Lesson 4: Fuel Efficiency
Grades 7 - 8

Objective

Graph variations in thrust/drag of F-15 ACTIVE when the tail sections are removed. Use the graph to draw conclusions about fuel efficiency.

Science Standards

Unifying Concepts and Processes
Change, Constancy, and Measurement
Evidence, Models, and Explanation
Science and Technology
Technological Design Abilities

Science Process Skills

Making Graphs
Controlling Variables

Mathematical Standards

Communicating
Reasoning
Computing and Estimating
Statistics

Management

This activity works best with students working individually, but giving assistance to each other. This is also best suited to students who have worked with formulas in the past. Allow 40-45 minutes to complete this activity. This activity is divided into two parts. In part 1 students use the formula for drag to calculate the difference in drag between an F-15 ACTIVE with the tail sections attached to the plane and again with the tail sections removed. In part 2 students will make conclusions about fuel efficiency with tails and without tails based on the graphs they constructed. This activity stresses precise calculations, graphing, analyzing graphical information, and drawing conclusions based on graphical information.

Background Information

One of the benefits of the thrust vectoring concept is the potential financial savings from increased fuel efficiency. Thrust vectoring may allow for the partial or complete removal of the vertical and horizontal tail. Doing this will reduce the weight of the aircraft and also reduce the amount of drag. When drag is reduced, the amount of thrust needed to fly the aircraft is also reduced, which reduces the amount of fuel required. Drag is calculated using the formula:

Drag = K x CD x V2

K = 1.06 (a constant calculated for flight at sea level. This number varies as wing area of the aircraft changes. Actual equation is included at the end for use if desired.)

CD = drag coefficient (assuming 0.02 with tails on, 0.01 without tails)

V = velocity of plane in feet per second

For straight and level flight under ideal conditions, when no wind is present and there is no acceleration or deceleration, thrust is equal to drag.

Description

Students will calculate the thrust/drag created by the F-15 ACTIVE with the vertical tails on and off. They will graph this information in a bar graph and make conclusions about the amount of fuel needed by both variations of the plane. The calculations can be done both at sea level and at 18,000 feet for additional comparisons.

Part 1

Materials and Tools

- Graph paper
- Colored pencils
- Straight edge
- Calculators

Procedures

1. Explain the concepts of thrust and drag to the students. Thrust is what pushes an object forward. Drag is what slows it down or pushes backwards.
2. Ask how thrust and drag have been demonstrated throughout the activities relating to the NASA F-15 ACTIVE project.
3. To this point these concepts have been observed subjectively. Now the students are going to learn how to calculate thrust and drag and make conclusions about fuel efficiency. NOTE: The number used for the drag coefficient is much larger for this activity than it is in actuality. This is so the students can draw conclusions based on the graph. The actual number is 2 percent of what is used here. Scientific calculations must be extremely precise and 2 percent is enough to make a difference to NASA engineers and scientists, it is simply too small for seventh and eighth grade students to notice a real difference. Precision in this activity is being sacrificed in order for the students to grasp more easily the concepts being presented.
4. Explain that in order for a plane to fly at a steady state, the amount of thrust put out by the engines must be equal to the amount of drag created by the plane (thrust=drag). Ask what they believe would happen if the amount of thrust was larger than the amount of drag. Then ask what would happen if the amount of thrust was less than the amount of drag.
5. Put this equation on the chalkboard or overhead:

   Drag = K x CD x V2 where:

   K = 1.06 (a constant calculated for flight at sea level. Actual equation is included at the end.)

