CHRONICLES OF COURAGE
Stories of WARTIME AND INNOVATION

"B-17 and the Ball Turret"

STEM Lesson Plan for Grades 7-12
Developed by the National Science Teachers Association
Access the Videos at NBCLearn.com/courage

"Well, I don't know how to say this but, when you're young, you're just not scared. You're scared but, it don't show. Until you get back."
— Mason Howe, B-17 ball turret gunner

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Video Preview

"B-17 Ball Turret" is one of 20 short videos in the series *Chronicles of Courage: Stories of Wartime and Innovation.* It tells the story of the B-17 "Flying Fortress"—one of the most recognizable bomber planes of World War II. Gunner Mason Howe describes his experience inside the B-17's ball turret—a metal and glass sphere that hangs under the plane and is equipped with two .50 caliber machine guns.

Time	Video content
000:0–00:16	Series opening
00:17–01:24	The danger of daylight strategic bombing over enemy territory
01:25–02:17	Introduction to the Boeing B-17 Flying Fortress four-engine bomber
02:18–02:25	Why the ball turret gunner had to be small
02:26–03:19	Mason Howe explains how to fight when in the ball turret
03:20–04:29	The Degrees of Freedom of the ball turret provide a significant defensive shield
04:30–05:03	The ball turret gunner, sitting between two machine guns, can still be scared
05:04-05:20	Closing credits

Video Voices—The Experts Tell the Story

By interviewing people who have demonstrated courage in the face of extraordinary events, the *Chronicles of Courage* series keeps history alive for current generations to explore. The technologies and solutions presented are contextualized by experts working to preserve classic aircraft technology.

- **Mason Howe, B-17 ball turret gunner.** Howe offers first-hand memories about what it was like to fly in the ball turret.
- **Cory Graff, Military Aviation Curator, Flying Heritage Collection.** Graff has over 20 years' experience working in aviation museums, creating exhibits, conducting historical research, and educating visitors. Curators are content specialists that are focused on a specific subject relevant to a museum's collection.

Find extensive interviews with Hill and other WWII veterans online at Flying Heritage Collection.

Connect the Video to Science and Engineering Design

World War II bombers involved in daylight bombing raids had to protect themselves from enemy fighters. A major component of the overall defensive effort was the ball turret. Ball turret gunners were responsible for defending the bomber from enemy fighters attacking from below.

The ball turret was added in the seventh iteration of the B-17. It was powered by an electric motor connected to two hydraulic units. One hydraulic unit controlled sideways motion while the other moved the ball up and down. The gunner directed the ball turret with two handles located on either side of the circular view port. The combination of sideways and up-and-down motion determines the orientation of the ball turret. Engineers quantify this motion as the "degrees of freedom" of the mechanism. The ball turret was designed to be as small as possible to reduce drag on the aircraft.

Related Concepts

- degrees of freedom
- hydraulic
- rotational movement
- hemisphere
- azimuth
- elevation

Explore the Video

Use video to explore students' prior knowledge, ideas, questions, and misconceptions. View the video as a whole or visit segments as needed. Have students write or use the bell ringers as discussion starters.

Time	Video content	Bell Ringers
0:17–01:24	The bomber war over Europe	High altitude bombing was conducted at altitudes between 18,000 and 30,000 feet (about 3.5–5.7 miles). Discuss the math issues involved in targeting these bombers with a land-based anti-aircraft gun.

02:18–02:25	Introduction to the Sperry ball turret	Students might demonstrate the approximate diameter of the ball turret using a piece of string 3 feet long. Then have students find the volume into which the ball turret gunner had to fit, with only limited movement, for 8 to 10 hours. Guide them to keep in mind that some of this volume was taken up by guns and ammunition. Note that most gunners didn't even have a parachute with them in the turret.
02:26–03:19	How the ball turret works	Students might make and label a drawing showing the "degrees of freedom" of the ball turret.
03:20–04:29	The importance of degrees of freedom	Students might identify other devices in which degrees of freedom are important design features.
04:30–05:03	Summary	Bomber crews had reason to be afraid. In 1943, each crew had to complete 25 missions before they were rotated back to the United States. Have students design a simulation that lets them learn the odds of completing a 25-mission tour of duty unharmed. A squadron of 18 B-17s would set out on each mission. Students can assume that 5% of the planes would not return from each mission, which is a rough average of actual statistics.

