# CLASSROOM TEACHER'S GUIDE

## YEARS 7 - 8 - 9

# ABOVE AND BEYOND℠

THE ULTIMATE INTERACTIVE FLIGHT EXHIBITION

PRESENTED BY BOEING

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ABOVE AND BEYOND – THE ULTIMATE INTERACTIVE FLIGHT EXHIBITION is made possible by Boeing. The exhibition is produced by Evergreen Exhibitions in association with Boeing, in collaboration with NASA.

This Teacher's Guide is created by TurnKey Education, Inc., for Evergreen Exhibitions.

Education resources and programming for ABOVE AND BEYOND are made possible by Boeing in celebration of its centennial and its ongoing commitment to prepare and inspire the next generation to dream, design, and build something better for the next century.

# WELCOME TO ABOVE AND BEYOND!

**Looking back at the history of flight, one thing is abundantly clear: the sky was never the limit. ABOVE AND BEYOND is a multisensory flight and aerospace exhibition that invites you and your students to experience what it takes to make the "impossible" possible in and above the sky.**

This unique learning opportunity is brought to you by The Boeing Company and developed in collaboration with a host of renowned aviation specialists, aerospace experts, historians, archivists, teachers, and educational programming professionals. These skilled partners bring science, technology, engineering, the arts, and math instruction to new heights in your classroom.
ABOVE AND BEYOND offers your students direct access to immersive simulations, interactive design challenges, iconic historical touchstones, visionary concepts for the future, and inspiring stories from game-changing innovators past and present. Imagine the teachable moments!

From the time humans first got off the ground, the race was on to go above and beyond. Faster . . . further . . . higher . . . smarter! Today, these goals propel aerospace innovators to apply the principles of Science and Technology learning to new discoveries and expand the boundaries of our universe. ABOVE AND BEYOND will engage your students and fellow teachers across the curriculum with its thought-provoking content. What if we could . . .

- *Get airborne wherever and whenever we wanted?*
- *Fly faster than the speed of sound with supersonic flights that don't make a lot of noise or burn too much fuel?*
- *Design ultra-green flying machines to carry more people more places and, at the same time, treat the planet better?*
- *Invent supersmart flying robots to assist us in our daily lives, such as delivery-bots, eco-bots, and more?*
- *Build a new generation of reusable space vehicles to make trips to Earth's orbit as common as air travel?*

ABOVE AND BEYOND is more than a visit to the museum. It is a way to inspire your students to aim higher and go further in their studies. Maybe someone you know will take us all above and beyond in the near future!

# EXPERIENCING ABOVE AND BEYOND: THE FIELD TRIP

**During your field trip to ABOVE AND BEYOND, you can experience five interactive galleries in any order: UP, FASTER, HIGHER, FURTHER, and SMARTER. Each one features simulations and design activities related to real-life engineering challenges in the aerospace industry. Here are some of the highlights your students will not want to miss!**

A field trip to ABOVE AND BEYOND celebrates the power of innovation to make dreams take flight. An expansive, multitouch timeline where students can explore the innovations and innovators that transformed our world introduces them to the history of flight. Next, a short film called Beyond the Limits immerses students into the spirit and power of aerospace innovation. Exhilarating imagery and soaring music will build anticipation for what comes next.

## UP

UP gets everyone into the action as they discover what it takes to get off the ground. Learn about the breakthroughs that enabled us to join the birds in the sky. Then check out some bold new concept vehicles designed to give us more freedom of mobility in the future.

The concepts of lift, drag, thrust, and weight come to life with a group flying game called Spread Your Wings. Here, students become birds and follow their leader heading south in a V formation. These four principles of flight are further explored through a comparison of how a balloon, an airship, a glider, a fixed wing aircraft, a rotorcraft and a rocket each reach the skies. A look at the amazing aircraft of the future shows your students how faster and greener models are already in development.

## FASTER

In 1947, test pilot Chuck Yeager proved the speed of sound wasn't a real barrier when he blazed past it at 1,100 KPH in a Bell X-1 rocket plane. In 2004, NASA's unpiloted X-43A broke the speed record for an air-breathing aircraft when it flew 11,000 KPH. Whether to get "there" quicker, to gain an advantage over an opponent, or for the pure adrenalin rush, the quest for speed has inspired innovative advances in flight. FASTER immerses you in the exhilarating thrills of high-speed flight.

To understand what is meant by "high-speed," your students will design and test-fly a jet in a virtual competition called Full Throttle. This supersonic fighter jet challenge demonstrates the effects of various shapes of the fuselage, wings, and tail on how well the craft flies, how fast it can go, and how easy it is to maneuver. A simulated wind tunnel test reveals how other aspects of an aircraft's shape determine where its top speed will be reached in the range from subsonic to supersonic. Students will also see small-scale aircraft models that Boeing and NASA have used in actual wind tunnel tests.

## HIGHER

Just 58 years after Wilbur Wright "soared" to 3 metres in the Wright Flyer, Soviet cosmonaut Yuri Gagarin became the first person to orbit Earth. Today, astronauts regularly live and work aboard the International Space Station (ISS). However, it is still difficult and expensive to reach space. Few people can experience its wonders . . . for now! HIGHER explores high-altitude flight and the innovations that might soon make it easier to get into orbit.

The highlight of this gallery is the International Space Elevator. Your class will explore the layers of the atmosphere and the possibilities of high-altitude flight. This experience is a visually stunning, simulated ascent in a space elevator loosely inspired by concepts that might one day transport cargo and people to the orbit around Earth.

## FURTHER

Across the Atlantic, around the world, to the Moon, and beyond! Since we first got off the ground, we have always wanted to fly even further. For aircraft, the current focus is on going further with less – using less fuel and creating less pollution. In space, we are shooting for Mars and the stars! What will it take to fly humans to Mars? Can we "sail" to the stars? FURTHER reveals the power of innovation to help us go the distance, on Earth and in space.

Marathon to Mars asks your students the very same questions aerospace engineers ponder about the challenges inherent in a months-long journey to Mars. How long will it take? What will you pack? What will you wear? Models of the future spacecraft that might someday get us to Mars – and beyond – are also on display. Students can then experiment with superstrong, lightweight composite materials that already help aircraft and spacecraft fly further using less fuel.