   CD = drag coefficient

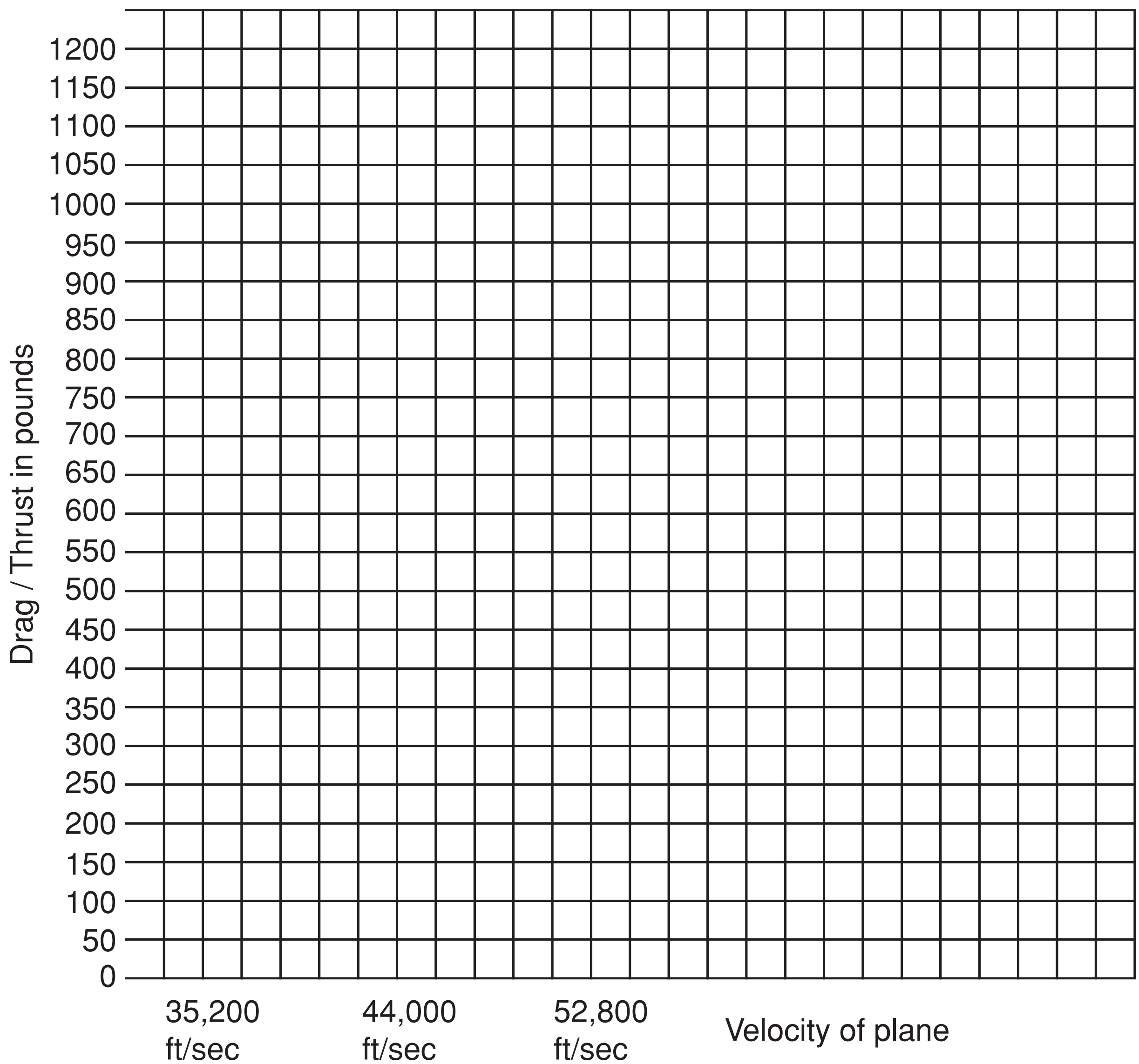
   V = velocity of plane in feet per second

   The drag coefficient of the F-15 ACTIVE is assumed to be 0.02 with tails on and 0.01 without tails. Work several examples with the students at various velocities and changing between the drag coefficient with tails and without tails so they understand the algebra involved.
6. Explain that they will only be focusing on straight and level flight. This means the amount of thrust is equal to the amount of drag. Therefore, the same equation for drag can be used to calculate thrust.
7. Have them calculate the thrust needed for three different velocities (for example: 35,200 ft/sec, 44,000 ft/sec, and 52,800 ft/sec). Make sure they calculate the thrust for both tails on (drag coefficient of 0.02) and tails off (drag coefficient of 0.01). The equation to convert from feet per second to miles per hour, and miles per hour to feet per second, has been included in the extension section.
8. Show them how to set up a set of axes for a bar graph using their straight edge to draw their lines. Vertical (y-axis) is thrust. Horizontal (x-axis) is for the labels for each bar. All three sets of double bar graphs may be done on one set of axes if desired. Indicate two colors for the bars should be used, one for tail on and the other for tails off. Also instruct them on setting the intervals for the vertical axis based on the calculations they made.

9. Draw the bar graphs using the straight edge. Make sure adequate space is allowed between each set of double bars. There should be one pair of bars for each of the different velocities. The students also should include a legend indicating which color was used for which condition.

