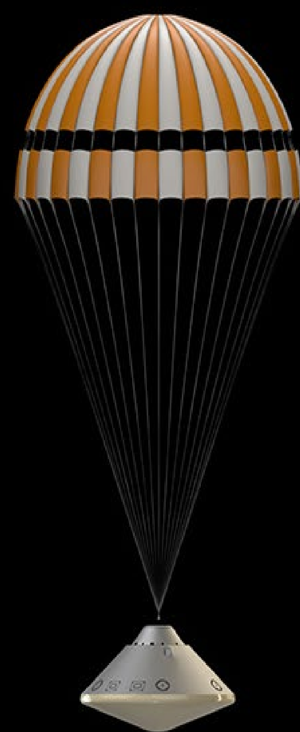
National Aeronautics and Space Administration

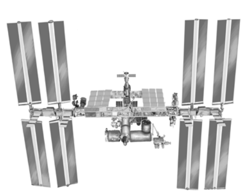
NEXT GEN STEM

COMMERCIAL

CREW



Eggstronaut Parachute Challenge **Educator Guide**



For more about Next Gen STEM visit http://www.nasa.gov/stem/ccp.

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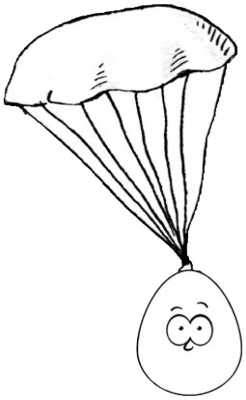

Eggstronaut Parachute Challenge Educator Guide

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Eggstronaut Parachute Challenge Overview

Grade Level: **5th-12th**

Suggested Time: **Three to five 50-min class periods** *(Note: these do not need to be consecutive class days)*

Day 1 – Introduce the Commercial Crew Program, discuss the STEM concepts, and introduce the challenge
Day 2 – Review the Engineering Design Process (EDP) and begin the challenge
Days 3 and 4 – Repeat iterations of the EDP to refine solutions
Day 5 – Wrap-up challenge and final discussion

Challenge Overview: Teams of 3-4 students will design and build parachutes to slow the descent of an egg and minimize the force of impact when landing.

Next Generation Science Standards (NGSS):

MS-ETS1. **Engineering Design**
HS-PS2-3. **Motion and Stability: Forces and Interactions**
MS-PS2-2. **Motion and Stability: Forces**
MS-PS3-5. **Energy**
HS-ETS1. **Engineering Design**
HS-PS3-3. **Energy**

Common Core Standards for Mathematics (CCSS):

5.G.A.2. **Geometry**
6.G.A.1. **Geometry**
7.G.B.6. **Geometry**
8.F.B.5. **Functions**
HSM. **Modeling**
MP4. **Standards for Mathematical Practice**

Objectives:

Following this activity, students will be able to:

- Use the engineering design process to construct, test and analyze a prototype parachute designed to slow the descent of an egg and minimize the force of impact when landing (Grades 5-12)
- Investigate forces on a falling object and the effect of various parachute shapes and sizes on energy of motion (Grades 5-12)
- Apply mathematics to solve real-life problems involving angles, graphing, and area (Grades 5-8)
- Apply mathematics and physics concepts to analyze motion and energy of a falling object and force of impact during a collision (Grades 9-12)

Use plastic eggs during the testing phase of the parachute designs. Each team's Eggstronaut should have the same mass, about 57 grams, equivalent to the mass of a large egg. After a team has demonstrated a parachute design safely lands Eggstronaut for at least three consecutive drops, then they can be certified to test a real egg.

Materials:

For testing phase:

- ☐ plastic eggs (approx. 4 g) weighted to the mass of a real egg (large egg 57 g)
- ☐ coins, washers, sand, or dirt (to add mass to the plastic egg)
- ☐ cotton balls to fill empty space inside the plastic egg
- ☐ parachute material: plastic bags or tablecloth, wrapping or tissue paper
- ☐ tape measure, meter stick, or other device for measuring height and distance (optional: smart phone app, laser distance finder, or use measuring wheel and clinometer to calculate height with right triangle trigonometry)
- ☐ optional: size 61 latex-free rubber bands (easy on/off harness to attach lines)
- ☐ optional: low temperature hot glue gun and glue sticks
- ☐ string
- ☐ scissors
- ☐ digital scale or balance
- ☐ stopwatch
- ☐ tape and/or glue
- ☐ Student Activity Sheets

For safety:

- ☐ safety cones and caution tape or stanchions to cordon off the drop zone
- ☐ small bowl of cold water to dunk your fingers in case you get hot glue on them
- ☐ sanitary gloves when handling raw eggs
- ☐ safety glasses
- ☐ hard hats

For demonstration phase:

- ☐ raw or hardboiled (recommended) egg for final demonstration of parachutes
- ☐ large trash bags or newspaper on the ground for drop zone cleanup

(Optional):

- ☐ smartphone and/or computer for digital video analysis of descent and landing (Examples: Tracker, Logger Pro, Video Physics)
- ☐ force plate to measure force of impact during landing
- ☐ motion sensor and/or wireless accelerometer to collect data for descent/landing
- ☐ grid paper for estimating surface area of parachutes

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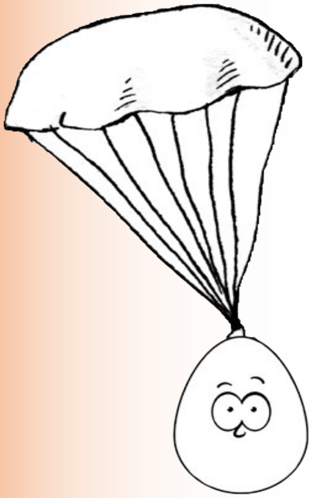


Teacher Preparation

NASA Connection:

NASA's Commercial Crew Program (CCP) was formed to facilitate the development of a U.S. commercial crew space transportation capability with the goal of achieving safe, reliable and cost-effective access to and from the International Space Station and low-Earth orbit. NASA's engineers and aerospace specialists work closely with industry partners Boeing and SpaceX, and the partnership approach allows NASA engineers insight into each company's development process while providing access to the agency's technical expertise and resources. Crew safety is paramount in the return of human spaceflight launches from NASA's Kennedy Space Center, and parachute testing provides valuable data to help each partner meet NASA's requirements for certification and safety. Boeing and SpaceX have rehearsed numerous scenarios in many different conditions including both low and high altitude drop tests (from as high as 50,000 feet), nominal and off-nominal entry, as well as ascent abort including pad abort demonstrations. These critical milestones for commercial crew partners help predict parachute performance and verify reliability which are important for crew safety. Find the CCP Primer for Educators at http://www.nasa.gov/stem/ccp.

The role of the educator (referred to as **Commercial Crew Teacher or CCT** in this activity) is similar to that of NASA's role with the industry partners for Commercial Crew:

- Set expectations and requirements for milestones, and certify performance requirements have been met to allow teams to proceed to the next step.
- Verify that teams are working **safely** and within constraints (time, materials, etc.).
- Provide guidance and oversight throughout the engineering design process as well as access to tools or information that will help teams achieve success.
- Encourage innovation. Ask questions that help teams think critically and openly about their design and the design process. *How would you test that? What does your data tell you about canopy size? What can you change to increase drag?*
- Encourage conjecturing. "I want to see what will happen if…"
- By requiring teams to complete milestones, you will be able to monitor their progress, assess their understanding of the engineering design process, and help them make course corrections as needed. Sign off on the student data sheets where indicated.

Safety and Warnings:

- Fresh eggs, even those with clean, uncracked shells, may contain bacteria called Salmonella that can cause foodborne illness, often called "food poisoning."
- Read all instructions and warnings provided by your glue gun's manufacturer.
- Clear the landing area of people. Supervise students when they are dropping their parachute. Do not allow anyone to attempt to catch a falling parachute.
- It is recommended that eggs are dropped on grass, sand, or dirt surfaces. Dropping plastic eggs on concrete or hard surfaces may result in plastic shattering. Keep students back from landing area to avoid shrapnel. If using coins or washers inside the egg, tape them together with the cotton balls to avoid pieces flying during impact.

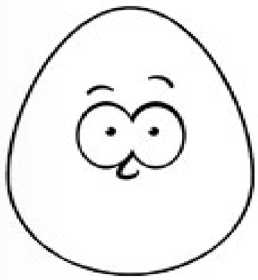
Management:

- Make sure to print student sheets, rubrics, posters, and other resources that could help your challenge be successful. Download all videos so they are ready to go.
- Get permission before dropping objects from second stories.
- Drop Zone Set-up: To get accurate data, drops should be at least 5 meters high, measured from the bottom of the egg to the ground. It is best to have a stairwell overhang or balcony protected from the wind with open space to setup a camera from a distance if recording the drop.
- Assign a committee for Timing and Technology which includes a member from each team. The committee would be responsible for set up of cameras in the Drop Zone and other data collection devices. This allows for consistency and objectivity during testing, measurement, and data collection.
- This activity works best on a non-windy day. High winds will carry parachutes away from the target landing area and data will be difficult to collect.
- Tip: Plan for additional adult supervision if teams will be working in the classroom while other teams test at the Drop Zone.