## SMARTER

In aerospace, there is no battle of "brains vs. brawn." You need both! SMARTER invites your students to discover what happens when flight and smart technologies unite. See how aerospace innovators are applying advances in computers, electronics, and robotics to invent more capable aircraft and spacecraft. Learn how smart technologies are transforming the way we build and operate these amazing, intelligent flying machines.

Real objects and multimedia displays tell the story of space junk – its dangers and potential solutions. Your students will see how smarter aircraft will make spaceflight safer for everyone in Space Junk. This challenge presents three out-of-this-world solutions to cleaning up orbital debris.

SMARTER also features an assortment of real unmanned aerial vehicles. Students will have an opportunity to program their own virtual UAV (unmanned aerial vehicle) to carry out a specific mission. In this Roboflyers activity, they will compare several design possibilities to evaluate the best solution based on the parameters of their mission. Mission options include flying into the eye of a storm, pollinating a green house on Mars, or tracking an endangered species. Students will also want to check out the Smart Skies video to discover how smart technologies will transform our airspace by improving efficiency, reducing pollution, decreasing weather delays, and lowering costs.

## DREAMS ALOFT

At the conclusion of the field trip, you virtually "meet" young Boeing employees who will share some of the exciting projects they are working on now, their personal inspirations, and how they followed a path from the classroom to outer space. Students can then contribute their own vision of the future of flight to a collaborative wall of dreams. Cool!

ABOVE AND BEYOND is designed to ignite a passion for the greatest adventure of all: our journey of flight in the air and in space. In doing so, it honours past world-changing innovations while looking ahead and demonstrating the impact of aerospace breakthroughs in our everyday lives. This exhibition inspires your students to imagine future careers in aerospace and helps you build Science and Technology awareness in your classroom. Your field trip to ABOVE AND BEYOND is, simply put, out of this world!

# USING THIS TEACHER'S GUIDE

**As a companion to your experience at ABOVE AND BEYOND this Teacher's Guide for Secondary School has been created to complement your classroom instructions and make the most of your school field trip. This Teacher's Guide contains original, assessable, Science and Technology-related classroom lesson plans for you to use and share.**

The Teacher's Guide for Secondary School contains dynamic activities and assignments for students in years 7, 8 and 9. There is also a Teacher's Guide for Primary School. Both these Guides are created to be flexible; use them to best meet the needs and capabilities of your class. You know your students better than anyone else!

Following this Introduction, you will find the section containing four interdisciplinary Classroom Lesson Plans designed to correlate with your curriculum standards. The lesson plans begin with Teacher Instruction pages, which include answer keys for those activities. At the top of the Teacher Instructions page, you will find the appropriate content areas and skills addressed by the activities in the lesson. Each lesson continues with complete, ready-to-copy, Student Activity worksheets that focus on key topics featured in the exhibition.

The first lesson plan is "Modeling the Future." Students will explore the dimensions of several experimental aircraft under development by NASA and Boeing, such as the Blended Wing Body X-48. Students will then practice calculating proportions, ratios, and scale modelling using the measurements of both the test models and their real counterparts.

"Swept for Speed," the second lesson plan, combines history, geometry, and physical science into a fascinating activity on the development of swept-wing technology in the mid-twentieth century. Students will begin with a firsthand account of secret research discovered in Germany at the end of World War II and end by calculating wing angles for today's subsonic and supersonic aircraft.

In the next lesson plan, "Beyond Biology," engineers and biologists cross paths to create innovations in aerospace inspired by biomimicry. From noise-dampening engine housing on jet engines based on the silent flight of a hunting owl to ideas from the animal kingdom on how to get humans to Mars, students will see how biomimicry has already advanced the possibilities of human flight.

The fourth lesson plan is "Logical Careers." Generally, students might think of airplane mechanics and rocket scientists when they imagine a career in the aerospace industry. However, this vibrant workforce – located all over the world – also moves forward on the shoulders of physicians, accountants, and interior designers, just to name a few. The logic puzzle in this lesson plan opens your students' eyes to the diversity of careers available in a company like Boeing while they practice making deductions and establishing equalities without using any numbers!

All these education resources can be used before or after your field trip. They will help prepare students for the teachable moments found throughout ABOVE AND BEYOND as well as when you return to school to further explore connections between the themes of the exhibition and your classroom Science and Technology instruction. Let's get ready for takeoff!

MATHEMATICS

PROPORTIONAL RELATIONSHIPS, SCALE MODELS

# LESSON PLAN 1: MODELLING THE FUTURE OF FLIGHT

## Teacher Instructions

**Across the Atlantic, around the world, to the Moon, and beyond! Since humankind got off the ground, we have worked to fly faster, higher, further and smarter. For aircraft, the focus is now all about going further with less – less fuel and less pollution. There are three cutting-edge, experimental aircraft – several featured in ABOVE AND BEYOND – that have moved from inspired ideas to workable models: the X-48, SUGAR Volt, and Phantom Swift.**

From the Wright Flyer of 1903 to the most experimental spaceplanes of today, every craft your students encounter during their field trip to ABOVE AND BEYOND started out as an idea and a model. Scale models save both resources and lives. Engineers gather valuable information by trying out their ideas on smaller models that use fewer materials and don't require a human pilot. If they discover that part of their design, such as the angle of a wing or the placement of an engine, makes the aircraft less efficient or unsafe, changes can be made.

### THE X-48/BWB-450

Conventional tube-and-wing aircraft produce drag because the wings stick out from the body. NASA and Boeing are experimenting with blending the wings and body of an aircraft into a single, smooth surface in order to reduce drag and improve fuel efficiency. The X-48 is a blended wing body, or BWB, craft. It is called the BWB-450 because someday, it could seat up to 450 passengers! The prototypes proved that this new shape is aerodynamic, fuel-efficient, and can reduce noise, making it a good candidate for an ultra-green flying machine in the future. During 2012 and 2013, different size models were flown many times. You will see one of the test models in ABOVE AND BEYOND.

### SUGAR VOLT

Another experimental green aircraft currently in development by Boeing is SUGAR Volt. It is a hybrid electric and jet fuel plane, similar to the hybrid cars we drive today that use both electricity and gasoline. SUGAR stands for Subsonic Ultra-Green Aircraft Research, a group that helps design airplane technologies needed 20 years from now to meet green aviation requirements, including fuel efficiency.

