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Lesson Focus

Lesson focuses on the engineering behind air traffic control systems. Teams of students explore principles of radar and how engineered equipment is compiled to provide data to help air traffic controllers keep planes at a safe distance from each other, yet efficiently landing and taking off on schedule. Students work in teams to evaluate data generated for a virtual air traffic system, and determine a plan to bring three planes safely through a set airspace. They then recommend engineering enhancement to the current system.



Lesson Synopsis

The Engineering Air Traffic lesson explores the engineering and principles behind radar and air traffic control systems. Students explore how radar and computer technology is used to provide critical data in an efficient way to air traffic controllers. Students work as a team of engineers to evaluate a current ATC system, virtually act as traffic controllers, and then develop guidelines to improve the engineered interface between the radar and the human controller.

Age Levels

11-18.

Objectives

- ◆ Learn about radar.
- ◆ Learn about air traffic control technology.
- ◆ Learn about systems engineering.
- ◆ Learn about teamwork and working in groups.

Anticipated Learner Outcomes

As a result of this activity, students should develop an understanding of:

- ◆ radar and air traffic technology
- ◆ problem solving
- ◆ teamwork

Engineering Air Traffic

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Lesson Activities

Students learn how the engineering and principles behind radar and air traffic control systems have impacted travel. Students work in teams to explore and use radar and computer technology to evaluate a current ATC system, virtually act as traffic controllers, and then develop guidelines to improve the engineered interface between the radar and the human controller.

Resources/Materials

- ◆ Teacher Resource Documents (attached)
- ◆ Student Worksheets (attached)
- ◆ Student Resource Sheets (attached)

Alignment to Curriculum Frameworks

See attached curriculum alignment sheet.

Internet Connections

- ◆ TryEngineering (www.tryengineering.org)
- ◆ Air Traffic Simulator (www.atcsim.nasa.gov/)
- ◆ NASA Future Flight Design (https://www.nasa.gov/audience/foreducators/5-8/features/F_Future_Flight_Design.html)
- ◆ Air Traffic Control System Command Center (www.fly.faa.gov/flyfaa/usmap.jsp)
- ◆ Listen to live air traffic controllers (www.liveatc.net/topfeeds.php)
- ◆ International Civil Aviation Organization (www.icao.int)

Departures			
Flight	Destination	Dep. Time	
LB 7935	LONDON	16:40	
JK 8257	ROME	16:40	
AC 9538	NEW YORK	16:50	
SR 6482	PARIS	17:00	
EV 7639	BERLIN	17:10	
TU 5422	MADRID	17:14	
XA 3675	BARCELONA	17:50	
HR 7365	STOCKHOLM	18:00	
UA 6537	HELSINKI	18:30	

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Recommended Reading

- ◆ Fundamentals of Air Traffic Control (ISBN: 0534393888)
- ◆ Organizational Simulation (Wiley Series in Systems Engineering and Management) (ISBN: 0471681636)

Extension Idea

For advanced high school students, consider exploring Microsoft Flight Simulator Software (www.microsoft.com/en-us/p/avion-flight-simulator-2015/9nblggh1p8lq#activetab=pivot:overviewtab).

Optional Writing Activities

- ◆ Write an essay or a paragraph about the how you think engineering developments in air traffic control have impacted the global economy. Consider the ability for more people and items to travel more efficiently.

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For Teachers: Teacher Resource

◆ **Lesson Goal**

The Engineering Air Traffic lesson explores the engineering and principles behind radar and air traffic control systems. Students explore how radar and computer technology is used to provide critical data in an efficient way to air traffic controllers. Students work as a team of engineers to evaluate a current ATC system, virtually act as traffic controllers, and then develop guidelines to improve the engineered interface between the radar and the human controller.

◆ **Lesson Objectives**

- ◆ Learn about radar.
- ◆ Learn about air traffic control technology.
- ◆ Learn about systems engineering.
- ◆ Learn about teamwork.

◆ **Materials**

- ◆ Student Resource Sheet
- ◆ Student Worksheets
- ◆ Internet or computer access (PC or MAC; current browsers recommended)

◆ **Procedure**

1. Show students the various Student Reference Sheets. These may be read in class, or provided as reading material for the prior night's homework. Divide students into groups of 2-3 students who will work as an "engineering team."
2. Now that students have an understanding of the engineering and technologies that are used by air traffic controllers, they will work as a team to virtually take over air traffic control in Sector 33 in the United States. Students will use a NASA simulation (www.atcsim.nasa.gov) to plan route and/or speed changes to line up three planes so that they are traveling 3 nautical miles apart when they reach Modesto, CA (MOD). In addition, time is critical, so the last plane must arrive as soon as possible, and the planes must never get closer than 2 nautical miles to each other.
3. Students meet and develop a plan for resolving the paths and speeds of their aircraft.
4. Student groups next execute their plans and tries out the simulator. Each team will complete four attempts at the problem and record their fastest completion speed.
5. Each student group evaluates their results, and then meets as an engineering team to identify improvements they would engineer into the current interface between the radar and the human. For example, students might consider the criteria for selecting which plane should land first. Would they recommend the one with the most people, the one with the least fuel, or the one with more people making time sensitive flight connections?
6. Teams then complete an evaluation/reflection worksheet, and present their ATC improvement plans to the class.