Introduce the Commercial Crew Program

- Ask students what they know about NASA's Commercial Crew Program. If the majority of students have little or no prior knowledge about Commercial Crew, play Commercial Crew: Dawn of a New Space Age (1:51).
  - o What makes Commercial Crew a unique approach for NASA?
  - o What are some of the benefits of NASA's Commercial Crew Program?

- After students have a base level of understanding about CCP, play Commercial Crew: The Flight Tests video (2:06).
  - o Why are flight tests critical to the success of Commercial Crew?
  - o What are some of the benefits of having astronauts that will fly aboard the spacecraft work closely with the engineers designing and building them?



Discuss the STEM Concepts

Discuss the STEM Concepts

- Using a hardboiled egg, introduce the newest member of the Commercial Crew "Eggstronaut" Corp, H. Dumpty.
- As a class, explore what will happen when the egg is dropped from the second story or higher of a building (at least 5m).
  - o This demonstration will provide some baseline information for the drop time which teams will use to analyze the effectiveness of their initial designs. This is also an opportunity to:
    - demonstrate lab safety
    - discuss some of the fundamental STEM concepts
    - talk about units of measure (centimeters, meters, seconds, etc.)
    - and explain any additional tools for data collection (video analysis, force plate, accelerometer, etc.)
  - o *What is the initial velocity of the egg? What will happen to the velocity of the egg as it falls? Why?* Discuss how gravity plays a role in launch, landing, and even orbit for the Commercial Crew vehicles.
  - o *How could we measure the height of the egg drop?* Discuss different techniques suggested by the class. Offer additional tools or mathematical approaches. Allow students to choose one and compare different results.
  - o Use the equations below to estimate the time it will take for the egg to fall the measured height.
    - Grades 5-8: basic free fall equation $d = \frac{1}{2}gt^2$
    - Grades 9-12: kinematics equations
  - o *How could we determine the amount of energy the egg has before it is released?* Gravitational potential energy: $PE_{grav} = mgh$
  - o *How will the gravitational potential energy change as the egg falls?*
  - o *How could we determine the amount of energy the egg has just before it hits the ground?* Kinetic energy: $KE = \frac{1}{2}mv^2$
- Release the egg and have several students measure the drop time using stopwatches. Calculate the average. Record this value on the student data sheet.
  - o *Why is the measured value for drop time different from the predicted value calculated using the formula above?* Discuss the validity of the equation when acceleration is not constant. Discuss the meaning of free fall.
- Drop two pieces of paper, one flat and the other crumpled to open the conversation about air resistance or drag.
  - o *How does drag affect the motion of a falling object?* (Discuss drag, net force, acceleration, and terminal velocity. Make connections back to drop time, kinetic energy, momentum and impulse or force of impact)
  - o *How do NASA's Commercial Crew partners slow the descent of the crew vehicle during landing and ascent abort?* Optional: CCP Parachute videos
- *Now Commercial Crew* **needs you** *to help* **safely** *return our Eggstronauts to Earth. This is your challenge.* (Emphasize the importance of crew safety)

Introduce the Eggstronaut Parachute Challenge

Challenge:

Design and build a parachute to slow the descent of an egg and minimize the force of impact when landing.

- Discuss the Engineering Design Process.
- Explain vocabulary including parts of a parachute.
- Go over the student activity sheets and rubric.
- Check for misconceptions and reinforce physics concepts.
- Share additional information about Commercial Crew Program parachute testing.

Constraints:

- Nothing can be attached to the egg except the harness.
- The egg must impact the ground first.
- Eggs must fall with the major or longer axis perpendicular to the ground.
- Use only materials provided unless given explicit permission for an exemption.
- Describe your role as Commercial Crew Teacher (CCT). Teams must meet key milestones to receive certification from CCT and proceed to the next step.

Key Milestones:

1. Preliminary Design Review (PDR) – Teams will submit a technical drawing and description of each parachute design before receiving a “budget” for supplies allowing students to collect the materials listed on their PDR and begin building. (Note: This activity doesn’t include keeping a budget, but it could easily be added. See the Extension Activities.)

2. Launch Readiness Review (LRR) – CCT will confirm each team has built their model to specifications from PDR including the weight of Eggstronaut and check for any safety concerns before allowing the team to perform a drop test.

3. Post-Launch Assessment Review (PLAR) – Teams will submit an analysis of data collected from drop test with recommendations for improving their design.

4. Safety and Mission Success Review (SMSR) – After teams have completed several iterations of PDR, LRR, and PLAR, they must demonstrate that they can safely land Eggstronaut for 3 consecutive drops with the same parachute. This is the final step to certify their design before testing with a real egg.

5. Debrief – Teams will submit a final presentation to CCT with an overview of the design challenge and what they learned from the process along with any recommendations for additional testing or improvements to their design.

The Engineering Design Process

ASK

o Help students answer any questions they have about the challenge.

o Use the interactive simulators in the Additional Resources to further explore difficult concepts or misconceptions.

o Students could research various geometries of parachute designs for some ideas of different shapes.

o Explain the mathematics for calculating surface area or making scale drawings.

  o The internet can provide formulas for unusual shapes. Alternatively, use grid paper for estimating area of irregular shapes. This is also a good method for students in lower-level math.

IMAGINE

o Grades 5-8 consider shape and size of canopy. Grades 9-12 also consider length and number of suspension lines, and if including a top vent, what size.

PLAN

o All drawings must be approved before building begins.

o Optional: Teams can plan to test multiple parachutes at the same time to better understand a specific variable. (For example, design and build three rectangular parachutes with proportional dimensions to determine the effect of surface area on drag. However, they cannot simultaneously vary the length or number of the suspension lines because then it becomes difficult to assess cause and effect.)

CREATE

o All parachute models must be to design specifications or they must recertify PDR.

TEST

o All teams will measure the amount of time it takes for the drag device to fall.

o Advanced students can also measure force of impact, analyze position, velocity, and acceleration data during the drop, and/or use video analysis of the fall and impact.

IMPROVE

o After completing each round of testing, students will make modifications to their designs to try to increase the amount of time it takes for their egg to drop (increasing drag). They must document and justify all design changes.

SHARE

o Not every team will be successful within the given constraints (time, materials, etc.) so the class discussion provides challenge closure.

o Discuss any obstacles the teams faced in completing this challenge.

o Engage students in a discussion by reviewing their data and posing questions:

- *o Which parachute design characteristics provided the most reliable results?*
- *o Which design had the slowest descent (longest drop time)?*
- *o What was discovered about the relationship between surface area and drop time (or speed)?*
- *o What information could engineers working on this project learn from your team's results?*
- *o What other tests and calculations could you do before submitting your recommendations to CCT?* Discuss testing different materials or shapes, how they might create and test for possible anomalies, or how they could determine maximum load the drag device can slow, etc.
- *o What do you think would be the best way to present your results?*

o Explore Commercial Crew Careers

DEBRIEF

o Choose a date for teams to submit a final presentation with an overview of the design challenge and what they learned from the process.

o Encourage creativity and use of multimedia tools (i.e. digital storytelling, slide deck, movie maker, etc.).

o Teams must explain their design and give results that quantify the performance with data analysis to justify their steps in the design process.

o Remind teams to share visual data (pictures, video, or drawings).

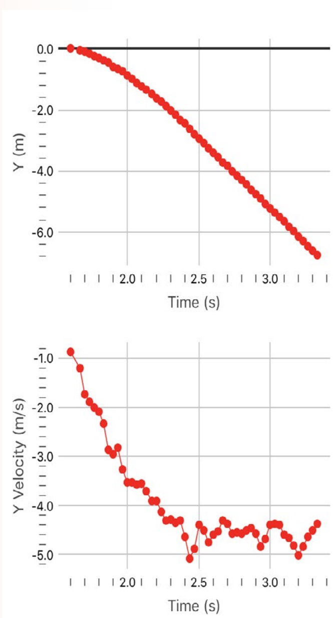
o They should also describe any challenges or setbacks, and consider what further analysis could be done to improve their design or how additional time and testing might benefit or fine tune their design.

o Emphasize that it's important to use correct terminology and vocabulary as you will be assessing their application of STEM concepts in this challenge.

Digital Video Analysis

Tips for capturing video:
- Record video of an object moving perpendicular to the camera lens.
- Use a tripod to keep the camera steady.
- Do not pan, tilt or zoom camera while capturing video.
- If possible, choose a location with a plain background and color contrasting that of Eggstronaut.
- Place a ruler or meter stick within the camera shot and perpendicular to the ground for scale.