Language Support
To aid those with limited English proficiency or others who need help focusing on the video, make available the transcript for the video. Click the TRANSCRIPT tab on the side of the video window, then copy and paste into a document for student reference.

Explore and Challenge

After prompting to uncover what students already know, use video for a common background experience and follow with a minds-on or hands-on collaboration.

1. Explore readiness to learn from the video with the following prompts:
   - *Examples of devices that can turn in many directions include….*
   - *Degrees of freedom refers to…*
   - *In order for machine guns to protect an aircraft they have to….*
   - *The orientation of a rotating device is determined by….*
   - *The pros and cons of a spherical turret are….*
2. Show the video and allow students to discuss their observations and questions. The video presents the Sperry ball turret, which was a key defensive element of the Boeing B-17. The ball turret was able to rotate in almost any direction in defense of the airspace

below the bomber. Elicit observations about the aircraft presented and how its technology and innovations helped it to be successful in its mission.

3. Explore understanding with the following prompts:
    - *The diameter of the ball turret must be kept as small as possible because….*
    - *A mechanism's degrees of freedom can be increased by….*
    - *A simulator for a ball turret would have to….*
    - *A better design for a ball turret would be….*
    - *The location of the B-17's 12 machine guns protected it by….*
4. Help students identify a challenge, which might be based on the questions they have. Teams should focus on questions that can be answered by research or an investigation. Possible activities that students might explore are offered in *Identify the Challenge*.

Identify the Challenge

Stimulate small-group discussion with the prompt: *This video makes me think about….* Encourage students to think about what aspects of the aircraft/technology shown in the video helped assure a successful completion of its mission. If needed, show the video segment about the importance of degrees of freedom (03:20–04:29) as a way to spark ideas or direct student thinking along the following lines.

- Statistics indicate that during World War II only 10% of bomber gunners that could have targeted an enemy aircraft within range did so, due to a variety of factors ranging from being focused in another direction to reloading guns at the opportune moment. At least four different gunners had to fire on an enemy aircraft *just to have a 50% chance of shooting it down.* Students might identify features and constraints that would have to be redesigned to make the manned ball turret more efficient. Note that such a design was available in 1944 with the advent of the B-29.
- Students might design a device for any end use that meets a specified degree of freedom.

Ask groups to choose their challenge and rephrase it in a way that it can be explored through illustrations or models.

Investigate, Compare, and Revise

Remind students that engineering design challenges connect to real-world problems and usually have multiple solutions. Each team should be able to explain and justify the challenge they will investigate using concepts and math previously learned. Approve each investigation based on student skill level and the practicality of each team completing an independent investigation. Help teams to revise their plans as needed.

Assemble Equipment and Materials

Many materials can be found in a classroom to help students investigate challenges such as those suggested in *Identify the Challenge*. Suggestions include:

- square and rectangular sheets of paper of various thicknesses
- paperclips
- scissors
- tape, clear and masking
- string or fishing line
- glue
- foam core

- Teacher Geek STEM components or other construction sets
- measuring tape
- sticky notes
- ruler
- protractor
- calculator
- cell phone camera
- modeling clay
- round balloons
- papier-mâché

Manipulate Materials to Trigger Ideas: Allow students a brief time to examine and manipulate available materials. Doing so aids students in refining the direction of their investigation or prompts new ideas that should be recorded for future investigation. Because conversation is critical in the science classroom, allow students to discuss available materials and change their minds as their investigations evolve. The class, as a whole, can decide to exclude certain materials if desired. Placing limitations on the investigations can also be agreed to as a class.

Safety Considerations: Foster and support a safe science classroom. While investigating students should follow all classroom safety routines. Review safe use of tools and measurement devices as needed. Augment your own safety procedures with NSTA's Safety Portal.

