CHRONICLES OF COURAGE
Stories of WARTIME AND INNOVATION

"The Torpedo Bomber"

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

"The way I trained in the TBM [Avenger torpedo bomber] at Fort Lauderdale was to climb in and put the throttle forward and take off. There were no special simulators for the TBM." — George H. W. Bush, Pilot, U.S. Navy, LTJG

Table of Contents

Click the section title to jump to it. Click any blue or purple head to return:

Video Preview

"The Torpedo Bomber" is one of 20 short videos in the series *Chronicles of Courage: Stories of Wartime and Innovation.* In October of 1944, during World War II, the United States Navy patrolled the dangerous Philippine island waters in the Pacific Ocean to support the Allied troops and intercept the Imperial Japanese Navy. They encountered one of the largest warships ever put to sea—the Japanese super-battleship *Musashi*. To carry out an attack, the U.S. relied on the Grumman TBF/TBM Avenger—a rugged 3-seat torpedo bomber with a powerful engine and a deadly 2,200-pound torpedo.

Time	Video Content
0:00–0:16	Series opening
0:17–1:11	Fighting the Japanese in the Pacific
1:12–1:37	The Grumman TBF/TBM Avenger Torpedo Bomber
1:38–2:35	Attacking a super-battleship
2:36–3:46	The torpedo as a weapon
3:47–4:20	Will Japan sink?
4:21–5:10	The end is in sight
5:11–5:25	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 are presented by experts who preserve classic aircraft technology.

- **Bernard St. John, pilot, U. S. Navy.** In the wake of the Japanese attack on Pearl Harbor, St. John decided to become a naval aviator. He trained as a civilian pilot at the start of the war and completed his training after joining the navy. He was awarded the Navy Cross by President Truman for scoring a direct torpedo hit on a Japanese cruiser that caused it to sink.
- **Gregory G. Fletcher, author and former naval aviator.** Fletcher is a former naval aviator and now a practicing attorney. He attended the University of Colorado at Boulder, Class of 1969, and received his navy Wings of Gold in 1971. He obtained his law degree from the University of Tennessee at Knoxville in 1977. He is the author of *Intrepid Aviators: The True Story of* USS Intrepid*'s Torpedo Squadron 18 and Its Epic Clash with the Superbattleship* Musashi*.* He is the son of Ensign Willard M. Fletcher, one of the principal characters in the book, and a long-time student of the carrier war in the Pacific. He continues to fly.

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

Connect the Video to Science and Engineering Design

Hitting a moving warship with an aerial-launched torpedo offers an interesting math problem. Avengers dropped torpedoes when flying less than 150 miles per hour. The angle at which the drop was made had to be closely controlled. When attacking a moving naval vessel, the torpedo's speed and course had to allow it to intersect with the moving ship. Torpedo bomber tactics also attempted to address the fact that the targeted naval vessel might alter its course to avoid the torpedo once the torpedo was in the water.

The physics of torpedoes revolves around the fact that water does not compress or absorb pressure. The pressure wave of an explosion in water travels faster and covers a greater distance. Unable to sustain tension, an underwater explosion causes the water to cavitate (create a water free zone), forming a hammer effect and secondary shockwave when it closes, and places additional stress on the target. The gases produced in the exothermic explosion make a series of bubbles that can cause additional damage. Depending of the depth of the water below the target ship, shock wave refraction may result in additional damage.

Grumman's TBF/TBM Avenger entered service in 1942 and first fought at the Battle of Midway only six months after the Japanese surprise attack on Pearl Harbor. During this debut effort, five of the six Avengers that engaged the enemy were shot down without damaging any enemy naval vessels. During the remainder of the war, the Avenger served well and was acknowledged to be an outstanding torpedo bomber even though only 40% of Avenger attacks on ships resulted in hits.

The Avenger was designed to replace the Douglas TBD Devastator—an older torpedo bomber first introduced in 1937. The Avenger offered several innovations:

- wings that folded flat against its fuselage requiring minimum storage space
- extreme ruggedness that could absorb a great deal of battle damage and remain airworthy
- large wings that made it easy to fly and handle
- internal munitions bay for one torpedo or four 500-pound bombs
- positions for three crew members—a pilot, gunner, and radioman/bombardier

Students might use the information in the table to compare the Avenger with its Japanese opponent.