Tips for video analysis:
- Upload your video to Tracker, a free program available for Windows and MacOS, or install an app for your phone or tablet like Vernier Video Physics (not free).
- Before analyzing the video, be sure to set the origin, coordinate axes, and scale.
- Both tools have options for automatic or manual tracking. Manual tracking can be used when auto-tracking fails (i.e. Eggstronaut gets "lost" in the background).
- Video Physics supports basic graphing for position and velocity data. Data can easily be shared with computers, tablets, and phones. Additional software, Graphical Analysis or Logger Pro, is required for more complex analysis.
- Tracker is a more sophisticated video analysis tool with many options for visualizing data and finding equations for best fit. Video, graphs, and data can also be exported and shared.
- Explore the features available for each tool to decide which would work best for your students or choose your own digital video analysis software.

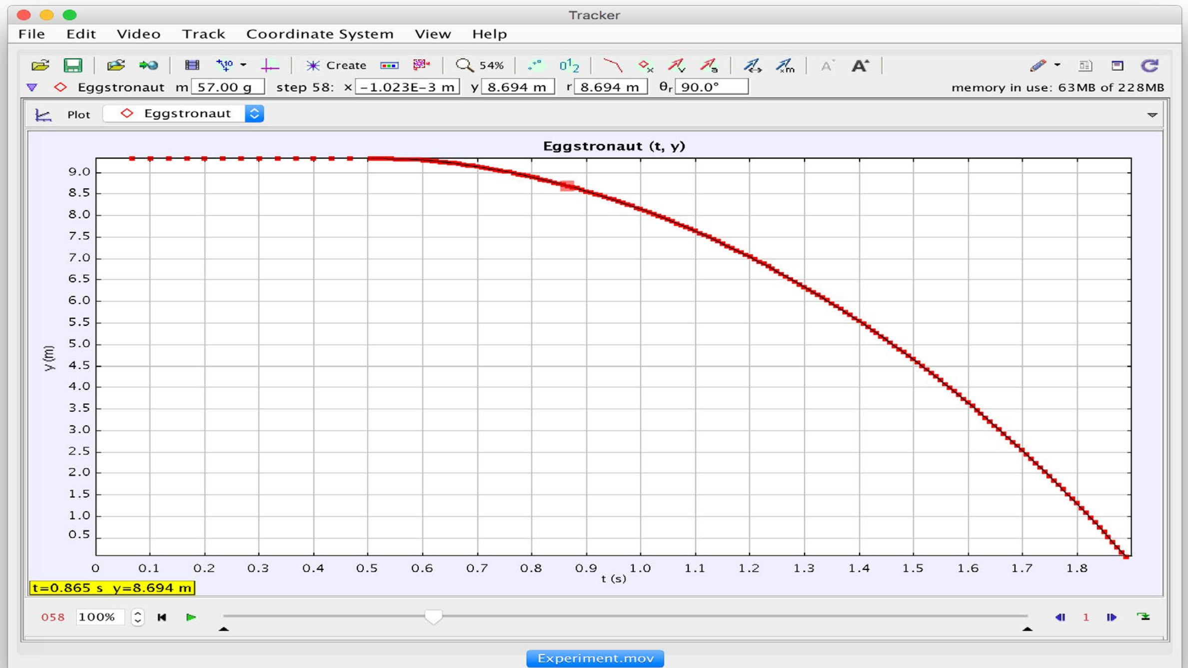


Video Physics Analysis of Eggstronaut with Parachute

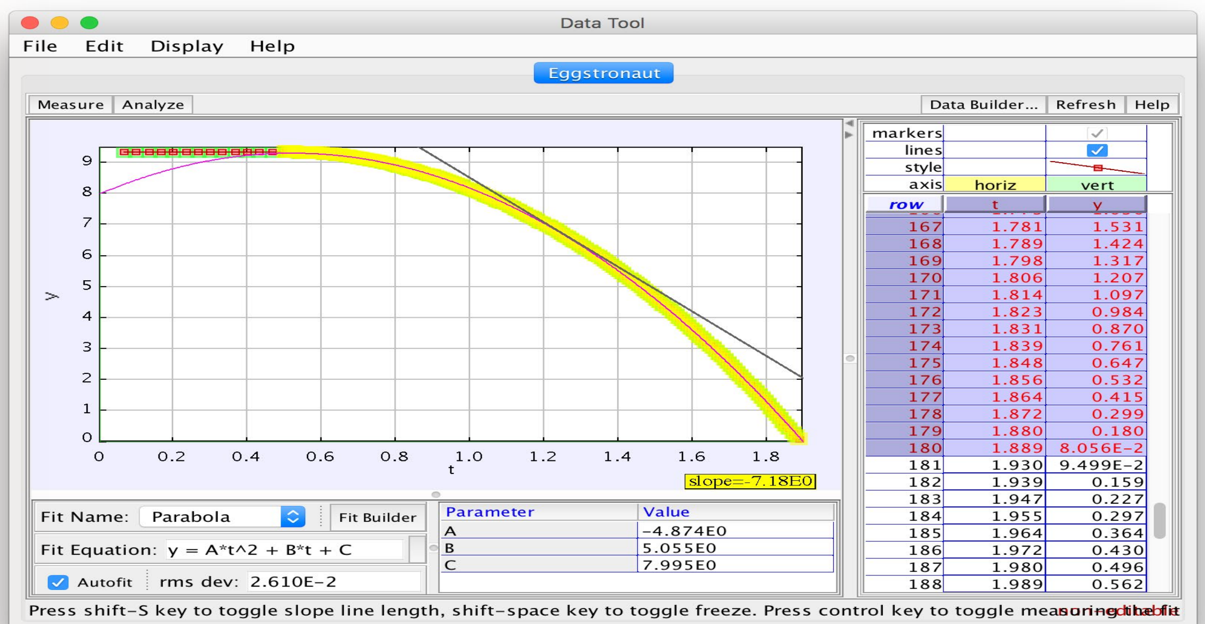
Discussion questions:
- *How does vertical position change as a function of time?*
- *How does vertical velocity change as a function of time?*
- *Why isn't the graph of velocity a smooth curve?*
- *Did Eggstronaut reach terminal velocity? How can you tell?*
- *What is the equation of best fit?*
- *Discuss the meaning of the coefficients and variables for the equations of best fit and what they mean in the context of this problem.* (Velocity is the derivative or rate of change of position with respect to time. Acceleration is the rate of change of velocity with respect to time)
- *Discuss any sources of error in measurement and analysis.*

Tracker Analysis of Egg in Freefall

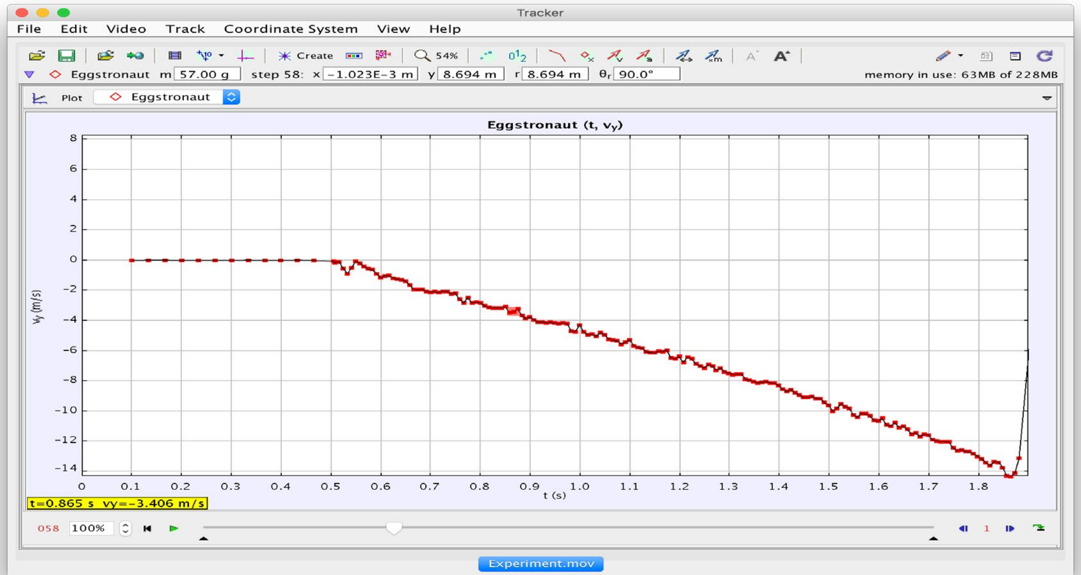
Students can move the cursor to see how the video, numerical and graphical data correspond. Discuss key points on the graph and what they mean in the context of the physical world.