Investigate

Determine the appropriate level of guidance you need to offer based on students' knowledge, creativity, ability levels, and available materials. Provide the rubric to students and review how it will be used to assess their investigations.

Guide the class as a whole to develop two to three criteria for their investigation at the outset. You or your students might also identify two to three constraints. One major constraint in any design investigation is time. Give students a clear understanding of how much time they will have to devise their plan, conduct their tests, and redesign.

Present/Compare/Revise

After teams demonstrate and communicate evidence-based information to the class about their findings and reflect on the findings of other groups, allow teams to make use of what they have learned during a brief redesign process. Encourage students to identify limitations of their investigative design and testing process. Students should also consider if there were variables that they did not identify earlier that had an impact on their results. It is also beneficial to discuss any unexpected results. Students should quickly make needed revisions to better meet the original criteria, or you might make suggestions to increase the difficulty of the challenge.

Pushing the Envelope

Engineers and aeronautical designers were intensely motivated by the devastating, ongoing impact of World War II. Most of the aircraft underwent iterative design improvements, resulting in different versions that had different capabilities.

Whether or not the B-17 was actually a Flying Fortress has been disputed for over 70 years. On many missions, one sixth of the bombers did not make it back. Students might explore features of today's aircraft that make them more likely to return safely from missions.

Time varies with students

Build Science Literacy THROUGH READING AND WRITING

Integrate English language arts standards for college and career readiness to help students become proficient in accessing complex informational text.

INTEGRATE INFORMATIONAL TEXT WITH VIDEO

Use the video to set the context for reading and writing. Then, provide students access to scientific and historical texts such as these:

- Ball turret, by Lester Schrenk
- How to become a ball turret gunner
- Sperry retractable ball turret
- Diary of a B-17 ball turret gunner

You can also find interviews with many WWII veterans online at Flying Heritage Collection. Encourage students to use search words to find the key ideas they are looking for or specific veterans who talk about those ideas. If students would benefit from a hard copy of the transcript or portions of it, triple-click on the transcript to copy-and-paste.

WRITE You might give students a writing assignment that allows them to integrate the text(s) and video as they write about an aspect of all the information they will examine. Students should cite specific support for their analysis of the science and use precise details and illustrations in their explanations and descriptions. Examples of writing prompts that integrate the video content with the text resources cited above include the following:

- Students might identify how they would design and implement a ball turret simulator using current technology.
- Students could analyze data to make and support a claim as to the need for a manned ball turret.
- Students might write a narrative piece in which they describe what a mission is like as a ball turret gunner. Their stories should include authentic design and technical information.
- Students might write creatively about the feelings that the gunner experiences.

READ Any good piece of writing must be carefully planned. Its internal segments must work together to produce meaning. According to Tim Shanahan, former Director of Reading for Chicago Public Schools, students must do "an intensive analysis of a text in order to come to terms with what it says, how it says it, and what it means."

Encourage close reading using strategies such as the following to help students identify the information they will use to develop a selected topic. For background on close reading, see the ASCD resource Closing in on Close Reading. As with any Close Reading Strategy, the strategies will be more helpful if students read the text more than once.

Reading Questions. Give students the following questions. **1.** Did some ball turret gunners keep track of their odds of survival? **2.** What design features of the ball turret made it effective? **3.** What were the biggest challenges to mission completion? **4.** What aspects of actual ball turret operation must be replicated in a ball turret simulator? **5.** How was the ball turret operated? **6.** How was gunnery effectiveness influence by training? As they read, students write the numbers above portions of the text that will help them to answer the questions.

HIPPO Document Analysis After reading text students are accountable for:

- ***H***istorical Context – Think about social, economic, and political happenings in the United States when the text was written. How does that help you to better understand the document?
- ***I***ntended Audience – Think about the person or group the author tried to influence or inform. How does this impact the way in which the message is presented?
- ***P***urpose – Why was the text created and what was its intended use?
- ***P***oint of View – Think about the author. How does the author's background and political position impact the perspective of the writing?
- ***O***utside Information – Think about any specific historical information that could be connected to the text. How does this information aid understanding of the text?