### PHANTOM SWIFT

Helicopters can take off and land just about anywhere, but they don't fly very quickly. Fixed-wing aircraft, like airplanes, can fly quickly but need runways to take off and land. A VTOL (vertical takeoff and landing) aircraft combines the best of both worlds! The Phantom Swift experimental aircraft began as Boeing's entry for a competition led by the US military's Defense Advanced Research Projects Agency (DARPA) to develop a new VTOL. In fact, DARPA competitions are behind the development of several cutting-edge technologies featured in ABOVE AND BEYOND. It sounds like the ultimate Science Fair!

In this lesson, your students will discover more about these three flights of the future designed to carry us faster, higher, further and smarter than ever before. First, they will calculate the full-size dimensions and scale model measurements for the X-48C, SUGAR Volt, and Phantom Swift. Then, to help them get a perspective on the sizes of both the scale models used in tests and their full-scale counterparts, they will compare these proportions to several locations in and around your school.

# LESSON PLAN 1: MODELLING THE FUTURE OF FLIGHT

## Answer Key

## PART 1

**1.**

| | Full Size | 8.5% Model | 5% Model |
|---|---|---|---|
| **Width** | **73.2 m** | 6.3 m | 3.7 m |
| **Weight** | 2,668.2 kg | **226.8 kg** | 133.4 kg |

**2.**

| | Full Size | 15% Model |
|---|---|---|
| **Width** | 52.8 m | **7.9 m** |
| **Weight** | 40.5 kg | **6.1 kg** |

**3.**

| | Full Size | 17% Model |
|---|---|---|
| **Width** | **15.2 m** | 2.6 m |
| **Length** | **13.4 m** | 2.3 m |
| **Weight** | **5,443.1 kg** | 925.3 kg |

## PART 2

1. **(a.)** Typical secondary school desk: 120 cm by 60 m.
   **(b.)** Answers will vary depending on the size of your classroom's desks.
2. **(a.)** Typical secondary school classroom: between 43 $m^2$ and 60 $m^2$.
   **(b.)** and **(c.)** Answers will vary depending on the size of your classroom.
3. **(a.)** Typical secondary school gym ranges between 18 m by 28 m to 20 m by 34.5 m.
   **(b.)** Answers will vary depending on the size of your school's gymnasium.
4. Answers will vary depending on the size of your school's largest car park.
5. SUGAR Volt
6. X-48
7. Phantom Swift
8. X-48 at the 5% scale model size
9. Phantom Swift
10. Answers will vary depending on each student's opinion on which vehicle should be developed.

### GO BEYOND!

**To further explore the work of the Boeing model builders, direct students to view the video clip Model Citizens: Inside Boeing's Wind Tunnel Model Shop, www.youtube.com/watch?v=9MFWnHkG6YU.html. Who knew that playing with model airplanes could lead to such a cool career?**

NAME________________________ CLASS ________________ DATE________

# MODELLING THE FUTURE OF FLIGHT

## Student Activity

**TERMS TO KNOW:** **dimension, hybrid, prototype, subsonic, unmanned, wingspan**

**Across the Atlantic, around the world, to the Moon, and beyond! Since humankind got off the ground, we have worked to fly faster, higher, further and smarter. For aircraft, the focus now is all about going further with less – less fuel and less pollution. There are three cutting-edge, experimental aircraft – several featured in ABOVE AND BEYOND – that have moved from inspired ideas to workable models.**

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### X-48/BWB-450


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Discover more about these three flights of the future designed to carry us faster, higher, further and smarter than ever before. First, you will calculate the full-size dimensions and scale model measurements for the X-48, SUGAR Volt, and Phantom Swift. Then, to help you get a perspective on the sizes of both the scale models used in these important tests and their full-scale counterparts, you will compare these proportions to several locations in and around your school.

NAME____________________ CLASS ____________________ DATE____________

# PART 1: SCALE MODELS

## Student Activity

**1.** Models of the X-48, or BWB-450, were created in more than one size. One model used for unmanned flying tests is 8.5% of the actual size. An earlier version was a wind test model built at 5% of its actual size. Complete this chart for the measurements of the full-size aircraft and two of its scale models. Round your calculations to the nearest tenth.

| | Full Size | 8.5% Model | 5% Model |
|---|---|---|---|
| Width | **73.2m** | | |
| Weight | | **226.8 kg** | |

**2.** The prototype for the SUGAR Volt used in wind tunnel testing was a 15% scale model. In the wind tunnel tests, only a semi-span, or half of the craft, was used. This half model was 3.96 m wide, which means a completed 15% model is 7.92 m wide. Complete this chart for the measurements of both the full-size aircraft and its scale model. Round your calculations to the nearest tenth.

| | Full Size | 15% Model |
|---|---|---|
| Width | | **7.9 m** |
| Weight | | **6.1 kg** |

**3.** Phantom Swift only exists as a scale model, built at 17% of what will be its actual size. With advanced prototyping technology, engineers at The Boeing Company conceived and created the remote-controlled model in less than a month. Look for other rapid prototypes in the SMARTER gallery at ABOVE AND BEYOND. Complete this chart for the measurements of both the full-size aircraft and its scale model. Round your calculations to the nearest tenth.

| | Full Size | 17% Model |
|---|---|---|
| Width | **15.2 m** | |
| Length | **13.4 m** | |
| Weight | **5,443.1 kg** | |

NAME______________________________ CLASS ____________________ DATE__________

# PART 2: RELATIVE SIZE

## Student Activity

For perspective on the sizes of both the scale models used in experimental aircrafts and their full-scale counterparts, compare their dimensions to several locations in and around your school.

**1. (a.)** Measure your desk: ____________________ m long ____________________ m wide

**(b.)** Which scale models would fit on your desk? ____________________

**2. (a.)** Measure your classroom: ____________________ m long ____________________ m wide

**(b.)** Which scale models might fit in your classroom? ____________________

**(c.)** Which full-scale versions would fit in your classroom? ____________________

**3. (a.)** Measure your gymnasium: ____________________ m long ____________________ m wide

**(b.)** Which full-scale versions might fit in your gymnasium? ____________________

**4. (a.)** Measure the school's largest car park: ____________________ m long ____________________ m wide

**(b.)** Which full-scale versions might fit in this car park? ____________________

**5.** Which experimental aircraft scale model is widest? ____________________

**6.** Which full-scale craft will have the widest wingspan? ____________________

**7.** Which of the scale model crafts is the smallest in size, but the closest to its full-sized counterpart? ____________________

**8.** Which of the models is built on the smallest scale? ____________________

**9.** Which full-scale craft will weigh more, the Phantom Swift or the X-48? ____________________

**10.** If it were up to you to select one of these three models to be built full-sized and fully functioning, which one would you choose? Why?