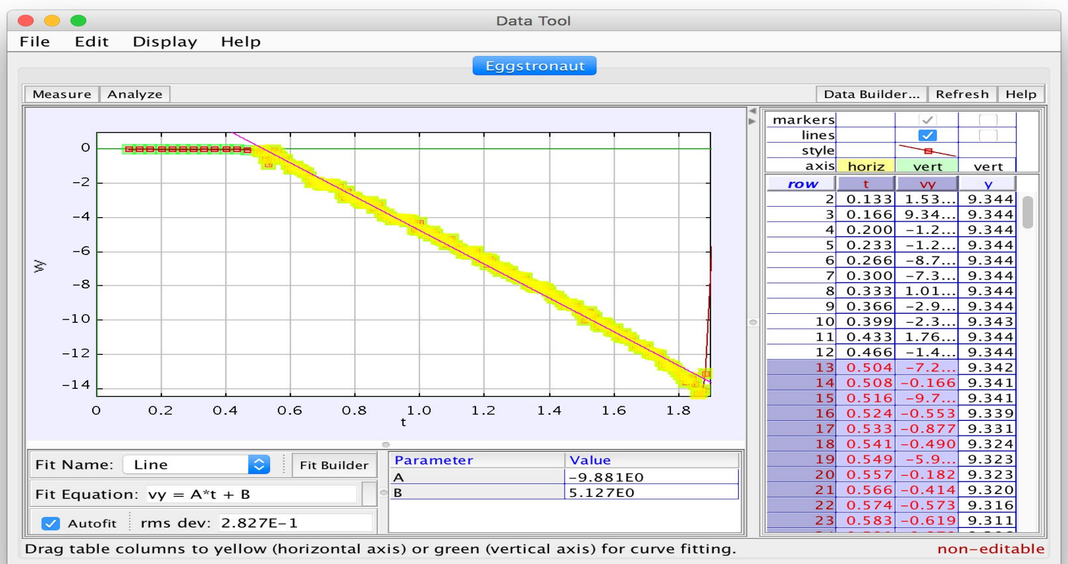
Graph from data of vertical position with respect to time



Fit equation: $y = -4.87t^2 + 5.06t + 8$



Graph from data of vertical velocity with respect to time



Fit equation: $v_y = -9.88t + 5.13$

Technology Extensions:

If you have access to additional resources in a physics laboratory, consider other tools for collecting and using data. A small wearable accelerometer can be placed inside the plastic egg to record data during the descent. Use a force plate to measure the force of impact. Please note that the force plate must be sensitive for low impact forces, and it can be challenging for Eggstronaut to land directly on the plate. A motion sensor can be used to collect position and velocity data, but aligning the motion sensor with the falling Eggstronaut can also be challenging.

Eggstronaut Parachute Challenge Rubric

Rubric Category	Score
Brainstorm to Identify the Problem and Constraints • The problem is identified and explained in detail. • All criteria and constraints are listed and clarified. • Possible solutions are listed from the brainstorming session. • The work others have done to solve the problem is included.	
Generate Ideas, Possibilities, and Design Choice • Two or three ideas are selected from brainstormed list. • Detailed sketches are created for the selected ideas. • Sketches are labeled with dimensions and materials for each component. • One design is selected to construct with reasons for the choice.	
Build the Model or Prototype • Detailed list of materials is included. • Detailed procedures are included and followed. • Materials are handled and stored appropriately. • Safety rules are followed.	
Test the Model and Evaluate • Hypothesis following an "if.., then…" format is developed for the design. • Strengths of the design are listed. • Weaknesses of the design or compromises of the design are listed. • Results are accurately recorded. • Data tables are complete and well organized. • The chosen design effectively addresses the identified problem.	
Refine the Design • Modifications to improve the design are based on test results. • Modifications to the design are documented. • Additional trials are conducted. • Reflections show great insight and understanding of process and goals of project.	
Share the Design • Presentation is well-organized. • Presentation covers all areas of the design process. • Presentation is clearly communicated (verbally or visually) with appropriate data, sketches, graphs or pictures. • Presentation includes contributions from all team members.	
TOTAL (out of 24 pts possible)	

4 (Advanced) = All criteria (procedures, steps, and details) are met or followed with rare mistakes.
3 (Proficient) = Most criteria are met with only a few mistakes.
2 (Developing) = Many criteria are not met and/or there are many mistakes.
1 (Beginning) = Most criteria are not met.
0 (No effort) = No effort to meet criteria.

Eggstronaut Parachute Challenge

Student Activity Sheet Grades 5-8

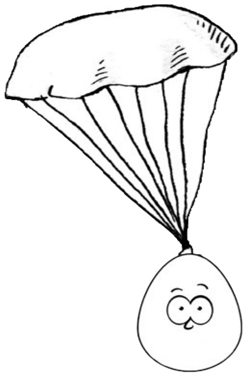
Overview:

NASA's Commercial Crew Program was formed to facilitate the development of a U.S. commercial crew space transportation capability with the goal of achieving safe, reliable and cost-effective access to and from the International Space Station and low-Earth orbit. NASA's engineers and aerospace specialists work closely with industry partners, Boeing and SpaceX, and the partnership approach allows NASA engineers insight into each company's development process while providing access to the agency's technical expertise and resources. Crew safety is paramount in the return of human spaceflight launches from NASA's Kennedy Space Center, and parachute testing provides valuable data to help each partner meet NASA's requirements for certification and safety. Boeing and SpaceX have rehearsed numerous scenarios in many different conditions including both low and high altitude drop tests (from as high as 50,000 feet), nominal and off-nominal entry, as well as ascent abort including pad abort demonstrations. These critical milestones for commercial crew partners help predict parachute performance and verify reliability which are important for crew safety.

Challenge: Work as a team to design and build parachutes to slow the descent of an egg and minimize the force of impact when landing. Each team member will build a parachute with the same shape but different size to determine the effect of surface area on drop time. Your team must ensure that each parachute has proportional dimensions.

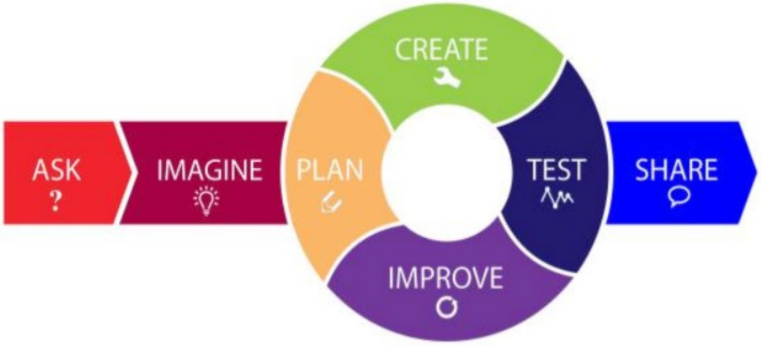
Constraints:

- Nothing can be attached to the egg except the harness.
- The egg must impact the ground first.
- Eggs must fall with the major or longer axis perpendicular to the ground.
- Use only materials provided unless given explicit permission for an exemption.
- Teams must meet key milestones to receive certification from CCT and proceed to the next step.



Ask: What parachute design will slow the descent of a falling egg the most?

Imagine: Brainstorm ideas and/or research parachute designs to come up with the best solution for safely landing your Eggstronaut.



Drop time for Eggstronaut without a parachute: ______ Height of drop: ______

Ask: Today you will design a parachute that will slow the descent of a falling egg. What questions do you have about today's challenge?

Imagine: Variables to consider are canopy shape and size. What will be the general shape of your canopy? What special features will you include? What variable will your team test and how? [Note: Remember to keep the number and length of the suspension lines constant for each design]

Plan: Make a scale drawing of your canopy design. Be sure to include measurements.

Surface area of canopy (show calculations):

Materials list (include quantities):

Write a hypothesis that describes how the variable being tested by your parachute design will affect the time it takes for the egg to drop.

Preliminary Design Review (PDR) Approved by: ___________________________________

Create: After building your canopy, harness, and suspension lines, weigh the Eggstronaut and parachute separately. Request certification by submitting your complete prototype for Launch Readiness Review to proceed to the next step.

Weight of Eggstronaut: ______ Weight of Parachute: ______

Launch Readiness Review (LRR) Approved by: ________________________________

☐ Model parachute meets design specifications from PDR.

☐ No safety concerns.

Test: Drop your Eggstronaut with the parachute from a consistent, known height. Use the provided tools to collect data.

Drop time: ______

Carefully note any observations about the performance of your parachute including any positive attributes (label with +) or problems to address (label with -) for the next iteration. Inspect your egg for signs of trauma and document below.

Improve: Review all data and compare it to previous designs and the results of the drop time for the Egg-stronaut without a parachute. How do the results of the previous tests help you decide what you will try differently next time? Explain.

What will you do to improve your design? Justify your conclusion.

Before returning to plan, create, and test phases, you must demonstrate that you have completed the Post-Launch Assessment Review milestone.

Post-Launch Assessment Review (PLAR) Approved by: ___________________________

☐ One variable is identified for improving design. Justification based on data analysis.

