“Build it strong, keep it simple, and make it work.”
—Leroy Grumman, Aeronautical Engineer

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Video Preview
"F6F Hellcat," is one of 20 short films in the series Chronicles of Courage: Stories of Wartime and Innovation. After years of destructive fighting in World War II, the U.S. Navy’s Fast Carrier Task Force is determined to defeat the Japanese military. Their fiercest weapon is the F6F Hellcat—an airplane designed with a unique folding wing called a STO-wing, allowing more planes to fit on an aircraft carrier and providing the U.S. with a stronger defense.

<table>
<thead>
<tr>
<th>Time</th>
<th>Video Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00–00:16</td>
<td>Series opening</td>
</tr>
<tr>
<td>00:17–00:43</td>
<td>By early 1944 the U.S. Navy begins to take on the Japanese in Japan’s own waters</td>
</tr>
<tr>
<td>00:44–02:08</td>
<td>The strategy behind the Fast Carrier Task Force</td>
</tr>
<tr>
<td>02:09–02:03</td>
<td>The weaknesses of the F4F Wildcat versus the Mitsubishi A6M Zero</td>
</tr>
<tr>
<td>02:04 –03:09</td>
<td>Introduction to the Grumman F6F Hellcat, a very capable naval fighter aircraft</td>
</tr>
<tr>
<td>03:10–04:58</td>
<td>The benefits of having folding wings</td>
</tr>
<tr>
<td>04:59–05:29</td>
<td>Hellcat, the Navy’s number one fighter</td>
</tr>
</tbody>
</table>
**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.

- **Robert Turnell, U.S. Navy fighter pilot.** Turnell served in Fighter Squadron VF-81 from March 1, 1944 until the end of WWII. He flew an F6F Hellcat and was wingman to the second section leader, Minos Miller. Turnell kept a diary of the VF-81 pilots that were missing or killed in action. He retired from the Navy with the rank of commander.

- **Dr. Rebecca Grant, President and CEO of IRIS Independent Research.** Dr. Grant earned her Ph.D. in International Relations from the London School of Economics. Through IRIS, she works on strategic planning for aerospace and government clients. She writes regularly for *Air Force Magazine* and has appeared on The Military Channel.

Find extensive interviews with Turnell and other WWII veterans online at [Flying Heritage Collection](https://www.flyingheritagecollection.org).

**Connect the Video to Science and Engineering Design**

During World War II, the Fast Carrier Task Forces were the main striking force against the Japanese military. The carriers could only be successful in this task if their fighter planes were able to control the skies over the carriers to keep the ships safe from Japanese attacks—most carried out by the light-weight Mitsubishi A6M Zero. See the comparison below.

### Specifications

<table>
<thead>
<tr>
<th></th>
<th>Grumman F6F Hellcat</th>
<th>Mitsubishi A6M Zero</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty Weight (lb)</td>
<td>9,238</td>
<td>3,704</td>
</tr>
<tr>
<td>Loaded Weight (lb)</td>
<td>12,598</td>
<td>5,313</td>
</tr>
<tr>
<td>Length (ft)</td>
<td>33</td>
<td>30</td>
</tr>
<tr>
<td>Wing Span (ft)</td>
<td>43</td>
<td>39</td>
</tr>
<tr>
<td>Maximum Speed (mph)</td>
<td>380</td>
<td>331</td>
</tr>
<tr>
<td>Power-to-weight ratio (hp/lb)</td>
<td>.16</td>
<td>.18</td>
</tr>
<tr>
<td>Wing Area (ft²)</td>
<td>334</td>
<td>242</td>
</tr>
<tr>
<td>Wing loading (lb/ft²)</td>
<td>37.7</td>
<td>22</td>
</tr>
<tr>
<td>Rate of climb (ft/min)</td>
<td>3,500</td>
<td>3,900</td>
</tr>
</tbody>
</table>

The Hellcat and the Zero faced each other from early 1943 until the end of World War II. Although the two aircraft are about the same size, their specifications are very different. In aeronautics 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. Power-to-weight ratio is determined by dividing the engine’s power output by the weight of the aircraft. 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 selected for a particular aircraft.