____________________

____________________

____________________

# LESSON PLAN 2: SWEPT FOR SPEED

## Teacher Instructions

MATHEMATICS, SCIENCE, SOCIAL STUDIES

GEOMETRY, PHYSICAL SCIENCE, HISTORY, PRIMARY SOURCE

**One of the highlights of a class field trip to ABOVE AND BEYOND is the fighter jet design challenge in the FASTER gallery. Your students' mission at the Full Throttle Virtual Jet Design and Test Facility is to design a manoeuvrable jet capable of supersonic flight. Their plans will focus on a jet's fuselage, wings, and tail shapes.**

Since the wings of a jet provide lift, their shape is key to creating the speed and maneuverability needed in this challenge. Therefore, your designers will want to select the type of wings that give them both. Which wing shape is best for a supersonic fighter jet?

### STRAIGHT WINGS

Straight wings are perpendicular to the fuselage. They provide excellent lift and stability at slow speeds. However, they cause significant buildup of shock waves making the aircraft unstable at supersonic speeds.

### SWEPT WINGS

Swept wings are angled to reduce drag. Drag is the force that opposes forward thrust. Swept wings reduce the buildup of shock waves near supersonic speeds and offer good maneuverability. However, they produce less lift and are less stable than straight wings at slow speeds.

### DELTA WINGS

Delta wings are triangular-shaped, like the Greek letter "delta." The extreme angle of their sweep greatly reduces the buildup of shock waves as the jet approaches the speed of sound. They also offer excellent maneuverability. However, similar to swept wings, they do not provide much lift at slow speeds.

So, where does this information leave your class of student jet designers? Ask them one more critical question: What do abandoned, top-secret research centers in Nazi Germany have to do with the shape of jet wings today? During World War II, aerospace engineers were trying to figure out how to use new, powerful jet engines with the aircraft they already had. Existing airplanes – with straight wings – tended to fall apart when they reached the high speeds possible with the new jet engines.

Some scientists, like Boeing engineer George Schairer, had just started to experiment with an idea called "swept wings." At the end of War World II, Schairer went to Germany with a group of American scientists and engineers. They were sent to find and collect any aeronautical research developed by the Nazis during the war.

In this activity, your students will begin by reading and analysing a primary source from Schairer. It is a memo he sent hurriedly to Boeing after the Americans discovered secret German documents hidden in an old well. The reports demonstrated that angled, swept-back wings really did work. Boeing then used this information on the B-47 for the military and on the first passenger jet, the 707. Next, students will find out what "angled" means geometrically by measuring and calculating the angles of swept wings on jets today.

### SUPPLIES

- **Protractors**

# LESSON PLAN 2: SWEPT FOR SPEED

## Answer Key

### PART 1

1. 20 May 1945
2. 1509 29th Ave. Seattle, Wash
3. Within a few miles of the front line, in the middle of a forest
4. Quiet; excellent quarters including lights, hot water, heat
5. The Germans were ahead in a few items
6. Sweepback or sweepforward has a very large effect on critical Mach number
7. ME163
8. Control and stability problems
9. **(a.)** Answers will vary and may mention that because it was wartime, sharing the information with other plane builders would help his country as a whole.
   **(b.)** Answers will vary and may mention that it might not happen today because of competition among the companies.
10. His razor

### PART 2

1. 90 degrees; right angle
2. The wing line and the fuselage line should be at right angles to each other
3. Lines should be drawn on diagram.
4. 125 degrees, obtuse
5. **(b.)** approximately 35 degrees
6. Subtraction; subtract the 90 degrees of the straight wing from the 125 degrees of the angle of swept wing from the line of symmetry: 125-90=35
7. Lines depicting new wings should be added at a 45-degree angle.
8. They will be harder to control at slower speeds (during takeoff and landing, for example).

### GO BEYOND!

**To learn more about George Schairer's historic swept-wing design and its wind tunnel testing, watch Boeing Wind Tunnel Blows Strong for Nearly 70 Years at www.boeing.com/features/2013/10/bca-wind-tunnel-history-10-28-13.page. You will be blown away!**

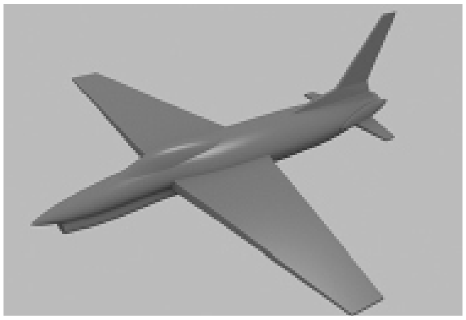
NAME______________________________ CLASS ______________________ DATE__________

# SWEPT FOR SPEED

## Student Activity

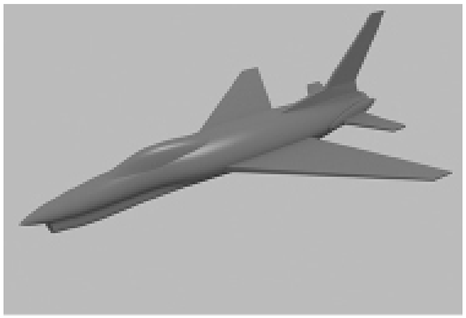
**One of the highlights of a class field trip to ABOVE AND BEYOND is the fighter jet design challenge in the FASTER gallery. At the Full Throttle Virtual Jet Design and Test Facility your mission will be to design a manoeuvrable jet capable of supersonic flight. Your design will focus on a jet's fuselage, wings, and tail shapes. Since the wings of a jet provide lift and their shape is key to speed and maneuverability, you will want to select the type of wings that give you both. Which wing shape do you think is best for a supersonic fighter jet?**

### STRAIGHT WINGS



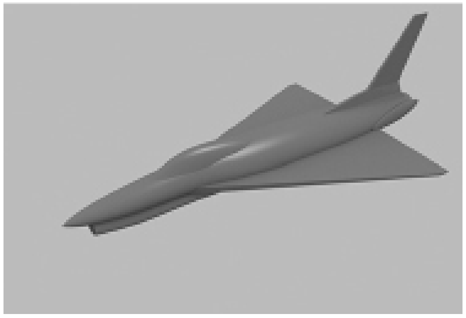
Straight wings are perpendicular to the fuselage and typically have more surface area than other wing shapes. They provide excellent lift and stability at slow speeds. However, they cause significant buildup of shock waves making the craft unstable at supersonic speeds.

