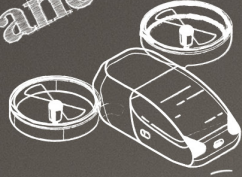advanced air mobility

drones

urban air mobility

air taxis

STEM LEARNING:

Advanced Air Mobility: The Science Behind Quadcopters Reader—Student Guide

www.nasa.gov

ADVANCED AIR MOBILITY (AAM)

When most people think of aircraft, they usually think about airplanes that travel at great speeds and cover large distances while flying routes between airports. More and more, however, new types of aircraft are transporting people and equipment to urban and rural locations where traditional airplanes cannot access. These new aircraft range in size from small cargo carrying drones to passenger-carrying air taxis, and carry out short range missions.

NASA is leading the nation to quickly open this new era in air travel called **Advanced Air Mobility**, or AAM. The vision of AAM is that of a safe, accessible, automated, and affordable air transportation system for passengers and cargo capable of serving previously hard-to-reach urban and rural locations.

According to recent NASA-commissioned market studies, by 2030 there will be as many as 500 million flights per year for package delivery services and 750 million flights per year for air taxi/metro services. AAM will help ensure this new airspace is properly managed.

Figure 1. AAM is a system of safe, accessible, affordable, and automated air transportation for passengers and cargo in urban and rural locations. Credit: NASA

Compared to airplanes and helicopters, the aircraft that fly in this new airspace are small. This, along with where they fly, makes it unrealistic to continuously track or control these aircraft using radar or satellite technology. Many of these aircraft are **Unmanned Aerial Vehicles**, or UAVs, meaning they are self-flying or autonomous.

QUADCOPTERS

Figure 2. NASA scientists use this quadcopter for experimentation.
Credit: NASA, David C. Bowman

Some of the aircraft controlled in the AAM system are quadcopters, similar to commercially available drones. The term quadcopter refers to the fact that they use four propellers to fly.

Several manufacturers are working on larger versions of quadcopters capable of carrying cargo and people. In fact, several **prototypes** have already flown! Prototypes are working models used by engineers to test whether a design works as expected.

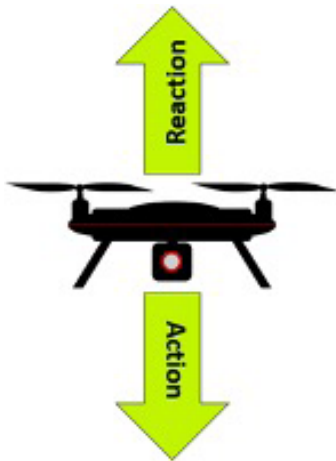## NEWTON'S THIRD LAW AND QUADCOPTERS

Figure 3. Newton's third law explains the upward motion of a quadcopter.

In 1687, English scientist Sir Isaac Newton published his now famous three laws of motion. These laws describe how forces and objects interact to affect motion. **Newton's third law of motion** states that for every action, there is an equal and opposite reaction.

When a quadcopter's propellers spin, they push air downward. Using Newton's third law, this represents the action. For Newton's law to be true, there must be an equal and opposite reaction. This reaction is an upward force pushing on the quadcopter. Once this force exceeds the force of gravity pulling the quadcopter downward, the quadcopter begins to move up.
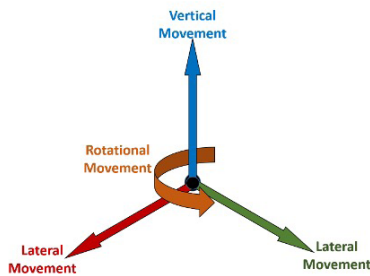
MOVEMENT OF A QUADCOPTER
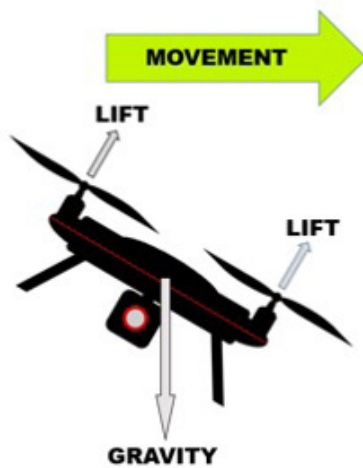

Figure 4. Drones move in three different ways.

For a quadcopter to fly, it must be capable of three different types of movement: **vertical movement, lateral movement,** and **rotational movement.** Based on Newton's third law, each of these can be achieved using the quadcopter's four propellers.

When the propellers spin, they push air down. Similar to a helicopter, pushing the air down is the action in Newton's third law of motion. The reaction is a force, called **lift**, which pushes the quadcopter up. Each of the propellers will create lift, and the total lift for the quadcopter will be the sum of the four propellers' lifts. The total force of the lift must be stronger than the force of gravity for the quadcopter to take off. Once in the air, the quadcopter can hover with no vertical movement by having the forces of lift and gravity equal.