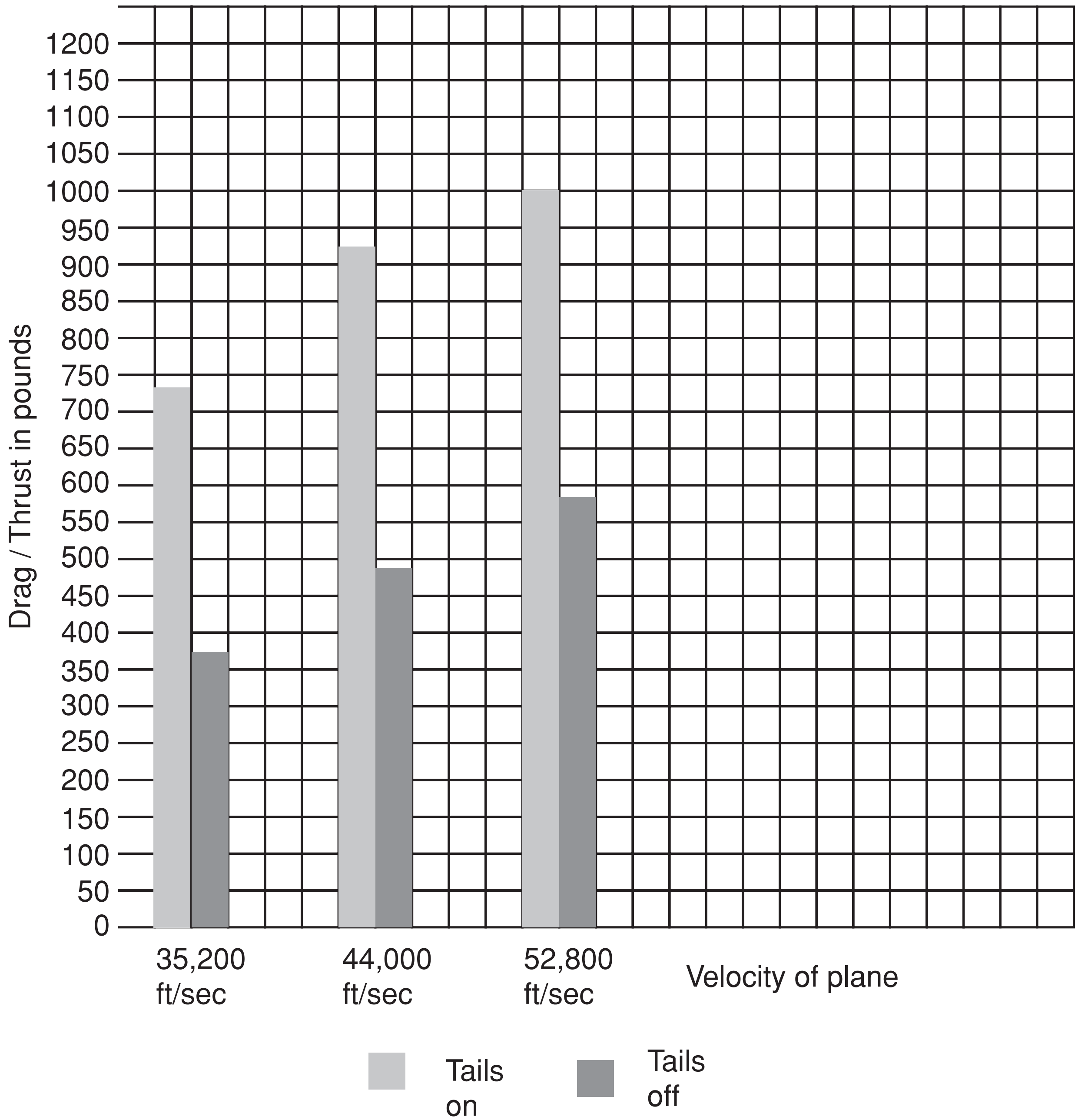
Tail on	Tail off
CD = 0.02	**CD = 0.01**
T1=1.06 x 0.02 x 35,200 = 746.24 lbs	**T1=1.06 x 0.01 x 35,200 = 373.12 lbs**
T2=1.06 x 0.02 x 44,000 = 932.81 lbs	**T2=1.06 x 0.01 x 44,000 = 466.41 lbs**
T3=1.06 x 0.02 x 52,800 = 1119.36 lbs	**T3=1.06 x 0.01 x 52,800 = 559.68 lbs**

Bar Graph



Drag / Thrust in pounds
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
35,200 ft/sec
44,000 ft/sec
52,800 ft/sec
Velocity of plane

Bar Graph Answers



Part 2

Materials and Tools

- Graph from Part 1
- One copy of Student Work Sheet per student (see page 63)

Assessment

Conduct a class discussion where students share their conclusions about thrust vectoring and fuel efficiency. Collect and review students' written conclusions.

Discussion Questions

Have students use their graphs to answer the following questions:

1. Which situation, with tails on or without tails, needs the most thrust?
2. Which situation creates the least amount of drag?
3. How would an increase in the thrust affect the amount of fuel needed?
4. Which situation would be the most fuel efficient? Least fuel efficient?
5. Which situation would need thrust vectoring to ensure controlled flight?
6. What conclusions can be drawn regarding the fuel efficiency of thrust vectoring based on your graph and the answers to the previous questions?

Extensions

1. Convert velocity, "V", from feet per second to miles per hour:

$$V \times \frac{60 \text{ seconds}}{1 \text{ hour}} \times \frac{1 \text{ mile}}{5280 \text{ feet}}$$

2. Convert velocity, "V", from miles per hour to feet per second:

$$V \times \frac{1 \text{ hour}}{60 \text{ seconds}} \times \frac{5280 \text{ feet}}{1 \text{ mile}}$$

Student Work Sheet
Name:_________________________
Date:__________________________

Fuel Efficiency Work Sheet

Use your graph to answer the following questions about the fuel efficiency of thrust vectoring.

1. Which situation, with tail or without tail, requires the most thrust?
____

2. Which situation, with tail or without tail, creates the least amount of drag?
____

3. How would an increase in the thrust affect the amount of fuel needed?
____
____

4. Which situation would be the most fuel efficient? Least fuel efficient?
____
____

5. In which situation, with tail or without tail, would thrust vectoring be used to ensure controlled flight? (Hint: Think back to the experiments done in lesson 4.)
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6. What conclusions can be drawn regarding the fuel efficiency of thrust vectoring based on your graph and the answers to the previous questions?
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