G-Forces in Fighter Planes

Companion Lesson Plan to X-STEM All Access Episode “Flying the F-35”

Grade/ Grade Band: High School	**Topic:** Physics	
Brief Lesson Description: Students use F=MA to calculate the acceleration for various planes and maneuvers.		
Performance Expectation(s): HS-PS2-1: Analyze data to support the claim that Newton’s Second Law of Motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.		
Specific Learning Outcomes: Students can describe experiences with a G-force from their own lives and from selected videos. Students can analyze and interpret data to determine patterns in G-Force data for a variety of aircraft and maneuvers Students can use Newton’s second law (F=ma) to calculate the acceleration for a variety of aircraft and maneuvers Students can obtain and evaluate information in order to use F=ma to predict the forces of loaded aircraft versus unloaded aircraft.		
Narrative / Background Information		
Prior Student Knowledge: This lesson assumes that students have experience analyzing data mathematically by using data tables and or graphs. Additionally, it assumes that students have an understanding of what the terms force, mass, and acceleration mean.		
Science & Engineering Practices: **Analyzing and Interpreting Data** Analyzing data in 9-12 builds on K-8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. ● Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal solution. (ETS ***Connections to Nature of Science*** **Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** ● Theories and laws provide explanations in science ● Laws are statements or descriptions of the relationships among observable phenomena.	**Disciplinary Core Ideas:** **PS2.A: Forces and Motion** ● Newton’s second law accurately predicts changes in the motion of macroscopic objects	**Crosscutting Concepts:** **Cause and Effect:** ● Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.
Possible Preconceptions/Misconceptions: Common misconceptions for Newton’s Second Law include: **-**Objects at rest do not have forces acting upon them instead of having a net force of zero. -Weight is the same as mass rather than being a force that is caused by mass. -Acceleration moves forward and deceleration slows down.		

LESSON PLAN – 5-E Model

ENGAGE: Opening Activity – Access Prior Learning / Stimulate Interest / Generate Questions:

Begin the lesson by showing students the X-STEM Video "Flying the F-35" with Capt. Ariel Knepper of the US Air Force. After the video, ask students ***how many of them have experienced the G-Forces that she described and allow them to share their experiences.***

Next, show the F-35 maneuver video (linked here). After the video, discuss with the students that these incredible maneuvers require pilots such as Capt. Knepper to undergo intense training to handle the physical stresses experienced during the flight.

Explain to students that Acceleration is described in units of the force called "Gs." A pilot in a steep turn may experience forces of acceleration equivalent to many times the force of gravity. This is especially true in military fighter jets and high-performance, aerobatic aircraft where the acceleration forces may be as high as 9 Gs.

In order to help students grasp this idea, conduct the following simple demonstration. Swing a bucket filled with water around in a circle and explain how the water remains in the bucket due to the force exerted on it. (Specifically centripetal force.) Relate this to the forces acting on a pilot during aerial maneuvers.

EXPLORE: Lesson Description – Materials Needed / Probing or Clarifying Questions:

Have students divide up into small groups. Provide each group a copy of the G-Force Data. Instruct the students to analyze and/or graph the data provided to answer the following questions:

1) ***How does Mass affect the amount of G-Force experienced by pilots?***
2) ***How does the maneuver affect the amount of G-Force experienced by pilots?***

Provide students ample time to interact with the data and come up with their answer to the question on white boards or chart paper. Finally, have students present their findings to the class and then discuss similarities and differences between various groups' answers. Come to a class consensus about what patterns they have found in the data.

EXPLAIN: Concepts Explained and Vocabulary Defined:

Explain the mathematical relationship among net force, mass, and acceleration as described by Newton's second law of motion

Force = Mass (acceleration)

F=ma

Discuss how the G-force data collected from fighter plane maneuvers align with Newton's second law, reinforcing the importance of understanding the forces experienced during flight.

Next, guide the students in calculating the acceleration experienced by the pilot using Newton's second law:

acceleration = net force / mass

where the net force is equal to the G-Force experienced by the pilot.