*Note: If your team has safely landed Eggstronaut with the same parachute for 3 consecutive drops, you can request Safety and Mission Success Review. Completing this milestone certifies your team is ready to run a drop test with a real egg.

Safety and Mission Success Review (SMSR) Approved by: ________________________

☐ Eggstronaut has landed safely for 3 consecutive drop tests with the same parachute.

Graphical Analysis of Surface Area vs Drop Time

Complete this graphing activity after all class data has been collected and shared for the Engineering Design Process. Plot surface area (independent variable on x-axis) vs drop time (dependent variable on y-axis) with a different color for each shape. Label graph appropriately. Plot at least four different data points, but the more the better.

What was discovered about the relationship between surface area and drop time?

Share: After you have successfully met the criteria of this challenge to drop test a real egg or constraints (time, materials, etc.) prevent any further design testing, share your results with the class. Some questions to consider:

- o Which parachute design characteristics provided the most reliable results?
- o Which design had the slowest descent (longest drop time)?
- o What information could engineers working on this project learn from your team's results?
- o What other tests and calculations could you do before submitting your recommendations to CCT?
- o What do you think would be the best way to present your results?

Debrief: Teams will submit a final presentation to CCT with an overview of the design challenge and what you learned from the process. Be creative. Use a multimedia tool (i.e. digital storytelling, slide deck, movie maker, etc.). Explain your design, give results that quantify the performance with data analysis, and justify your steps in the design process. Share visual data (pictures, video, or drawings). Describe any challenges or setbacks. Consider what further analysis could be done to improve your design or how additional time and testing might benefit or fine tune your design. It's important to use correct terminology and vocabulary to demonstrate your understanding of the science, technology, engineering and math concepts.

Debrief must be submitted by: ___________________________________

Eggstronaut Parachute Challenge

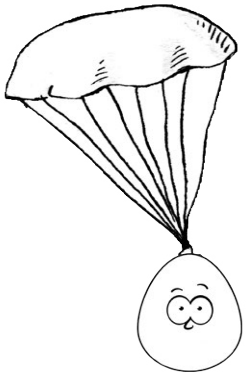
Student Activity Sheet Grades 9-12

Overview:
NASA's Commercial Crew Program was formed to facilitate the development of a U.S. commercial crew space transportation capability with the goal of achieving safe, reliable and cost-effective access to and from the International Space Station and low-Earth orbit. NASA's engineers and aerospace specialists work closely with industry partners, Boeing and SpaceX, and the partnership approach allows NASA engineers insight into each company's development process while providing access to the agency's technical expertise and resources. Crew safety is paramount in the return of human spaceflight launches from NASA's Kennedy Space Center, and parachute testing provides valuable data to help each partner meet NASA's requirements for certification and safety. Boeing and SpaceX have rehearsed numerous scenarios in many different conditions including both low and high altitude drop tests (from as high as 50,000 feet), nominal and off-nominal entry, as well as ascent abort including pad abort demonstrations. These critical milestones for commercial crew partners help predict parachute performance and verify reliability which are important for crew safety.

Challenge: Work as a team to design and build a parachute to slow the descent of an egg and minimize the force of impact when landing.

Constraints:

- Nothing can be attached to the egg except the harness.
- The egg must impact the ground first.
- Eggs must fall with the major or longer axis perpendicular to the ground.
- Use only materials provided unless given explicit permission for an exemption.
- Teams must meet key milestones to receive certification from CCT and proceed to the next step.



Ask: What parachute design will slow the descent of a falling egg the most?

Imagine: Brainstorm ideas and/or research parachute designs to come up with the best solution for safely landing your Eggstronaut.

Drop time for Eggstronaut without a parachute: ______ Height of drop: ______

Ask: Today you will design a parachute that will slow down the descent of a falling egg. What questions do you have about today's challenge?

Imagine: Variables to consider are canopy shape and size, length and number of suspension lines, and if including a top vent, what size? What will be the general shape of your canopy? What special features will you include? What variables will your team test and how?

Plan: Make a scale drawing of your canopy design. Be sure to include measurements.

Surface area of canopy (show calculations):

Materials list (include quantities):

Write a hypothesis that describes how the variable being tested by your parachute design will affect the time it takes for the egg to drop.

Preliminary Design Review (PDR) Approved by: ___________________________________

Create: After building your canopy, harness, and suspension lines, weigh the Eggstronaut and parachute separately. Request certification by submitting your complete prototype for Launch Readiness Review to proceed to the drop test.

Weight of Eggstronaut: ______ Weight of Parachute: ______

Launch Readiness Review (LRR) Approved by: ________________________________

- ☐ Model parachute meets design specifications from PDR.
- ☐ No safety concerns.

Test: Drop your Eggstronaut with the parachute from a consistent, known height. Use the provided tools to collect data.

Drop time: ______

Carefully note any observations about the performance of your parachute including any positive attributes (label with +) or problems to address (label with -) for the next iteration. Inspect your egg for signs of trauma and document below.

Include or attach any additional data gathered such as force of impact, graphs of position, velocity, and acceleration, and indicate if video was taken to document the fall or impact.

Improve: Review all data and compare it to previous designs and the results of the drop time for the Egg-stronaut without a parachute. How do the results of the previous tests help you decide what you will try differently next time? Explain.

What will you do to improve your design? What variable will you change and test in the next iteration of your design? Justify your conclusion.

Before returning to plan, create, and test phases, you must demonstrate that you have completed the Post-Launch Assessment Review milestone.

Post-Launch Assessment Review (PLAR) Approved by: ___________________________

- ☐ One variable is identified for improving design. Justification based on data analysis.

*Note: If your team has safely landed the Eggstronaut with the same parachute for 3 consecutive drops, you can request Safety and Mission Success Review. Completing this milestone certifies your team is ready to run a drop test with a real egg.

Safety and Mission Success Review (SMSR) Approved by: ________________________

- ☐ Eggstronaut has landed safely for 3 consecutive drop tests with the same parachute.

Share: After you have successfully met the criteria of this challenge to drop test a real egg or constraints (time, materials, etc.) prevent any further design testing, share your results with the class. Some questions to consider:

- o Which parachute design characteristics provided the most reliable results?
- o Which design had the slowest descent (longest drop time)?
- o What was discovered about the relationship between surface area and drop time (or speed)?
- o What information could engineers working on this project learn from your team's results?
- o What other tests and calculations could you do before submitting your recommendations to CCT?
- o What do you think would be the best way to present your results?

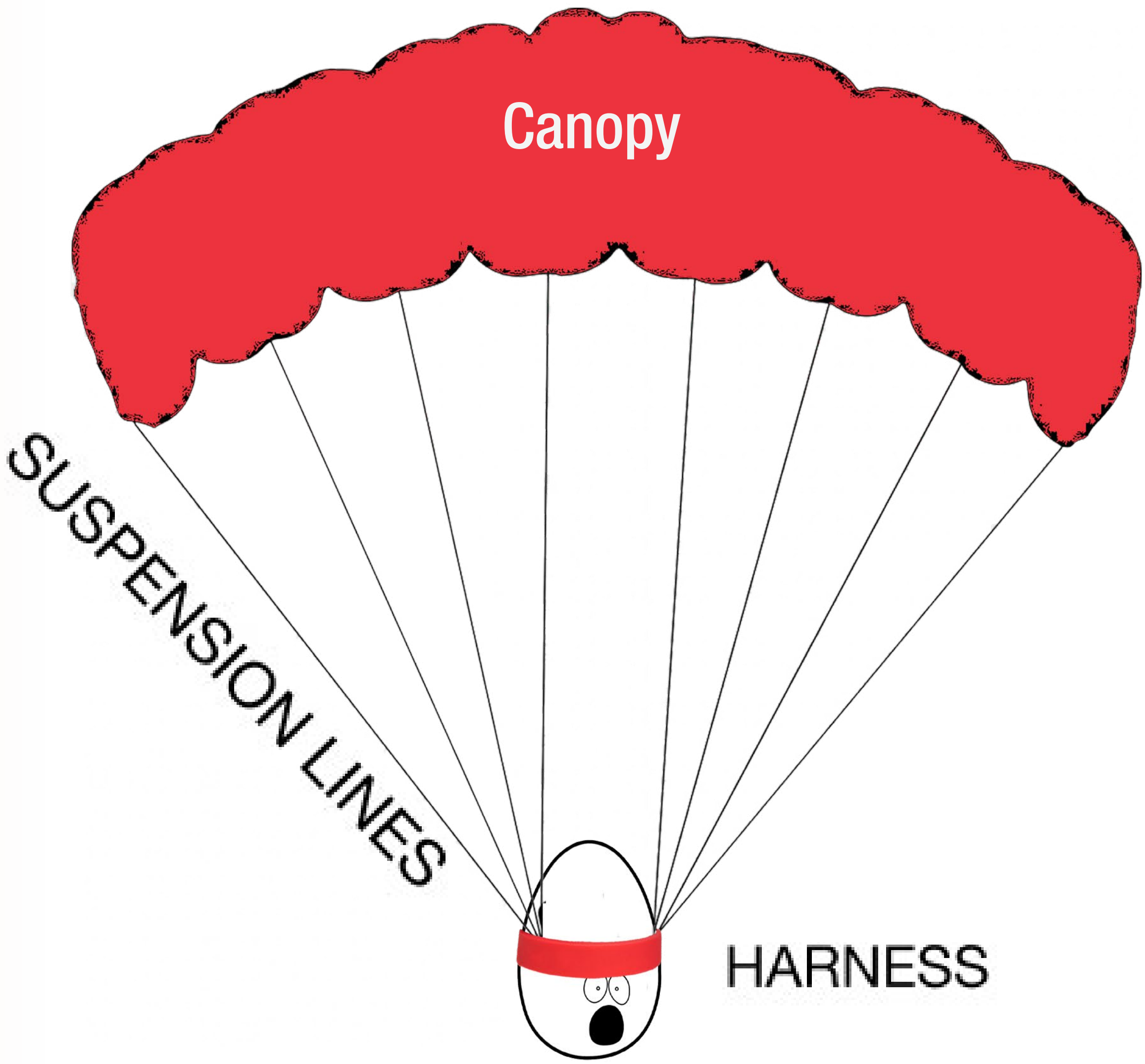
Debrief: Teams will submit a final presentation to CCT with an overview of the design challenge and what you learned from the process. Be creative. Use a multimedia tool (i.e. digital storytelling, slide deck, movie maker, etc.). Explain your design, give results that quantify the performance with data analysis, and justify your steps in the design process. Share visual data (pictures, video, or drawings). Describe any challenges or setbacks. Consider what further analysis could be done to improve your design or how additional time and testing might benefit or fine tune your design. It's important to use correct terminology and vocabulary to demonstrate your understanding of the science, technology, engineering and math concepts.