### SWEPT WINGS



Swept wings are angled to reduce drag. Drag is the force that opposes forward thrust. Swept wings reduce the buildup of shock waves near supersonic speeds and offer good maneuverability. However, they produce less lift and are less stable than straight wings at slow speeds.

### DELTA WINGS



Delta wings are triangular-shaped, like the Greek letter "delta." The extreme angle of their sweep greatly reduces the buildup of shock waves as the jet approaches the speed of sound. They also offer excellent maneuverability. However, similar to swept wings, they do not provide much lift at slow speeds.

To begin your research, ask yourself this critical question: What do abandoned, top-secret research centres in Nazi Germany have to do with the shape of jet wings today? During World War II, aerospace engineers were trying to figure out how to use new, powerful, jet engines with the aircraft they already had. Existing airplanes – with straight wings – tended to fall apart when they reached the high speeds possible with the new jet engines.

Some scientists, like Boeing engineer George Schairer, had just started to experiment with an idea called "swept wings." At the end of World War II, Schairer went to Germany with a group of American scientists and engineers. They were sent to find and collect any aeronautical research developed by the Nazis during the war.

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**TERMS TO KNOW:** **aerodynamics, aeronautical, airfoil, drag, fuselage, lift, Mach, manoeuvrable, perpendicular, supersonic, symmetry, thrust**

NAME______________________________ CLASS ______________________ DATE__________

# PART 1

## Student Activity

After the secret German research on swept wings was discovered, Schairer sent a seven-page letter to his friend and coworker, Benedict Cohn. Read the excerpt below and answer the questions that follow.

*20 May 1945*

*To: Mr. Benedict Cohn*
*1509 29th Ave.*
*Seattle, Wash*
*USA*

*Dear Ben,*

*It is hard to believe I am in Germany within a few miles of the front line. Everything is very quiet and I am living very normally in the middle of a forest. We have excellent quarters including lights, hot water, heat, electric razors, etc.*

*We are seeing much of German aerodynamics. They are ahead of us in a few items which I will mention. Here the Germans have been doing extensive work on high-speed aerodynamics. This has led to one very important discovery. Sweepback or sweepforward has a very large effect on critical Mach number[1]. This is quite reasonable on second thought. The flow parallel to the wing cannot affect the critical Mach number and the component normal to the airfoil is the one of importance. Thus the critical M [Mach] is determined by the airfoil section normal to the wing and by the sweepback….*

*A certain amount of experimental proof exists for this sweepback effect. Only the ME163[2] has used it in so far as I can find out. Naturally many control and stability problems are to be encountered in using large amounts of sweep here.*

*I do not know how soon this info will get around to other manufacturers so will you write letters to Ozzie, C.L. Johnson, R. Bayless, E. Horky, E. Sheafer, & Darby quoting pages 2 – 5 for their information.*

*I am having a fine time. I even use my electric razor wherever I go. …Hope things are going well for you. My best to all the gang. They are sure tops in all comparisons.*

*Sincerely,*
*George*

Notes:

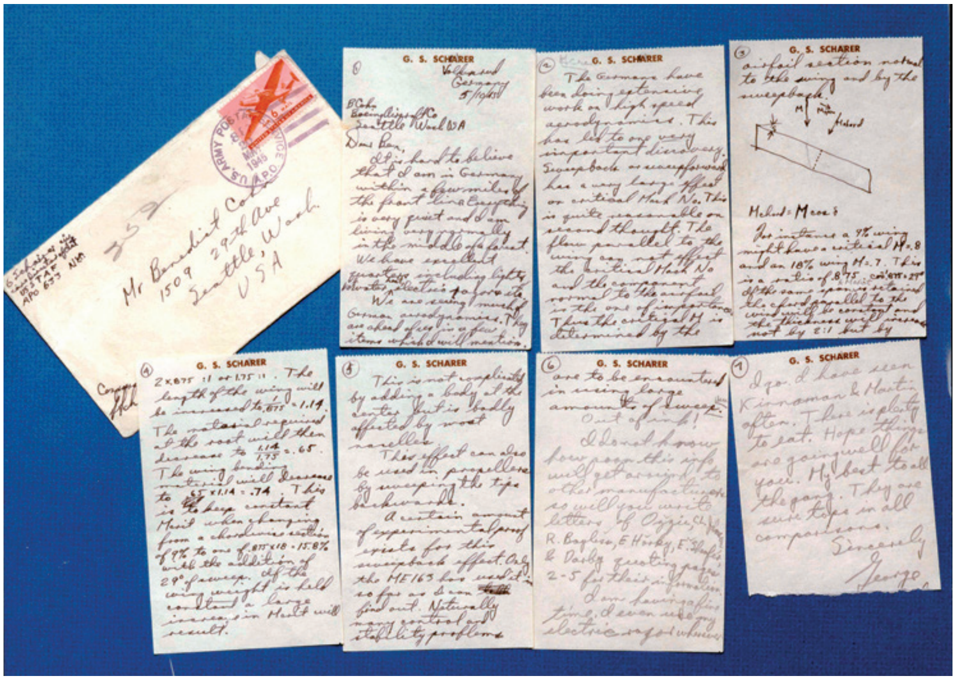
[1]The "critical Mach number" is the speed at which air flowing over any part of an aircraft gets close to, but does not pass, the speed of sound. You will see examples of how the speed of the airflow is tracked in the sample wind tunnel test at ABOVE AND BEYOND.

[2]ME163: The Messerschmitt ME163 Komet was a German rocket-powered fighter aircraft. It was the only rocket-powered fighter actually used in the war.