Figure 5. Gravity and lift act on a quadcopter.

When the force of lift acts straight upward, the quadcopter moves vertically. But, when lift acts at an angle, it can also move laterally. This is because part of the force of the lift is upward and part of it is to the side, resulting in lateral movement that can be from side-to-side or forward and backward.

Figure 6. When lift acts at an angle, it causes lateral movement.

Lateral movement occurs by varying the speed of the propellers. Increasing the speed of the two propellers on one side of the quadcopter and/or decreasing the speed of the two propellers on the other side creates uneven amounts of lift on the two sides. The lift created on the side with the faster spinning propellers is greater than the lift created on the opposite side. The result is that the quadcopter moves in the direction of the side where less lift is created.

The final type of movement happens when the quadcopter rotates. This type of movement relies on a force called torque, a twisting force that causes rotation. When a propeller spins, this force is produced. And, according to Newton's third law of motion, an equal and opposite force is produced as well.

We see this in action when we look at a helicopter like the one in figure 7. When the blades on top of the helicopter (the rotor) spin, torque is created. The equal and opposite force rotates the body of the helicopter in the opposite direction of the blades' rotation. Since this would make the helicopter unusable, a tail rotor is added. It creates a force that counteracts the torque and stops the helicopter from rotating uncontrollably.
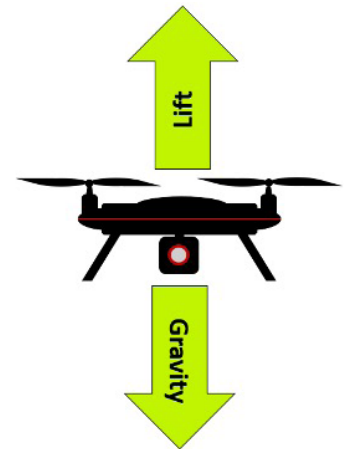

Figure 7. This S-64 heavy-lift helicopter uses the tail rotor to balance out the torque created by the rotor. Credit: NASA, Tony Landis
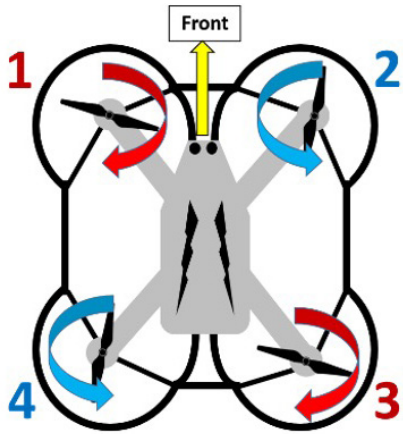
Figure 8. Propellers spin in different directions to cancel out the torque.
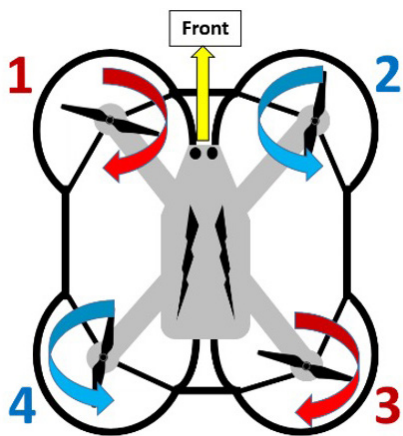

Figure 10. Top view of a quadcopter showing propellers rotating clockwise and counterclockwise.

Torque also affects a quadcopter when its propellers spin because each propeller individually creates torque when it rotates. All four torques are added up to determine the total torque acting on the quadcopter. Engineers have come up with a clever way of counteracting this torque—two of the propellers spin clockwise and two spin counterclockwise, as shown in figure 8. This results in two propellers creating torque that acts clockwise and two creating torque that acts counterclockwise. Thus, the forces cancel each other out.

This torque can also be used to create rotational movement for the quadcopter. In figure 8, when propellers 1 and 3 rotate, they produce counterclockwise torque (remember, equal and opposite reactions). If these propellers rotate faster than propellers 2 and 4, the counterclockwise torque acting on the quadcopter will be stronger than the clockwise torque acting on it. This results in the quadcopter rotating counterclockwise. Of course, if propellers 2 and 4 rotate faster than propellers 1 and 3, the quadcopter will rotate clockwise.