Debrief must be submitted by: ________________________________

Vocabulary

Acceleration – rate of change of velocity with respect to time which is the net result of all forces acting on an object causing a change in speed, direction or both (measured in meters per second)
Air resistance or aerodynamic drag – a frictional force acting in the opposite direction of a solid object moving through air (measured in Newtons)
Apex or top vent – a hole in the canopy that allows turbulent trapped air to escape and may improve parachute stability
Canopy – the fabric portion of the parachute commonly made from nylon and used to slow the motion of an object by creating drag
Design review – an independent assessment that a concept is realistic and attainable with an acceptable level of risk and meets all technical and programmatic requirements
Gravitational potential energy – the energy an object has stored due to its mass and position above Earth (measured in Joules)
Gravity – an attractive force that all objects have for one another which is proportional to the product of their two masses and inversely proportional to the square of the distance between their centers of mass (measured in Newtons)
Harness/Container – worn by skydivers to attach themselves to the parachute and connects directly to suspension lines or through thick straps called risers
Impulse – change in momentum of an object due to a force acting for an interval of time (measured in Newton-seconds or kilogram-meter per second)
Kinetic Energy – the energy of motion which is proportional to the square of its speed (measured in Joules)
Momentum – equal to the mass of an object multiplied by its velocity (measured in Newton-seconds or kilogram-meter per second)
Nominal – according to plan or design
Suspension lines – lines that connect the parachute canopy to the parachute harness and form a net or skeleton for the canopy which distributes the weight of the payload and absorbs much of the shock of the parachute opening
Terminal velocity – the constant velocity of an object when it falls through a fluid which occurs when drag is equal to weight, so there is no net external force and the vertical acceleration is zero (measured in meters per second)
Weight – the force generated by the gravitational attraction of the Earth which is equal to the mass of the object times the gravitational acceleration or 9.8 m/s^2 on the surface of Earth (measured in Newtons)
Work – a change in kinetic or gravitational potential energy due to a force applied over a distance (measured in Newton-meters or Joules)

Parts of a Parachute



Drop Zone Setup

STEM Concepts:

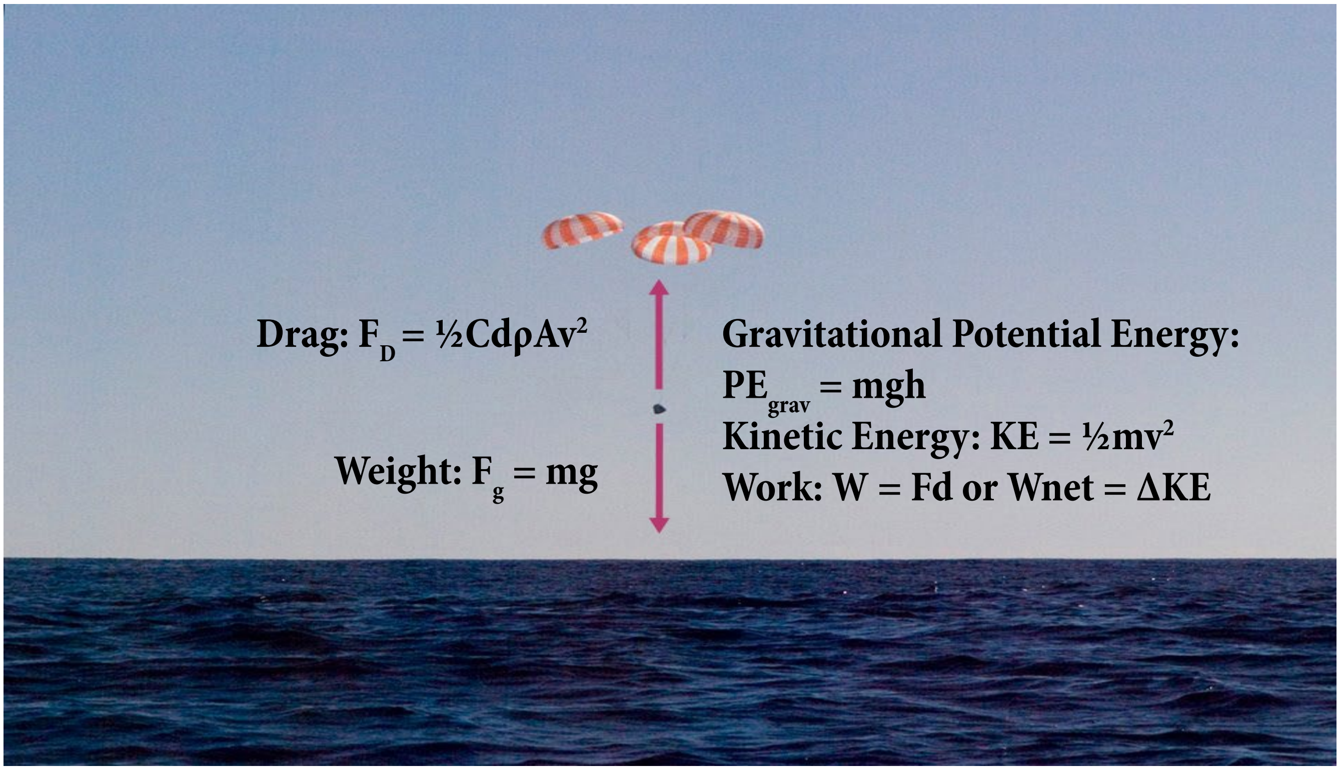
The **Scientific** aspects of this lesson focus on the physics of falling. Students will use kinematics to make a prediction about how long it would take an egg to free fall and the expected velocity when it reaches the ground if acceleration were constant. After comparing the expected drop time to the actual drop time, the class will discuss the forces acting during the fall including weight and aerodynamic drag or air resistance and their relationship to net force, acceleration, and terminal velocity. Students will also calculate gravitational potential energy at the height that the egg is dropped to find the initial mechanical energy of the system. Of course, drag is not constant and it's also a non-conservative force, so the total mechanical energy of the system is not conserved and acceleration is not constant during the fall. This means that the final velocity of the egg before impact would be less than the predicted value. The actual final velocity could be used to calculate the kinetic energy of the egg before landing, find the work done by the drag force on the egg, and determine the change in momentum or impulse of the force of impact with the ground. The goal of this challenge is to design a parachute that maximizes the amount of energy transferred from the egg to slow its descent thus minimizing the force of impact during landing. Measuring the time of descent for each drop test will allow students to compare successive design iterations and determine which of their designs provides the best solution to the challenge.

Technology is the application of scientific knowledge to solve a practical problem. In this lesson, students will need to utilize their understanding of forces and motion and specifically drag to design a parachute technology that successfully slows the descent of a falling egg.