Related Concepts
- lift
- drag
- thrust
- weight
- maneuverability
- dive
- climb
- roll
- pitch
- yaw
- elevator
- rudder
- aircraft shape
- control surfaces
- ailerons
- flap
- camber

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.

<table>
<thead>
<tr>
<th>Time</th>
<th>Video content</th>
<th>Bell Ringers</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:17–00:43</td>
<td>Battle status early 1944</td>
<td>Think-Pair-Share teams can discuss the preparations that would have to occur for the Navy to be “on the move” against its enemy.</td>
</tr>
<tr>
<td>00:44–02:08</td>
<td>Introduction to the Fast Carrier Task Force</td>
<td>Students might compare and contrast combat between aircraft carriers and combat between battle ships. A simple graphic organizer such as a student-generated Venn diagram would help to focus their efforts.</td>
</tr>
<tr>
<td>02:09–02:03</td>
<td>The weaknesses of the F4F Wildcat</td>
<td>Have students evaluate the scientific and engineering aspects of manual controls that require the pilot to be an athlete. Students might also discuss why a fighter plane with heavy controls is an oxymoron.</td>
</tr>
<tr>
<td>02:04–03:09</td>
<td>The F6F Hellcat—designed to beat the Zero</td>
<td>Students could identify why powered landing gear is a mechanical advantage to a naval pilot.</td>
</tr>
<tr>
<td>03:10–04:58</td>
<td>Grumman’s STO-wing technology is carried over from the</td>
<td>Students might create a series of cartoon cells that depict how the STO-wing operates. Encourage students to think of other examples of bio-inspired engineering they have encountered or design solutions that look like something they’ve seen in nature.</td>
</tr>
</tbody>
</table>
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:
   - One way to deal with limited hangar space on an aircraft carrier is....
   - Maximizing the number of aircraft able to be transported in an aircraft carrier ...
   - A naval aircraft with a folding wing....
   - The wing area of an airplane determines....
   - Bio-inspired engineering design could be described as....

2. Show the video and allow students to discuss their observations and questions. The video presents the extensive technological and mechanical improvements that made the best U.S. Navy fighter plane. Particular attention is given to the STO-wings, which is a folding mechanism that reduces its wingspan from 42’10” to 16’2”. This mechanism allows the aircraft carrier to carry many more aircraft than it could have otherwise. Because aircraft are the carrier’s main offensive weapons, this is a powerful technology. 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:
   - Engineering weaknesses of the F4F Wildcat include....
   - The Wildcat had to be replaced because....
   - The inspiration for the STO-wing was the ___, which resulted in a design solution for....
   - The STO-wing, which was first implemented in the Wildcat, was kept in the Hellcat because....
   - The Hellcat was more equipped to dogfight a Zero 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 video segment 03:10–04:58 about the STO-wing as a way to spark ideas or direct student thinking along the following lines.
- Students (given the size of the Hellcat with its wings folded—42’10” x 16’2”—and the dimensions of an aircraft carrier’s hangar deck—47’ x 546’) might recommend a plan to stow the maximum number of aircraft in the school’s gym or on the football field.
• Students could construct a model that demonstrates the STO-wing, or an alternative method, that would reduce an aircraft’s wing span to maximize the number of aircraft that can be stored in a given space.

• Students might research other examples of bio-inspired design solutions associated with aircraft or items with which they are more familiar. Students could extend this into a design investigation by identifying a feature of a plant or animal and reflecting it in a design solution to a problem.

• The Hellcat and Zero wings have a difference in area of 92 ft\(^2\). Students might explore how wing area is connected to flight characteristics. (Lift is directly related to surface area.)

An example of a possible design that can explore the connection between wing area and lift might look like this:

![Image of paper airplanes demonstrating wing area and lift](image)

Ask groups to choose their challenge and rephrase it in a way that it can be explored through elaborations on the classic paper airplane or modeling with mathematics or physical materials.

If students choose to explore navigation with paper airplanes and need more support, they might use one of these resources.

• [Paper airplanes](#)
• [10 of the best paper plane designs](#)
• [Secret paper aeroplanes](#)
• [Paper airplane aerodynamics](#)
• [Launchable drinking straw planes](#)
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
- sticky notes
- glue
- measuring tape
- ruler
- protractor
- Teacher Geek™ or other connector materials
- 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.