NAME______________________________ CLASS ______________________ DATE__________

# PART 1

## Student Activity




*Schairer sent this letter describing swept-back wings from Germany*

**1.** On what date does George Schairer write the letter?

______________________________________________________________________

**2.** Where did Benedict Cohn live?

______________________________________________________________________

**3.** Where in Germany is Schairer located when he writes the letter?

______________________________________________________________________

**4.** How does Schairer describe their living conditions?

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

NAME______________________ CLASS ______________________ DATE__________

# PART 1

## Student Activity

**5.** How do the German aerodynamics compare to those of Schairer's country?

**6.** What is one very important discovery made by the Germans?

**7.** At that point in history, what is the only aircraft to have used swept wings?

**8.** What kinds of problems can be expected if the angle is swept too far back?

**9.** The names listed toward the end of his letter are fellow aeronautical engineers at companies other than Boeing.
**(a.)** Why do you think Schairer wanted to pass this discovery on to his competitors?
**(b.)** Do you think companies would still share such information today? Why or why not?

**10.** What electric appliance does Schairer mention twice in this letter?

NAME______________________________ CLASS ____________________ DATE__________

# PART 2

## Student Activity

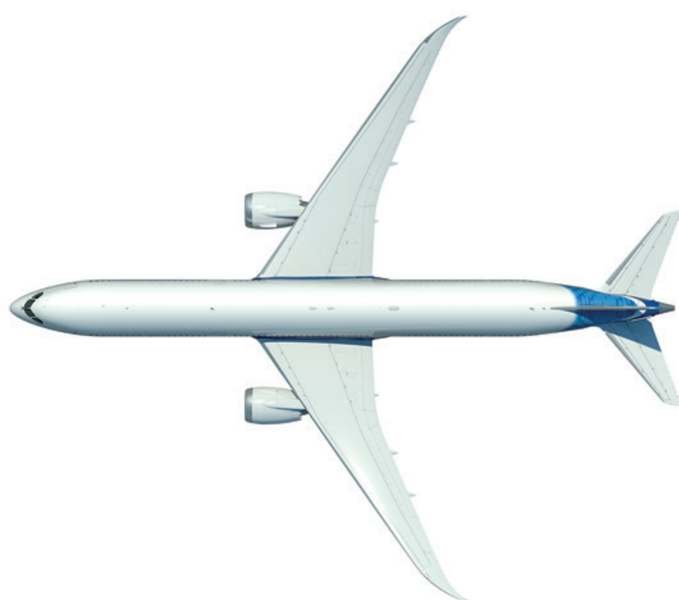
You will need a protractor to complete this section.

**1.** Because straight wings are perpendicular to the fuselage, what is the measurement of the angle formed by the leading, or front, edge of a straight wing and a line of symmetry drawn through the fuselage? Which kind of angle is formed: right, acute, or obtuse?

______________________________________________________________________________

**2.** Sketch a diagram of an aircraft with straight wings in the space below.

**3.** On the diagram of the 787, draw a line of symmetry through the fuselage. Next, extend the line from the leading, or front, edge of a wing until it intersects the line of symmetry.



NAME______________________________ CLASS ______________________ DATE________

# PART 2

## Student Activity

**4.** Measure the angle formed by the two lines you drew on the diagram. What size is the angle? Which kind of angle is it: right, acute, or obtuse?

______________________________________________________________________

______________________________________________________________________

**5.** When describing swept wings on aircraft, the angle is actually measured from what would be an invisible, perpendicular straight wing.

**(a.)** Draw a line on the diagram of the 787 to show where straight wings would go. This line is your new 0 degrees!

**(b.)** Now measure the angle for the swept wings on this jet. How many degrees are they swept back from your new 0 degree line??

______________________________________________________________________

**6.** Based on your answer to questions 3 and 4, explain another way you can find the answer to question 5, without using your protractor.

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

**7.** Fighter jets and other high-speed aircraft have wings swept back an additional 10 degrees. Measure and draw in wings at this new angle to turn the 787 on the previous page into a supersonic jet.

**8.** At ABOVE AND BEYOND, you will see ideas for low-boom, supersonic passenger jets of the future, featuring highly swept-back delta wings. These wings delay the onset of the loud "sonic boom" that is heard when jets break the sound barrier. Based on Schairer's letter and what you learned about wing angles during the Full Throttle challenge, what is one disadvantage that needs to be considered when designing jets for high speed?

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

# LESSON PLAN 3: BEYOND BIOLOGY

## Teacher Instructions

SCIENCE, TECHNOLOGY

BIOLOGY, BIOMIMICRY, ENGINEERING

**While ABOVE AND BEYOND is an exhibition full of high-tech engineering, supersmart computers, and cutting-edge technology, it also features the study of plants and animals – life sciences – if you know where to look! In the UP gallery, for example, your students can spread their wings to join birds in flight heading south.**

**In SMARTER, they will see unmanned aerial vehicles named after the creatures that inspire them, like the Raven. Even the small satellites featured in SMARTER will flock together like their namesakes, Doves. These designs are all examples of biomimicry, where imitation really is the sincerest form of flattery!**

Biomimicry introduces engineers and biologists to each other in order to explore problems in one area that could have solutions in another. Often the answers to difficult technological questions can be found outside in the world around us, perfected by millions of years of trial and error. One of the most famous examples of biomimicry is the hook and loop fastener now best known as Velcro®. It was invented by George de Mestral, a Swiss electrical engineer, after he noticed how tiny hooks on burrs stuck to the loops in the fabric of his clothing and in his dog's fur.

The fact that birds first inspired humans to take to the skies is not news. Aerospace engineers have often looked to Mother Nature with questions about how to take flight further, higher, faster and smarter. The Boeing Company even has teams who study biological topics such as bird evolution or sound sensors on rainforest insects in Costa Rica! In fact, the carpet on the floor in many airplanes has roots in biomimicry. Inspired by the patterns of fallen leaves on the forest floor, carpet tiles are designed to be removed, repaired, or replaced at random. This way, they can be maintained without disturbing the pattern or wasting time, resources, and money to take out the entire carpet.

Biomimicry has applications far beyond aerospace. For example, robots that can move like snakes are being created to assist in search and rescue missions when it is too difficult for people to look amongst the rubble of a fallen building. In medicine, the ways that fish are able to stay alive in icy cold waters may someday inspire a form of antifreeze to keep human organs viable longer for transplants. Architectural engineers are studying termite towers in Africa to learn how to design tall buildings that stay cool in the heat.