While having pairs of propellers rotating in opposite directions effectively controls the torque acting on the quadcopter, it presents a new problem for engineers. If propellers spin in opposite directions, two of the propellers push air upward while two push air downward. When you combine these forces, the total lift is zero and the quadcopter cannot take off. To overcome this, engineers use two different propeller blades. In figure 9, you

Figure 9. Propeller blades can have different angles.

can see that the leftmost propeller has the left edge higher in the front while the other has the right edge higher. This design changes the direction the air is pushed by the two propellers, meaning that when they spin in opposite directions, they actually push the air in the same direction.
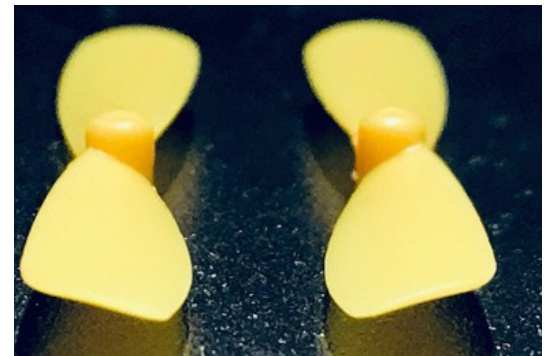
Figure 10 shows a quadcopter with the propellers numbered and their directions of rotation indicated. This quadcopter weighs 4 Newtons (N), meaning that gravity pulls it downward with a force of 4 N.

To determine the movement of the quadcopter, the following rules are used:

Rules for Determining the Movement of the Quadcopter:

1. Rules for determining vertical movement: To calculate the total lift, add up the lifts created by each of the four propellers.

    - If the total lift is greater than the force of gravity (4 N), the quadcopter moves up.

    - If the total lift is equal to the force of gravity (4 N), the quadcopter doesn't move vertically.

    - If the total lift is less than the force of gravity (4 N), the quadcopter moves down.

2. Rules for determining lateral movement:

    - If the lifts of propellers 1 and 4 add up to more than the lifts of propellers 2 and 3 added together, it moves right.

    - If the lifts of propellers 2 and 3 add up to more than the lifts of propellers 1 and 4 added together, it moves left.

    - If the lifts of propellers 1 and 2 add up to more than the lifts of propellers 3 and 4 added together, it moves backward.

    - If the lifts of propellers 3 and 4 add up to more than the lifts of propellers 1 and 2 added together, it moves forward.

3. Rules for determining rotational movement:

    - If the lifts of propellers 1 and 3 add up to more than the lifts of propellers 2 and 4, it rotates counterclockwise.

    - If the lifts of propellers 2 and 4 add up to more than the lifts of propellers 1 and 3, it rotates clockwise.

    - Otherwise, there is no rotational movement.

Using the rules for determining the movement of the quadcopter, determine and fill in the missing information in the chart:

Lift Produced (N)				Vertical Movement (None, Up, or Down)	Lateral Movement (None, Right, Left, Forward, or Backward)	Rotational Movement (None, Clockwise, or Counterclockwise)
Propeller 1	Propeller 2	Propeller 3	Propeller 4			
1.25	1.25	1.25	1.25	Up	None	None
1.2	1.2	0.8	0.8	None	Backward	None
0.25	0.25	0.5	0.5	Down	Forward	None
1	1.5	1	1.5	Up	None	Clockwise
1.5	0.5	1.25	0.75	None	Backward	None
0.5		0.5		None	Right	None
2	1	1	1	Up	Right and Backward	Counterclockwise
0.25	1	1	0.25	Down	Left	None

Figure 11. Completed chart showing the lift produced by each of the four propellers and what movement that causes.

READING COMPREHENSION QUESTIONS

1. Why does NASA believe that there will be a need for AAM as an air traffic management system in the near future?

2. If a system like AAM is not put in place, what sort of problems might arise?

3. Hovering is when an aircraft is in the air but remains motionless. For a quadcopter to hover, why must the forces of lift and gravity be equal?

4. Keeping mind how the propellers are used to balance out the torque, could you create a drone with just three propellers? If so, how? If not, why?

5. How does the quadcopter in figure 10 move if propellers 2 and 3 rotate faster than the other two propellers?

6. Look at the data in figure 11. Why would propellers 1 and 4 producing more lift than propellers 2 and 3 make the quadcopter move to the right?

GOING FURTHER

1. In science, a law describes what will happen under certain conditions every time, whereas a theory explains why something happens. Why is Newton's third law of motion a law and not a theory?

2. Sir Isaac Newton devised three laws of motion. Investigate these laws. How would his first and second laws of motion be important in determining how a quadcopter works?

3. Read through the article found at *https://www.nasa.gov/aero/taking-air-travel-to-the-streets-or-just-above-them/*. What is NASA's role in AAM and what other groups or organizations are involved?

4. Some air taxi prototypes have two rotors on top and no tail rotor. How is this possible when the rotors produce torque?

GLOSSARY

Advanced Air Mobility (AAM)—a safe and efficient air transportation system for short range aircraft

Lateral movement—movement to the right, left, forward, or backward

Lift—force that pushes upward (against gravity)

Newton's third law of motion—for every action, there is an equal and opposite reaction

Prototype—an early model of something that can be used to test its functionality

Rotational movement—spinning around an axis

Torque—a twisting force created when something rotates

Unmanned Aerial Vehicle (UAV)—small aircraft that can be remotely or autonomously controlled

Vertical movement—movement up or down

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