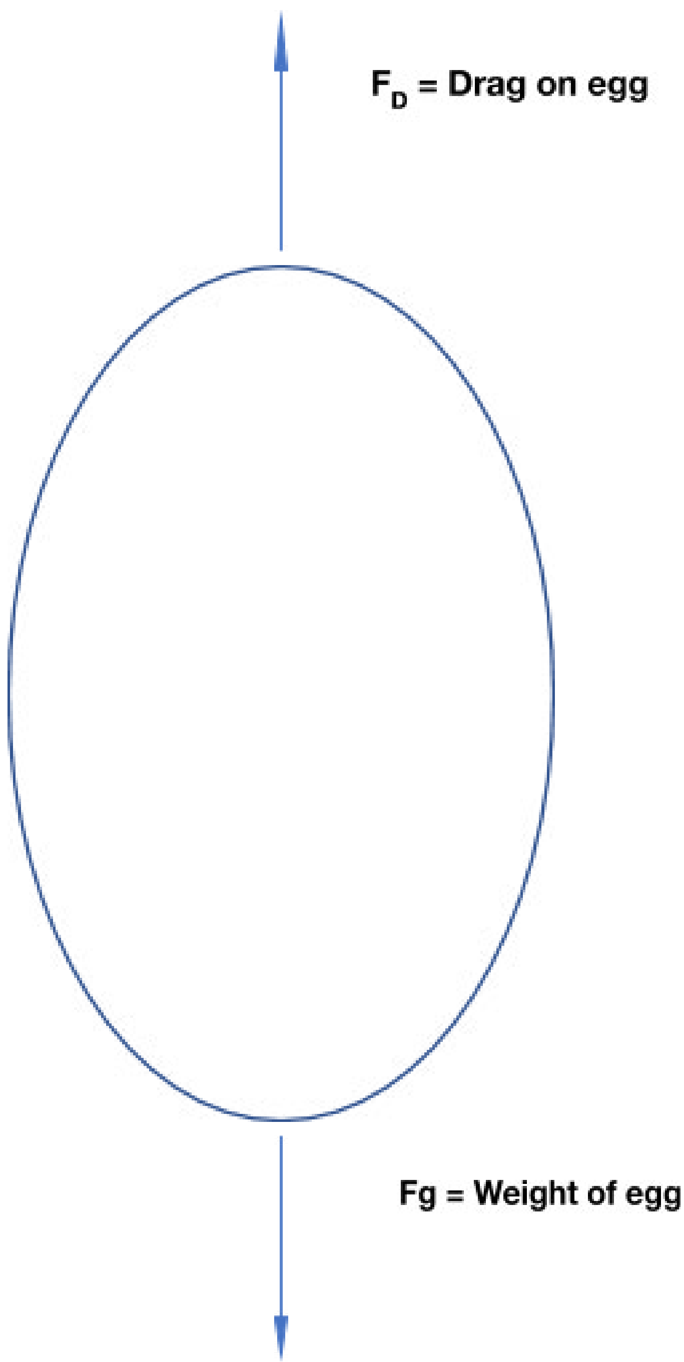
Throughout the challenge students will engage in the **Engineering** Design Process (EDP), an iterative process involving a series of steps that engineers use to guide them in problem solving. The EDP includes asking questions, imagining a solution, planning the design, creating and testing models, and using the information gathered to make intentional changes for improvement. For more information about the EDP, go to https://www.jpl.nasa.gov/edu/teach/resources/engineering-in-the-classroom.php.

Mathematics is an essential tool for creating models, analyzing data, and solving problems. In this activity, students will apply mathematics in a variety of ways including the use of geometry to calculate the surface area of their canopy designs. Using ratios, teams will create scale drawings with detailed measurements to make it easier for others to understand and be able to replicate their designs. Trigonometry can also be used to measure the drop height. During the drop tests, measurements of drop time are critical, so students may want to use multiple timers and average the results. Depending on the data collection tools used (stopwatch, force plate, video analysis, accelerometer, motion sensor) and the ability level of the students, teams may analyze their data using basic graphing, algebraic equations, or even calculus.