Specifications

	Grumman TBF Avenger	**Nakajima B6N "Jill"**
Empty Weight (lb)	10,545	6,636
Loaded Weight (lb)	17,893	11,460
Length (ft)	40	36
Wing Span (ft)	54	49
Maximum Speed (mph)	275	299
Power-to-weight ratio (hp/lb)	.11	.28
Wing loading (lb/ft^2)	36.5	16.6
Rate of climb (ft/min)	2,1060	1,640

Additional Aeronautical Background

- The rate of positive altitude change over time is known as rate of climb.
- Wing loading reflects the weight of the aircraft divided by the area of its wing. An aircraft with higher wing loading is less maneuverable and has a higher takeoff and landing speed.
- Dividing the aircraft's engine power output by the weight of the aircraft gives its power-to-weight ratio. This ratio indicates how efficient an aircraft is at producing lift, with a higher ratio producing more lift. It also can be used to predict aircraft performance.
- Maximum speed influences the rate at which an aircraft dives.

All of this information has to be taken into account when tactics are employed by the pilot of a particular aircraft.

Related Concepts

- self-propelled
- propulsion system
- drag
- guidance system
- weight
- explosive warhead
- launch angle
- preset depth
- wake
- depth-keeping mechanism
- release point
- speed
- speed and altitude restrictions
- control surfaces

Explore the Video

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

Time	Video Content	Bell Ringers
0:017–1:11	Patrolling the Pacific	The Pacific Ocean covers 62,460,000 square miles. Students might discuss the variables involved in spotting a ship or even several ships in this vast area. They should focus on distances involved, speeds of surface ships and aircraft and realities presented by Earth's shape.
1:12–1:37	Introduction to the Grumman TBF/TBM Avenger	Students might list bulleted points that identify the benefits presented by each of the design features of the Avenger mentioned in this portion of the video.
1:38–2:35	Attack on the Japanese battleship *Musashi*	The *Musashi* was 800 feet long with more than 120 feet of width at its beam. Its loaded weight was more than 161,000,000 pounds. Each Avenger carried a single Mark 13 torpedo that was just more than 13 feet long with a weight of 2,216 pounds. Have students work with this data to make it easily understandable. Their efforts might be in the form of an illustration or a data table.
2:36–3:46	How an aerial-launched torpedo functions	Students might explain why they think torpedoes are designed to explode below the waterline of a ship that is being attacked.
3:47–4:20	Successful attack	Students might, based on what they know about buoyancy and volume, attempt to explain why it is so difficult to sink a large ship.
4:21–5:10	Helping end a brutal war	Students might discuss how science and engineering innovations presented in this video helped to bring a brutal war to a conclusion.

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:
   - *It is difficult to find a ship or group of ships in the Pacific Ocean because….*
   - *It is easier to spot objects on Earth from an aircraft because….*
   - *Possible ways to destroy a surface warship include….*
   - *Variables involved in successfully dropping an aerial torpedo include….*
   - *Advantages of larger battleships include….*
   - *Torpedoes are designed to detonate below the waterline because….*
2. Show the video and allow students to discuss their observations and questions. The video presents the largest single-engine aircraft of WWII. The Grumman TBF/TBM Avenger has actually been described as portly. Its ample fuselage had room, internally, for a 2,216 pound torpedo and three crewmen. While not mentioned in the video, its internal weapons bay was designed specifically to improve the aircraft's aerodynamics. Nicknames for the aircraft included *turkey* and *pregnant beast*. Pilots have related that it flew like a truck.
3. Explore understanding with the following prompts:
   - *Design features that would allow a torpedo bomber to successfully complete its missions include….*
   - *Knowledge that torpedo bomber pilots must have in order to successfully drop an aerial-launched torpedo include….*
   - *The launch angle of an aerial torpedo is critical because….*
   - *Drawbacks of dropping an aerial torpedo include….*
   - *Building a single-engine aircraft with a large fuselage is an advantage because….*
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 that describes the features of the Grumman TBF/TBM Avenger torpedo bomber (1:12–1:37) as a way to spark ideas or direct student thinking along the following lines.