In this activity, your students will see how some of the latest advances in flight are based in nature. Ten examples of biomimicry in aerospace engineering are featured. Some innovations are either already in use or in development, while others are realistic possibilities for future generations. If your class has access to the internet, direct them to the website www.asknature.org to learn more about the practical applications of these and other examples of biomimicry.

Students should understand the "Terms to Know" listed in the box on their Student Activity page. Keep a dictionary nearby to help them use the context clues in this matching activity. For a further challenge, use these examples of biomimicry as prompts for research projects and design challenges. Imagine hosting a Biomimicry Science Fair at your school or creating a picture book series on life sciences in space for your local primary school!

# LESSON PLAN 3: BEYOND BIOLOGY

## Answer Key

1. e
2. h
3. b
4. g
5. f
6. j
7. a
8. c
9. i
10. d

### GO BEYOND!

**For a closer look at how The Boeing Company studies birds to learn how to reduce fuel burning in their aircraft, look at the video clip Saving Energy in Flight at www.youtube.com/watch?v=srNTtuTqUBE Biomimicry and aerospace make good science!**

NAME______________________ CLASS ______________________ DATE__________

# BEYOND BIOLOGY

## Student Activity

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**TERMS TO KNOW:** **albatross, biomimicry, chevron, dormancy, hover, manoeuvrable, nanotubes, primate, serrated, transonic, viable, unfurl**

NAME______________________________ CLASS ____________________ DATE__________

# PART 1

## Student Activity

Match the example from nature on this page with the photo and description of the technology it inspires in the list on the next two pages.

**a. Hummingbird:** Hummingbirds are small, lightweight, and very manoeuvrable. They can change directions quickly, hover, and fly sideways.

**b. Bird migrations:** Groups of birds fly in a V formation to go further on less energy. The air currents created by one bird help lift the one behind it, so it doesn't have to work as hard.

**c. Hibernation:** Bears, like many animals, spend their winters hibernating. Recently, scientists have discovered that the fat-tailed dwarf lemur from Madagascar can lower its body temperature, decrease its heart rate, and require less oxygen in a form of primate hibernation.

**d. Honeycomb:** The six-sided cells of the honeycomb have been known for centuries as being strong yet lightweight structures.

**e. Plant buds:** Large flower blossoms and leaves unfurl from inside small buds.

**f. Owl feathers:** Serrated feathers on the edges of owl wings allow the birds to fly silently. The sawtooth pattern dampens sounds the bird makes while swooping toward its prey.

**g. Spider webs:** Scientists know that spider silk is one of the strongest materials on Earth. It is five times stronger than both piano wire and Kevlar, the material used in bullet-proof vests.

**h. Bumblebees:** Many plants on Earth, including our food crops, rely on the pollinating powers of bees and other flying insects.

**i. Eagle wingtips:** The feathers on the end of a steppe eagle's wings curl up at the ends, until they are almost vertical. The shape of these wingtips allows the eagle to maximise lift, without having unnecessarily long wings.

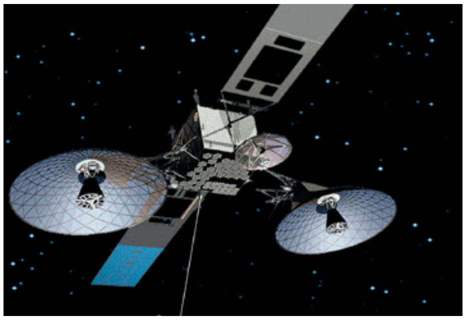
**j. Albatross:** Birds with long wingspans are able to soar efficiently over incredibly long distances. An albatross can spend weeks, or even months, at sea before returning to land.

NAME________________________ CLASS ________________ DATE__________

# PART 1

## Student Activity

**1.** ___________ Large solar panels and antennae on satellites have to be folded and packed into very small spaces in order to be launched on rockets. Once in orbit, however, they must be able to safely open up to their full size.



*Satellites like this Tracking and Data Relay Satellite (TDRS) have large antennae and solar panels that deploy once they are in orbit.*


**2.** ___________ Swarms of tiny RoboBees with flapping wings could be shipped to Mars. Once released inside greenhouses built there, their sensors will be able to identify flower types and where to land on a flower in order to pollinate food crops.

**3.** ___________ Aerospace engineers study the benefits of commercial or military aircraft flying together in order to conserve energy. NASA recently demonstrated a 5% to 10% fuel saving by flying aircraft up to a kilometer apart, which eliminates many of the fears of having commercial aircraft fly too close to each other.

**4.** ___________ Before an elevator to space can become a reality, a material must be found that is strong enough for the cable car to stretch nearly 100,000 kilometres above the Earth. So far, scientists and engineers are betting on carbon nanotubes, but biomimicry might have the solution hidden in a web.

**5.** ___________ Engineers developed a jagged, chevron nozzle that fits onto the back of jet engines. The shape of the nozzle reduces the amount of noise created by the jet.


*Testing on this All Nippon Airways 777-300ER showed that the chevron shape of the engine nozzle helps reduce noise.* 

NAME______________________________ CLASS ____________________ DATE__________

# PART 1
## Student Activity

**6.** __________ The SUGAR Volt is an experimental aircraft. Its exceptionally wide wingspan combined with composite materials and a hybrid electric engine should allow it to fly for long periods of time without refueling.

*This drawing shows how a full-sized SUGAR Volt would look in flight.*


**7.** __________ This tiny, unmanned aerial vehicle is a remote-controlled, undercover aircraft. It has flapping wings, can change directions quickly, and navigate tight spaces. Even though it carries a small camera, it still weighs less than an AA battery.

**8.** __________ Scientists are studying the genetic mechanisms of dormancy as a way of suspending animation in humans. It could be used to safely transport astronauts on the long-distance journey to Mars, or beyond.

**9.** __________ The benefits of winglets on the tips of airplane wings were first explored by NASA and Boeing in 1977. With wingtips curled upward at the ends, airplanes fly more efficiently and with fewer emissions.

*This 737-MAX features the latest in winglet technology.* 

**10.** __________ Hexagons have been used for years on projects big and small in aeronautical research and construction. They are featured in everything from floor panels to wind tunnels to nanotubes.