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For Teachers:
Teacher Resource (continued)

◆ **Time Needed**

Two to three 45 minute sessions

◆ **Problem Solving Strategies**

In the Engineering Air Traffic lesson, students use a virtual radar system that provides information about air speed, weather problems, and available routes. Teams will have to apply proportional reasoning to make decisions and resolve conflicts in realistic air traffic control problems involving three planes. The challenge in each problem is to "line up" the planes safely, with proper spacing, at a given intersection of jet routes -- but they must do it in the shortest period of time. Engineering teams will also then, based on their experience with the current engineered system, recommend improvements to the system to improve ATC safety and efficiency. They'll need to consider economic and safety issues when developing improvements to the current system.



Student Resource: Air Traffic Control System Technology

◆ ATC Explained

Air traffic control (ATC) is a service provided by ground-based controllers who direct aircraft on the ground and in the air. A controller's primary task is to separate certain aircraft — to prevent them from coming too close to each other by use of lateral, vertical and longitudinal separation. Secondary tasks include ensuring orderly and expeditious flow of traffic and providing information to pilots, such as weather, navigation information and NOTAMs (Notices to Airmen).



◆ Technology Makes a Difference

While some air traffic is managed visually, many technologies are used in air traffic control systems. Primary and secondary radar are used to enhance a controller's "situational awareness" within his assigned airspace, because all types of aircraft send back primary echoes of varying sizes to controllers' screens as radar energy is bounced off their skins, and transponder-equipped aircraft reply to secondary radar interrogations by giving an ID, an altitude and/or a unique callsign. Certain types of weather may also register on the radar screen. These inputs, added to data from other radars, are correlated to build the air situation. Some basic processing occurs on the radar tracks, such as calculating ground speed and magnetic headings. Other correlations with electronic flight plans are also available to controllers on modern operational display systems.

◆ How Radar Works

Radar is a system that uses electromagnetic waves to identify the range, altitude, direction, or speed of both moving and fixed objects such as aircraft, ships, motor vehicles, weather formations, and terrain. A transmitter emits radio waves, which are reflected by the target and detected by a receiver, typically in the same location as the transmitter. Although the radio signal returned is usually very weak, radio signals can easily be amplified. Radar is used in many contexts, including meteorological detection of precipitation, air traffic control, police detection of speeding traffic, and by the military. The term RADAR was coined in 1941 as an acronym for Radio Detection and Ranging. This acronym of American origin replaced the previously used British abbreviation RDF (which stands for Radio Direction Finding).



Student Resource:
Air Traffic Control System Technology (continued)**◆ Measuring Distance**

One way to measure the distance to an object is to transmit a short pulse of radio signal (electromagnetic radiation), and measure the time it takes for the reflection to return. The distance is one-half the product of round trip time (because the signal has to travel to the target and then back to the receiver) and the speed of the signal. Since radio waves travel at the speed of light (186,000 miles per second or 300,000,000 meters per second), accurate distance measurement requires high-performance electronics. Another form of distance measuring radar is based on frequency modulation. Frequency comparison between two signals is considerably more accurate, even with older electronics, than timing the signal. By changing the frequency of the returned signal and comparing that with the original, the difference can be easily measured. This technique can be used in continuous wave radar, and is often found in aircraft radar altimeters.

◆ Global Radar Coverage

Since air traffic centers control a large airspace area, they will typically use long range radar that has the capability to see aircraft within 200 nautical miles (370 km) of the radar antenna. In the U.S. system, at higher altitudes, over 90% of the U.S. airspace is covered by radar and often by multiple radar systems. A center may require numerous radar systems to cover the airspace assigned to them. This results in a large amount of data being available to the controller. To address this, automation systems have been designed that consolidate the radar data for the controller. This consolidation includes eliminating duplicate radar returns, ensuring the best radar for each geographical area is providing the data, and displaying the data in an effective format. Some Air Navigation Service Providers (e.g. Airservices Australia, Alaska Center, etc.) are implementing Automatic dependent Surveillance - Broadcast (ADS-B) as part of their surveillance capability. This new technology reverses the radar concept. Instead of radar "finding" a target by interrogating the transponder, ADS transmits the aircraft's position several times a second. ADS also has other modes such as the "contract" mode where the aircraft reports a position based on a predetermined time interval. This is significant because it can be used where it is not possible to locate the infrastructure for a radar system (e.g. over water). Computerized radar displays are now being designed to accept ADS inputs as part of the display. As this technology develops, oceanic ATC procedures will be modernized to take advantage of the benefits this technology provides.