Next, have students compare the acceleration values for different maneuvers and compare the numeric values calculated with the patterns observed during the explore portion of the lesson. (Can be used as formative assessment) As a class, construct a graph comparing the G-Force magnitude and the acceleration for each maneuver. Connect back to the mathematical relationship for Newton's second law.

ELABORATE: Applications and Extensions:

Challenge students to research the following question:
"The data provided is for fighter planes that are empty. What mass would need to be used to calculate the G-forces for a fully loaded plane? Assuming that the acceleration is constant when the plane is loaded, predict what would happen to the G-forces for a fully loaded plane. Create a poster that shows your prediction mathematically with clear reasoning."

Students should present their findings to the class. After presentations, discuss similarities and differences between various groups' answers. Come to a class consensus about what patterns they have found in the data. Other possible discussion questions include:

1) ***Is it reasonable to assume similar acceleration? Why or why not?***
2) ***How reliable are your calculations? Support with clear reasoning.***
3) ***There are many limitations on the size of pilots in the military. How might this connect to pilot safety based on your predictions?***
4) ***How might the differences in G-forces impact the engineering design of an airplane? Support based on your predictions.***

EVALUATE:
Formative Monitoring (Questioning / Discussion): Formative assessment questions throughout the lesson are found in ***italics and bold text.***
Summative Assessment (Quiz / Project / Report): The students may complete a data analysis of one (or more) of the aircraft listed on the data table. This data analysis should include calculations for acceleration based on the provided data, an explanation of why the g-force changes by maneuver, and how the forces would be impacted by loading the plan.

Elaborate Further / Reflect: Enrichment:
For each of the maneuvers found in the data table, have students brainstorm and research possible physiological effects on the pilot from the G-Forces. Based upon these effects, have students propose an engineering design for a safety system that could help pilots withstand the maneuver. Groups should sketch or create a visual representation of their design and provide reasoning about how this device will improve the safety of the pilot.

SOCIAL EMOTIONAL LEARNING ACTIVITY

CASEL Competency Addressed:

In the X-STEM Video, Capt. Knepper left us with the advice to never limit yourself. This lesson will help students to consider what self-limiting beliefs are and have students role play with a partner how to flip that belief.

1. Begin by asking students to share their thoughts on limitations. What are limitations? Do they come from the inside or outside? What are some examples of limitations in your lives? Write responses on the board.
2. Discuss the concept of self-limiting beliefs: Beliefs that hinder personal growth and potential. Share relatable examples such as "I'm not good at math, so I'll never be able to understand it."
3. In small groups, have students review the "Common Limiting Beliefs" list. Ask them to share which one they have either experienced themselves or have seen classmates struggle with.
4. Explain to students that in order to overcome self-limiting beliefs, one strategy to use is to "reframe" the thought from negative to positive. This requires someone to change their thinking.
5. Show the video "Your brain is wired for negative thoughts. Here's how to change it."
6. Have students work with a partner. Have each partner pick one of the ""Common Limiting Beliefs" and think of ways that they can "flip" or get "unstuck" on that thought. Have each set of partners share their ideas with the class.

INTERDISCIPLINARY CONNECTIONS/IDEAS

Biology: Students can create a presentation on the Physiological Effects of G-Forces on Pilots based on the information from the FAA (https://www.faa.gov/pilots/safety/pilotsafetybrochures/media/acceleration.pdf)

Computer Science: Students can create computer simulations (such as a G-force calculator) to show how the G-Forces change for pilots based on the maneuver that they are conducting. The calculator can be adjusted for mass of plane, acceleration, and type of plane.

Materials Required for This Lesson/Activity

Quantity	Description
1 per class	Bucket filled with water
1 per student	Copy of G-Force Data
1 per group	Chart Paper with Markers -OR- Whiteboard with Dry Erase Markers

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Lesson Created by Jess Noffsinger
For questions please contact info@usasciencefestival.org