*This honeycomb installation is from a Boeing transonic wind tunnel in the 1960s.*

MATHEMATICS, CRITICAL THINKING

ALGEBRA, EQUALITIES & EQUATIONS

# LESSON PLAN 4: LOGICAL CAREERS

## Teacher Instructions

**In this lesson, your class will read a short story about a field trip to ABOVE AND BEYOND then solve a logic puzzle that matches three fictitious students to the Science and Technology-related careers they hope to have someday. Logic puzzles are a fun way to practice mathematical skills without using any numbers! Your students will be making deductions and establishing equalities similar to those used in algebra: If A = B and B = C, then A = C.**

To solve the puzzle, read each clue carefully. Use the chart to help you keep track of what you do and do not know about each student's career plans. Because each student in the puzzle can only have one career, and each career can only have one student, you will use the process of elimination to solve the mystery.

If a clue tells you that a person does NOT like something, then place an X in the box for that person and that career or location. When you are able to match a student to his or her career choice, tick off that box. For example, the first clue says that Cora does not want to live in the southern hemisphere. Therefore, Australia cannot be the location for her future career. This first clue has been marked on the grid for you.

Keep reading the clues. Write an X on the answer grid for what you know is not true and tick off what you know is true until you have matched all the students with their future aerospace careers. Perhaps one of your own students will be inspired to join them some day!

# LESSON PLAN 4: LOGICAL CAREERS

## Answer Key

**Paul** - Australia - Accountant

**Cora** - USA - Biofuel chemist

**Ruby** - Saudi Arabia - F-15 technician

### GO BEYOND!

For an inside look at the inspiring innovations dreamed and manufactured by committed Boeing employees all over the world, watch Who We Are: In the Words of Boeing Employees: https://www.youtube.com/watch?v=gdu05M3LnPY. There may be a Boeing volunteer in your area available to speak to your class about Science and Technology in real life!

NAME______________________________ CLASS ______________________ DATE________

# LOGICAL CAREERS

## Student Activity

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Keep reading the clues. Write an X on the answer grid for what you know is not true and tick off what you know is true until you have matched all the students with their future aerospace careers. Perhaps you will be inspired to join them some day!

**TERMS TO KNOW:** **accountant, deduction, financial, grid, renewable**

NAME________________________ CLASS ____________________ DATE__________

# LOGICAL CAREERS

## Student Activity

**The Story**

On the bus ride back to school from their field trip to ABOVE AND BEYOND, three students talk about careers they have been inspired to pursue after learning so much about the aerospace industry. One student is fascinated by fighter jets like the F-15 and hopes to work on them in Saudi Arabia. Another student is concerned about the environment and would like to become a biofuel chemist at a research laboratory in the USA. The third student has always wanted to live in Australia and will consider applying for an accounting job at an aerospace company's office in Melbourne after college.

**Students**

- Cora
- Paul
- Ruby

**Country**

- Saudi Arabia
- Australia
- USA

**Careers**

- F-15 Maintenance Technician
- Accountant
- Biofuel Chemist

Use the clues below to match each student to her or his future career.

**The Clues**

**1.** Cora does not want to live in the southern hemisphere.

**2.** Ruby expects her career choice will bring her to Saudi Arabia someday.

**3.** The student who wants to live in the USA hopes to create new kinds of jet fuel from renewable resources, like plants.

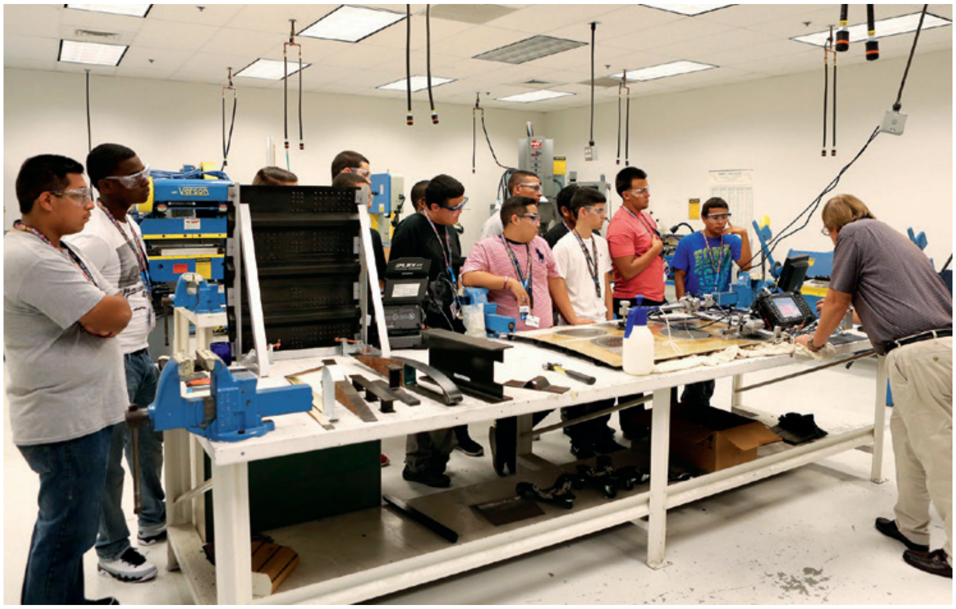
**4.** The student whose dream job is in Australia loves finance and aeronautics, which is perfect for becoming an accountant at an aerospace company.

| | | Career | | | Country | | |
|---|---|---|---|---|---|---|---|
| | | Accountant | F-15 Technician | Chemist | Australia | USA | Saudi Arabia |
| Student | Ruby | | | | | | |
| | Paul | | | | | | |
| | Cora | | | | x | | |
| Country | Australia | | | | | | |
| | USA | | | | | | |
| | Saudi Arabia | | | | | | |

NAME________________________ CLASS ________________________ DATE____________

# LOGICAL CAREERS

## Student Activity



*Occasionally, companies like Boeing host Career Expos for students like this one in Miami where students got hands-on experience with aircraft maintenance tools.* 

*F-15s are flown all over the world, which means that qualified technicians are needed to work on them in locations across the globe.*


*Boeing and South African Airways are working together to help farmers grow crops, like this sorghum, that can be used for biofuel.*


Write the solution to the puzzle here.

| Student | Country | Career |
|---|---|---|
| | | |
| | | |
| | | |