◆ Global Considerations

Global Air Traffic Management (GATM) is a concept for satellite-based communication, navigation, surveillance, and air traffic management. The Federal Aviation Administration and the International Civil Aviation Organization, a special agency of the United Nations, established GATM standards in order to keep air travel safe and effective in increasingly crowded worldwide air space. Efforts are made all over the world to implement the new technologies that will allow GATM to efficiently support Air Traffic Controller. Airservices Australia ADS-B initiative is one of the major implementation programs in this field.

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Student Worksheet: Using Radar for ATC

You are a team of engineers who have been given the challenge of evaluating current Air Traffic Control (ATC) technology -- by using it yourselves -- and recommending engineering changes that might make ATC safer or more efficient.

◆ Preparation Phase

1. Review the various Student Reference Sheets.

◆ Research Phase

1. Now that your team has an understanding of the engineering and technologies that are used by air traffic controllers, you will work as a team to virtually take over air traffic control in Sector 33 in the United States using a NASA simulation at www.atcsim.nasa.gov to plan route and/or speed changes to line up three planes so that the planes are traveling 3 nautical miles apart when they reach Modesto, CA (MOD). In addition, time is critical, so the last plane must arrive as soon as possible, and the planes must never get closer than 2 nautical miles to each other.
2. Meet as a team to develop a plan for resolving the paths and speeds of their aircraft.

Departures		
Flight	Destination	Dep.Time
LB 7935	LONDON	16:40
JK 8257	ROME	16:40
AC 9538	NEW YORK	16:50
SR 6482	PARIS	17:00
FV 7639	BERLIN	17:10
TU 5422	MADRID	17:14
XA 3675	BARCELONA	17:50
HR 7365	STOCKHOLM	18:00
UA 6537	HELSINKI	18:30

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◆ Simulator Phase

1. Now execute your plans and try out the simulator. Your team will have four attempts at the problem and record your four completion speeds in the box below:

	Time Needed	Strategy	Observations
Attempt 1			
Attempt 2			
Attempt 3			
Attempt 4			

◆ Evaluation/Recommendation Phase

1. Next, evaluate your team's results, and discuss what your "engineering team" would recommend changing in the current interface between the radar and the human. Perhaps you thought you needed additional information to make decisions about which plane to slow down or speed up, or you wanted different tools that software engineers might be able to program to make the ATC function either more safely or more efficiently. For example, would the remaining fuel in a plane help with your decision?
2. Complete an evaluation/reflection worksheet, and present your ATC improvement plans to the class.



Student Worksheet: Evaluation

Use this worksheet to evaluate your team's results in the Engineering Air Traffic lesson:

1. What was your team's fastest speed in solving the air traffic control problem? How did this compare to the speed of other teams in your class?

2. What enhancements did your team determine engineers should consider adding to the radar interface? What problems did you think these engineered improvements would solve? Complete in box below:

Problem Identified with Existing System	Suggested Engineering Improvements
1.	
2.	
3.	



Student Worksheet: Evaluation

3. Software and hardware used in computing and data systems are frequently re-engineered. List a few examples in your classroom or school of equipment that has changed over the past few years? What problems do you think the engineers were attempting to address through their new design?

4. Discuss as a team what you think travel would be like if all the supporting technology and engineering were eliminated. Describe how a trip across your country would change in terms of time, cost, and comfort.

5. How else could air traffic be controlled? Consider the use of global positioning systems, simple visual controls, and other methods. What system or combination of current systems do you think is safest?

For Teachers:

Alignment to Curriculum Frameworks

Note: Lesson plans in this series are aligned to one or more of the following sets of standards:

- U.S. Science Education Standards (http://www.nap.edu/catalog.php?record_id=4962)
- U.S. Next Generation Science Standards (<http://www.nextgenscience.org/>)
- International Technology Education Association's Standards for Technological Literacy (<http://www.iteea.org/TAA/PDFs/xstnd.pdf>)
- U.S. National Council of Teachers of Mathematics' Principles and Standards for School Mathematics (<http://www.nctm.org/standards/content.aspx?id=16909>)
- U.S. Common Core State Standards for Mathematics (<http://www.corestandards.org/Math>)
- Computer Science Teachers Association K-12 Computer Science Standards (<http://csta.acm.org/Curriculum/sub/K12Standards.html>)

◆ National Science Education Standards Grades 5-8 (ages 10 - 14)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- ◆ Abilities necessary to do scientific inquiry
- ◆ Understandings about scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop an understanding of