Summary Activity

Increase retention of information with a brief, focused wrap-up.

Remind students that the vocabulary specific to a given topic is a key aspect of comprehension. Have students identify five to seven vocabulary words tied to this topic. They should then write a few meaningful sentences that summarize their learning and incorporate these words.

NATIONAL STANDARDS CONNECTIONS

Next Generation Science Standards

Visit the online references to review the supportive Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts for these connected Performance Expectations.

MS-PS2 Motion and Stability: Forces and Interactions

MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

MS-PS2-4. Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects.

MS-PS3 Energy

MS-PS3-1. Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.

MS-PS3-5. Construct, use, and present arguments to support the claim that when the motion energy of an object changes, energy is transferred to or from the object.

MS-ETS1 Engineering Design

MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

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

MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Common Core State Standards for ELA & Literacy in Science and Technical Subjects

Visit the online references to find out more about how to support science literacy during science instruction.

College and Career Readiness Anchor Standards for Reading

1. Read closely to determine what the text says explicitly and to make logical inferences from it; cite specific textual evidence when writing or speaking to support conclusions drawn from the text.
6. Assess how point of view or purpose shapes the content and style of a text.
7. Integrate and evaluate content presented in diverse formats and media, including visually and quantitatively, as well as in words.
8. Delineate and evaluate the argument and specific claims in a text, including the validity of the reasoning as well as the relevance and sufficiency of the evidence.

College and Career Readiness Anchor Standards for Writing

1. Write arguments to support claims in an analysis of substantive topics or texts using valid reasoning and relevant and sufficient evidence.
2. Write informative/explanatory texts to examine and convey complex ideas and information clearly and accurately through the effective selection, organization, and analysis of content.
7. Conduct short as well as more sustained research projects based on focused questions, demonstrating understanding of the subject under investigation.
8. Gather relevant information from multiple print and digital sources, assess the credibility and accuracy of each source, and integrate the information while avoiding plagiarism.
9. Draw evidence from literary or informational texts to support analysis, reflection, and research.

ASSESSMENT RUBRIC FOR INQUIRY INVESTIGATION

Criteria	1 point	2 points	3 points
Initial problem	Problem had only one solution, was off topic, or was not researchable or testable.	Problem was researchable or testable but too broad or not answerable by the chosen investigation.	Problem was clearly stated, was researchable or testable, and was directly related to the investigation.
Investigation design	The design did not support a response to the initial question or provide a solution to the problem.	While the design supported the initial problem, the procedure used to collect data (e.g., number of trials, or control of variables) was insufficient.	Variables were clearly identified and controlled as needed with steps and trials that resulted in data that could be used to answer the question or solve the problem.
Variables (if applicable)	Either the dependent or independent variable was not identified.	While the dependent and independent variables were identified, no controls were present.	Variables were identified and controlled in a way that resulting data could be analyzed and compared.
Safety procedures	Basic laboratory safety procedures were followed, but practices specific to the activity were not identified.	Basic laboratory safety procedures were followed but only some safety practices needed for this investigation were followed.	Appropriate safety procedures and equipment were used and safe practices adhered to.
Data and analysis (based on iterations)	Observations were not made or recorded, and data are unreasonable in nature, or do not reflect what actually took place during the investigation.	Observations were made but lack detail, or data appear invalid or were not recorded appropriately.	Detailed observations were made and data are plausible and recorded appropriately.
Claim	No claim was made or the claim had no relationship to the evidence used to support it.	Claim was related to evidence from investigation.	Claim was backed by investigative or research evidence.
Findings comparison	Comparison of findings was limited to a description of the initial problem.	Comparison of findings was not supported by the data collected.	Comparison of findings included both group data and data collected by another resource.
Reflection	Student reflection was limited to a description of the procedure used.	Student reflections were related to the initial problem.	Student reflections described at least one impact on thinking.