- Students might develop a strategy that allows an Avenger-launched torpedo traveling at 76 feet per second through water to hit a naval vessel traveling at 50 feet per second. Students might offer scenarios for one, two, or three attacking Avengers.
- The American Mark 13 aerial torpedo was unreliable. It actually had a 70% failure rate when dropped from an aircraft flying faster than 170 miles per hour. However, flying slower than 170 mph made the torpedo bombers easy targets for heavily defended naval vessels. Teams of students might identify engineering ideas/suggestions that would allow the torpedo to be successfully dropped from an aircraft traveling at a

higher speed. (Students might start with a simulated torpedo that is dropped from a given height without incurring damage. Both American and Japanese navies accomplished this with a wooden nose covering and tail rings that sheared off when the torpedo impacted the water).

- The Grumman TBF/TBM Avenger lived up to its nickname: *pregnant beast*. Students might design and fly a paper aircraft in which they vary the width of its fuselage to observe the impact on its flight characteristics.
- Students might explore how an underwater explosion causes the water to cavitate (create a water free zone), forming a hammer effect. For example, they might puncture an air-filled balloon underwater, filming it in slow motion with a cell phone camera, or use other materials to design an activity that will allow them to safely explore and explain the cavitation phenomenon.

Ask groups to choose their challenge and rephrase it in a way that can be explored through elaborations on a classic paper airplane or through research or other investigative methods.

Investigate, Compare, and Revise

Remind students that their 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
- sticky notes
- glue
- measuring tape
- ruler
- protractor
- balloons
- classroom stapler
- air cushion protective packaging
- calculator
- cell phone camera
- electric plane launcher (optional)

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.

Consider having students record their initial observations and thoughts in their science notebooks. Encourage them to write down questions, ideas, and terms that come to mind and make simple sketches. This will lead to ideas for exploration.

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 found at the end of this lesson plan to students prior to the activity and review how it will be used to assess their investigations.

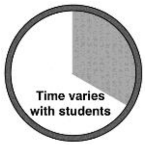
Guide the class as a whole to develop two or three criteria for their investigation at the outset. You or your students might also identify two or three constraints. One major constraint in any design investigation is time. Give students a clear understanding of how much time they will have to devise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

Innovations in technology and strategies can make a weapon system more efficient and effective or obsolete. Have students research the state of aerial torpedoing today and report on what they learn.



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 or historical texts such as these.

- TBF/TBM Avenger
- The Grumman TBF Avenger
- Loyce Edward Deen, Avenger gunner
- Lieutenant Junior Grade Ben St. John
- Eastern TBM-3 Avenger
- Nakajima B6N (Jill)
- Aerial torpedo
- Torpedo Attacks

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 students 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:

- During WWII U.S. torpedo bombers carried out almost 1,300 attacks on ships. Their efforts scored hits only 40% of the time. Students might examine the science and math behind the task of hitting a moving target with an aerial-launched torpedo to explain such poor results.
- The TBF Avenger was the heaviest single-engine aircraft of WWII. Its weight meant it was very rugged with space for a crew of three. Students might write to explain (with illustrations) the design features of the Avenger that made it a successful aerial torpedo bomber.
- Students might compare the data of the TBF/TBM Avenger with the Nakajima B6N "Jill" (see the table) to explain why the nature of the aerial torpedo bomber's task places constraints on the aircraft's capabilities.
- Students might write a newspaper article that explains why no battleships exist in today's Navy and why they were replaced with carriers.

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, these strategies will be more helpful if students read the text more than once.

Make Predictions. As students read the source materials, guide them to identify the main idea of each paragraph, chunk, or section. They then can use the margins to record a prediction for what will come in the next paragraph, chunk, or section. When rereading each source material, students might place a check beside predictions that are correct.

HIPPO. After reading a text students are accountable for:

- **H**istorical Context – How does what was happening when the text was written help you to better understand the document?
- **I**ntended Audience – Learn the person or group the author attempted to influence or inform. How does this effort change the manner in which the message is presented?
- **P**oint of View – How does the race, gender, and socioeconomic class of the author impact the perspective of the writing?
- **P**urpose – Why was the text created and what was its intended use?
- **O**utside Information – What specific historical information not included in the document can be connected to it? How does this information aid in comprehension of the document?

Summary Activity

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

Give students an index card. On one side have them write three things that they learned during the lesson. On the reverse side they could identify two things they still have questions about and one thing about the lesson that they want you to know.

NATIONAL STANDARDS CONNECTIONS

Next Generation Science Standards

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

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.