- ◆ Motions and forces

CONTENT STANDARD E: Science and Technology

As a result of activities in grades 5-8, all students should develop

- ◆ Abilities of technological design
- ◆ Understandings about science and technology

CONTENT STANDARD F: Science in Personal and Social Perspectives

As a result of activities, all students should develop understanding of

- ◆ Science and technology in society

◆ National Science Education Standards Grades 9-12 (ages 14-18)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- ◆ Abilities necessary to do scientific inquiry
- ◆ Understandings about scientific inquiry

CONTENT STANDARD E: Science and Technology

As a result of activities, all students should develop

- ◆ Abilities of technological design
- ◆ Understandings about science and technology

CONTENT STANDARD F: Science in Personal and Social Perspectives

As a result of activities, all students should develop understanding of

- ◆ Science and technology in local, national, and global challenges

◆ Next Generation Science Standards Grades 3-5 (Ages 8-11)

Energy

Students who demonstrate understanding can:

- ◆ 4-PS3-1. Use evidence to construct an explanation relating the speed of an object to the energy of that object.

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For Teachers:

Alignment to Curriculum Frameworks

◆ Next Generation Science Standards Grades 3-5 (Ages 8-11)

Engineering Design

Students who demonstrate understanding can:

- ◆ 3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- ◆ 3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- ◆ 3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

◆ Next Generation Science Standards Grades 6-8 (Ages 11-14)

Engineering Design

Students who demonstrate understanding can:

- ◆ MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

◆ Next Generation Science Standards Grades 9-12 (Ages 14-18)

Engineering Design

- ◆ HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

◆ Principles and Standards for School Mathematics (ages 11 – 14)

Numbers and Operations

- Compute fluently and make reasonable estimates
 - ◆ Develop, analyze, and explain methods for solving problems involving proportions, such as scaling and finding equivalent ratios.

Algebra

- Use mathematical models to represent and understand quantitative relationships.
 - ◆ Model and solve contextualized problems using various representations, such as graphs, tables, and equations.

Measurement

- Apply appropriate techniques, tools, and formulas to determine measurements.
 - ◆ Solve simple problems involving rates and derived measurements for such attributes as velocity and density.

Problem Solving

- ◆ Solve problems that arise in mathematics and other contexts.
- ◆ Apply and adapt a variety of strategies to solve problems.

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For Teachers: Alignment to Curriculum Frameworks

◆ Principles and Standards for School Mathematics (ages 11 – 14) (continued)

Connections

- ◆ Recognize and apply mathematics in contexts outside of mathematics.

Representation

- ◆ Select, apply, and translate among mathematical representations to solve problems.
- ◆ Use representation to model and interpret physical, social, and mathematical phenomena.

Algebra

- ◆ Analyze change in various contexts.
- ◆ Approximate and interpret rates of change from graphical and numerical data.

Problem Solving

- ◆ Solve problems that arise in mathematics and other contexts.
- ◆ Apply and adapt a variety of strategies to solve problems.

Connections

- ◆ Recognize and apply mathematics in contexts outside of mathematics.

Representation

- ◆ Select, apply, and translate among mathematical representations to solve problems.

◆ Common Core State Standards for School Mathematics: Content (ages 10-14)

Ratios and Proportional Relationships

- Analyze proportional relationships and use them to solve real-world and mathematical problems.
 - ◆ CCSS.Math.Content.7.RP.A.1 Compute unit rates associated with ratios of fractions, including ratios of lengths, areas and other quantities measured in like or different units. For example, if a person walks $\frac{1}{2}$ mile in each $\frac{1}{4}$ hour, compute the unit rate as the complex fraction $\frac{1/2}{1/4}$ miles per hour, equivalently 2 miles per hour.

For Teachers: Alignment to Curriculum Frameworks

◆ Standards for Technological Literacy - All Ages

The Nature of Technology

- ◆ Standard 1: Students will develop an understanding of the characteristics and scope of technology.
- ◆ Standard 2: Students will develop an understanding of the core concepts of technology.
- ◆ Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

Technology and Society

- ◆ Standard 4: Students will develop an understanding of the cultural, social, economic, and political effects of technology.
- ◆ Standard 6: Students will develop an understanding of the role of society in the development and use of technology.

Design

- ◆ Standard 9: Students will develop an understanding of engineering design.
- ◆ Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

Abilities for a Technological World

- ◆ Standard 12: Students will develop abilities to use and maintain technological products and systems.
- ◆ Standard 13: Students will develop abilities to assess the impact of products and systems.

The Designed World

- ◆ Standard 17: Students will develop an understanding of and be able to select and use information and communication technologies.
- ◆ Standard 18: Students will develop an understanding of and be able to select and use transportation technologies.