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.

Elicit from students the features of the Hellcat that suited its use in the mission presented in F6F Hellcat. Have students conduct research and report on how modern aircraft or aircraft carriers are designed to deal with this same issue. Students might examine the folding wings of today’s naval aircraft or how landing gear deal with the much heavier aircraft in the current inventory.

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. Then, provide students access to scientific and historical texts such as these:

- Zero vs. Hellcat
- 22 facts about the Grumman F6F Hellcat – the "Wildcat's big brother"
- Wing-folding mechanism of the Grumman Wildcat

You can also find interviews with many WWII veterans familiar with the Hellcat and the Wildcat 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 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:
• Leroy Grumman, of the Grumman Aircraft Engineering Corporation, built aircraft based on the credo quoted at the beginning of this lesson plan. After examining the video and readings, students might explain how the F6F Hellcat reflects Grumman’s doctrine.
• Make and support a claim about the impact of the STO-wing.
• Compare and contrast aeronautical aspects of the Hellcat and Zero fighters.

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.

Chunk the source materials. Break long reading passages into manageable chunks. Students might divide groups of related paragraphs by drawing a horizontal line between them. Students might write in the margin to the left of each chunk what its purpose is and why paragraphs are grouped together.

Close Reading and Art. Students read the text closely and markup the text as instructed. Their focus should be to generate six story board panels worth of illustrations that represent the main points of the texts. They might do this on a piece of paper that is folded into thirds. Under each drawing, students write evidence from the text to support each image.

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

Advise students that words are priced at five cents each. Have students write a summary of the lesson that is worth two dollars. The summaries should include words that are specific to the lesson.
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.
<table>
<thead>
<tr>
<th>Criteria</th>
<th>1 point</th>
<th>2 points</th>
<th>3 points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial problem</td>
<td>Problem had only one solution, was off topic, or was not reseachable or testable.</td>
<td>Problem was reseachable or testable but too broad or not answerable by the chosen investigation.</td>
<td>Problem was clearly stated, was reseachable or testable, and was directly related to the investigation.</td>
</tr>
<tr>
<td>Investigation design</td>
<td>The design did not support a response to the initial question or provide a solution to the problem.</td>
<td>While the design supported the initial problem, the procedure used to collect data (e.g., number of trials, or control of variables) was insufficient.</td>
<td>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.</td>
</tr>
<tr>
<td>Variables (if applicable)</td>
<td>Neither the dependent nor independent variable was not identified.</td>
<td>While the dependent and independent variables were identified, no controls were present.</td>
<td>Variables were identified and controlled in a way that resulting data could be analyzed and compared.</td>
</tr>
<tr>
<td>Safety procedures</td>
<td>Basic laboratory safety procedures were followed, but practices specific to the activity were not identified.</td>
<td>Basic laboratory safety procedures were followed but only some safety practices needed for this investigation were followed.</td>
<td>Appropriate safety procedures and equipment were used and safe practices adhered to.</td>
</tr>
<tr>
<td>Data and analysis (based on iterations)</td>
<td>Observations were not made or recorded, and data are unreasonable in nature, or do not reflect what actually took place during the investigation.</td>
<td>Observations were made but lack detail, or data appear invalid or were not recorded appropriately.</td>
<td>Detailed observations were made and data are plausible and recorded appropriately.</td>
</tr>
<tr>
<td>Claim</td>
<td>No claim was made or the claim had no relationship to the evidence used to support it.</td>
<td>Claim was related to evidence from investigation.</td>
<td>Claim was backed by investigative or research evidence.</td>
</tr>
<tr>
<td>Findings comparison</td>
<td>Comparison of findings was limited to a description of the initial problem.</td>
<td>Comparison of findings was not supported by the data collected.</td>
<td>Comparison of findings included both group data and data collected by another resource.</td>
</tr>
<tr>
<td>Reflection</td>
<td>Student reflection was limited to a description of the procedure used.</td>
<td>Student reflections were related to the initial problem.</td>
<td>Student reflections described at least one impact on thinking.</td>
</tr>
</tbody>
</table>