment of speed to stay lined up with the adjacent F/A-18.

In the case of EO-1, the orbit correction maneuver must be done only when the spacecraft can be seen by a spacecraft tracking station and when the EO-1 ground crew is awake and on duty at NASA's Goddard Space Flight Center in Greenbelt, Maryland. It must also be made when the spacecraft is on the daylight side of Earth so that it will have sufficient power (from solar cells) for computing and for communicating with Earth. EO-1's computer software must figure out not only when would be a good time for the maneuver given all these conditions, but then predict how much farther "off course" it will be at that time and then plan exactly what maneuver will achieve the desired result (that is, how much thrust, for how long, and in what direction).

FUZZ IS NOT A BAD THING

There may be no one right answer to all these questions. But EO-1 will try to find the best answer. Like a human brain, its computer will use *fuzzy logic*. That is, the conditions that are fed into the equation are not very definite—not definitely black or white, on or off, yes or no. They may be sort of gray or fuzzy. Sort of like real life!

The Blue Angels are using fuzzy logic too, although they are so good at it and do it so fast that they probably aren't even aware that is what they are doing. The pilot is watching how the edge of his wing lines up with the insignia on the plane next to his. If it moves up a bit very slowly, at some point he makes the decision to do a tiny corrective maneuver. If it moves too far too quickly, he may have to quickly decide to break out of the formation to prevent an accident. Meanwhile, he is listening and responding to maneuver calls from the boss, keeping an eye on the instruments, and maybe the horizon and ground, and processing and responding to a thousand different bits of information each second.

We make decisions every day using fuzzy logic. We weigh alternatives, thinking "well, if I eat dinner now and then go out and play football with my friends I might not feel too good. But if I play football first, I might miss dinner altogether. What to do?" We might figure out a "gray" or "fuzzy" solution: Have a few bites of dinner now, go out and play football, and pig out on dessert later!

Here are some games you can play to try out these different ways of formation flying.



GAME 1: WE'RE BLUE ANGELS!

Put yourself into the cockpit of an F/A-18 Hornet and experiment with the Navy's Blue Angels method of formation flying.

1. Get into groups of 4 to 6 in a large open area. Number off. The numbers determine which plane position in your flight pattern you will pilot. You decide!
 2. Talk about the kinds of movements you could make while in this basic pattern. For example, you could all "fly" forward for about 10 feet, and then, at a voice command from your #1 pilot, you could all turn 20 degrees to the left, fly another 10-15 feet, and do some other maneuver. Be creative! Some planes could stay in the main position while others move out, perform a special maneuver, and then rejoin the main group, and so on.
 3. Be sure that everyone in your group gets to test their ideas.
 4. To help stay in formation, visually line up some part of your body with the other planes. (For example, keep your fingertips in line with the lower ear of the pilot to your right, etc.)
 5. After you plan your maneuvers, work out the "calls" that #1 will make during your flight. These will be your signals to begin changing your positions.
 6. Practice your formation flying pattern, discuss problems, and make adjustments.
2. EO-1 and Landsat-7 should position themselves one in front of the other, about 3 feet apart, facing the same direction. They begin moving slowly, keeping the same distance apart.
 3. The caller makes up a maneuver (for example, turn 20 degrees to the right) AND a set of three conditions that must be true in order for EO-1 and Landsat-7 to carry out the maneuver. For example, turn 20 degrees to the right, but ONLY if it is a weekday, between the hours of 10 and 11:00 A.M., and both players are wearing white shoes!
 4. If both spacecraft cannot answer "Yes" to all three conditions, "flight" continues as before without the new maneuver.
 5. Practice for a while, making sure that everyone gets a chance to try each position.

GAME 2: NOW WE'RE FUZZY LOGIC COMPUTERS!

Now let's practice with the method Earth Observing-1 will use to fly in formation with Landsat-7.

1. Get into groups of 3. One student will be the caller while the others will be EO-1 and Landsat-7. Don't worry! You will take turns during the activity.

AFTER THE GAMES:

What did you learn about the different formation flying methods? How are they different? How are they alike? Compare your observations with your group and with others in your class. You could discuss, write about, and or draw and label your observations.

KEEPING AN ELEVATED PERSPECTIVE

Landsat-7 and the advanced imaging instruments on EO-1 are helping us better understand planet Earth so we will be able to take better care of it.

When Lt. Commander Dunleavy is flying in his Hornet to their next performance location, he thinks about how much he loves his job. He says, "When I see sunrises and sunsets from 45,000 feet, I feel lucky to be living on such a magnificent planet. I realize how small we are and how we all have the responsibility to look after our home."