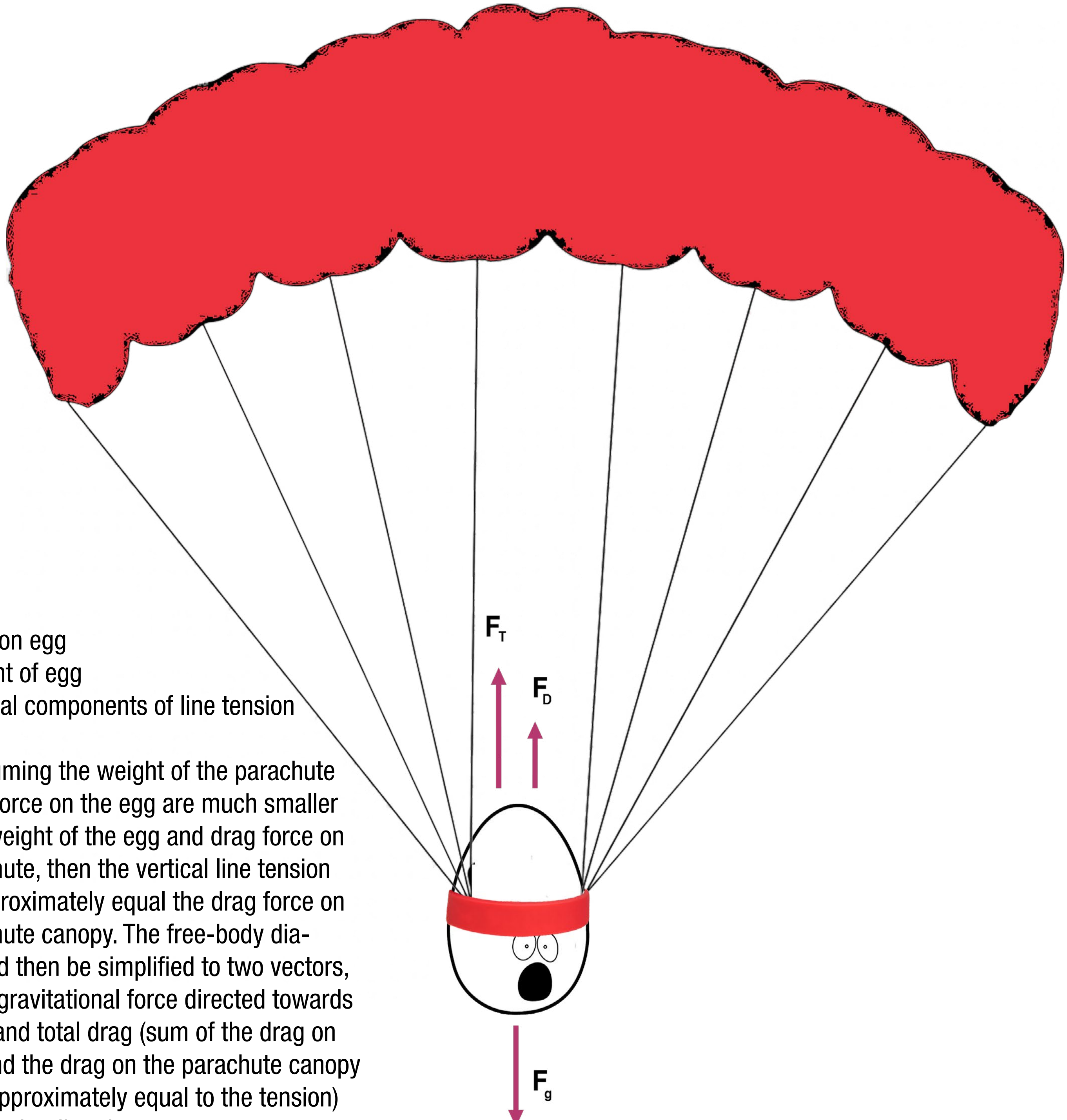
Physics Concepts for Parachute Drop



Free-body Diagram of Egg Falling



Free-body Diagram of Egg in Parachute Drop

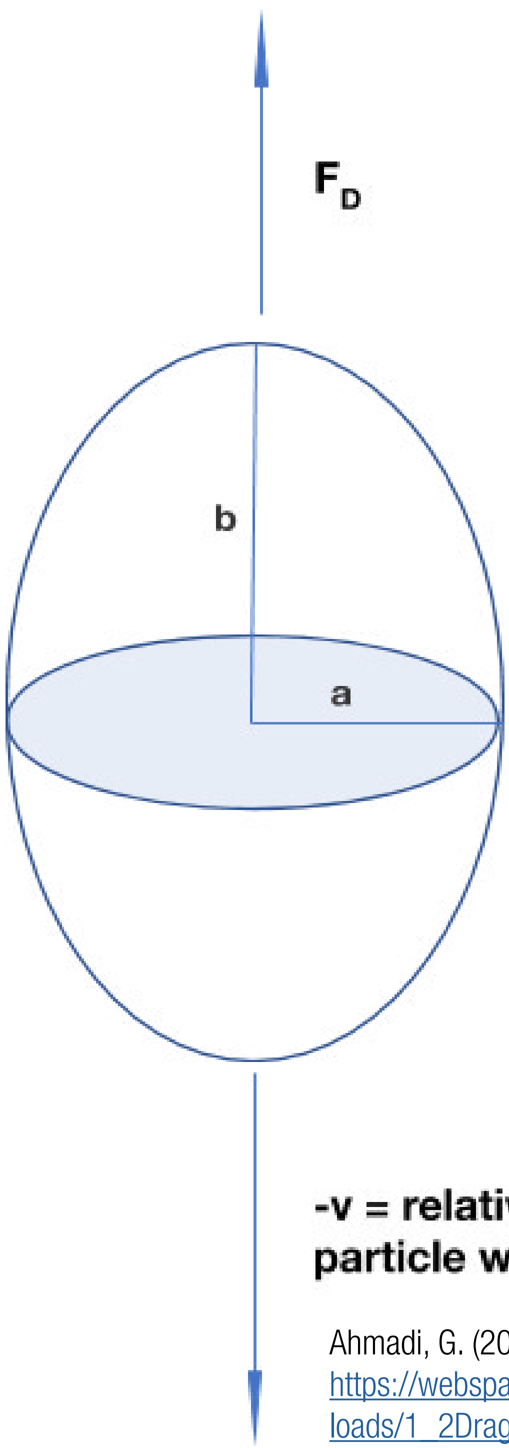


F_D = Drag on egg
F_g = Weight of egg
F_T = Vertical components of line tension

Note: Assuming the weight of the parachute and drag force on the egg are much smaller than the weight of the egg and drag force on the parachute, then the vertical line tension would approximately equal the drag force on the parachute canopy. The free-body diagram could then be simplified to two vectors, weight or gravitational force directed towards the Earth and total drag (sum of the drag on the egg and the drag on the parachute canopy which is approximately equal to the tension) in the opposite direction.

Theoretical Drag Force on Egg-shaped Particle

For particles that are ellipsoids of revolution, the drag force is given by FD = 6π μvaK’ where μ is the coefficient of viscosity, v is the relative velocity of the fluid with respect to the particle, a is the equatorial semi-axis of the ellipsoid, K’ is a shape factor, and β is the ratio of the major axis b to the minor axis a.



$$K' = \frac{\frac{4}{3}(\beta^2 - 1)}{\frac{(2\beta^2 - 1)}{(\beta^2 - 1)^{1/2}} \ln[\beta + (\beta^2 - 1)^{1/2}] - \beta} \qquad (\beta = \frac{b}{a})$$

Ahmadi, G. (2018). Hydrodynamic Forces [PDF file]. Retrieved from https://webspace.clarkson.edu/projects/crcd/public_html/me537/downloads/1_2Drag.pdf

NASA News Article: Parachute Testing Lands Partners Closer to Crewed Flight Tests

At left, Boeing conducted the first in a series of parachute reliability tests its Starliner flight drogue and main parachute system Feb. 22, 2018, over Yuma Arizona. Photo Credit: NASA. At right, SpaceX performed its fourteenth overall parachute test supporting Crew Dragon development March 4, 2018, over the Mojave Desert in Southern California. The test demonstrated an off-nominal, or abnormal, situation, deploying only one of the two drogue chutes and three of the four main parachutes. Photo credit: SpaceX

By Marie Lewis
NASA's John F. Kennedy Space Center
Last Updated: March 30, 2018
Editor: Linda Herridge

Crew safety is paramount in the return of human spaceflight launches from Florida's Space Coast, and the latest round of parachute testing is providing valuable data to help industry partners Boeing and SpaceX meet NASA's requirements for certification.

On March 4, SpaceX performed its 14th overall parachute test supporting Crew Dragon development. This exercise was the first of several planned parachute system qualification tests ahead of the spacecraft's first crewed flight and resulted in the successful touchdown of Crew Dragon's parachute system.

During this test, a C-130 aircraft transported the parachute test vehicle, designed to achieve the maximum speeds that Crew Dragon could experience on reentry, over the Mojave Desert in Southern California and dropped the spacecraft from an altitude of 25,000 feet. The test demonstrated an off-nominal, or abnormal, situation, deploying only one of the two drogue chutes and intentionally skipping a deployment stage on one of the four main parachutes, proving a safe landing in such a contingency scenario.

In February, the first in a series of reliability tests of the Boeing flight drogue and main parachute system was conducted by releasing a long, dart-shaped test vehicle from a C-17 aircraft over Yuma, Arizona. Two more tests are planned using the dart module, as well as three similar reliability tests using a high-fidelity capsule simulator designed to simulate the CST-100 Starliner capsule's exact shape and mass. These three tests involve a giant helium-filled balloon that lifts the capsule over the desert before releasing it at altitudes above 30,000 feet to test parachute deployments and overall system performance.

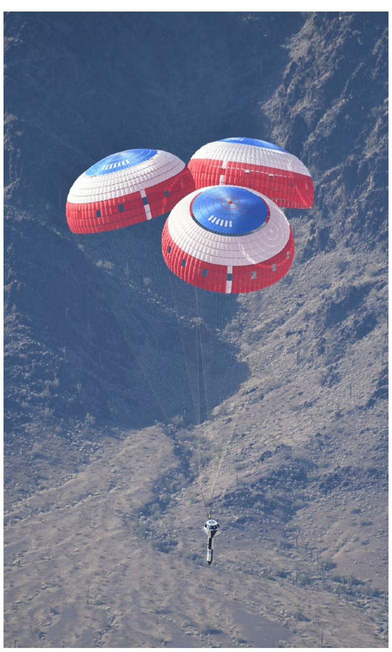
In both the dart and capsule simulator tests, the test spacecraft are released at various altitudes to test the parachute system at different deployment speeds, aerodynamic loads, and or weight demands. Data collected from each test is fed into computer models to more accurately predict parachute performance and to verify consistency from test to test.

SpaceX performed its fourteenth overall parachute test supporting Crew Dragon Development March 4, 2018, over the Mojave Desert in Southern California. The test demonstrated an off-nominal, or abnormal, situation, deploying only one of the two drogue chutes and intentionally skipping a deployment stage on one of the four main parachutes. Photo credit: SpaceX

Mark Biesack, a lead NASA engineer at Kennedy Space Center overseeing parachute testing for the agency's Commercial Crew Program said, "We test the parachutes at many different conditions for nominal entry, ascent abort conditions including a pad abort, and for contingencies, so that we know the chutes can safely deploy in flight and handle the loads."

SpaceX will conduct its next parachute system test in the coming weeks in the California desert, again using a C-130 to drop the parachute test vehicle from about 25,000 feet. The test will be similar to the one conducted earlier this month, but with a different deployment configuration. The test will intentionally skip deployment of one drogue parachute and one main parachute to further demonstrate SpaceX's ability to safely land the vehicle in an off-nominal situation. The ongoing testing verifies the safety of the parachute system for our astronauts.

Boeing is scheduled for its third of five planned qualification tests of its parachute system in May, using the same type of helium-filled balloon that will be used in the reliability tests. For the qualification test, the balloon lifts a full-size version of the Starliner spacecraft over the desert in New Mexico before releasing it. The balloon lifts the spacecraft at more than 1,000 feet per minute before it is dropped from an altitude of about 40,000 feet. A choreographed parachute deployment sequence initiates, involving three pilot, two drogue and three main chutes that slow the spacecraft's descent permitting a safe touchdown.



Boeing conducted the first in a series of reliability tests of its CST-100 Starliner flight drogue and main parachute system Feb. 22, 2018, over Yuma, Arizona. Photo credit: NASA

Both Boeing and SpaceX's parachute system qualification testing is scheduled to be completed by fall 2018. The partners are targeting the return of human spaceflight from Florida's Space Coast this year, and are currently scheduled to begin flight tests late this summer.

"The partners are making great strides in testing their respective parachute systems, and the data they are collecting during every test is critical to demonstrating that their systems work as designed," said Kathy Lueders, Commercial Crew Program Manager at Kennedy Space Center. "NASA is proud of their commitment to safely fly our crew members to the International Space Station and return them home safely."

NASA's Orion Program, which is nearing completion of its parachute tests to qualify the exploration-class spacecraft for missions with crew, has provided

Commercial Crew Program partners with data and insight from its tests. NASA has matured computer modeling of how the system works in various scenarios and helped partner companies understand certain elements of parachute systems, such as seams and joints, for example. In some cases, NASA's work has provided enough information for the partners to reduce the need for some developmental parachute tests. The goal of the Commercial Crew Program is safe, reliable and cost-effective transportation to and from the space station from the United States through a public-private approach.

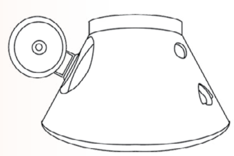
Commercial Crew Parachute Drop Tests

Boeing CST-100 Starliner Parachute Drop Test (1:51)

SpaceX Dragon2 Parachute Drop Test (1:00)

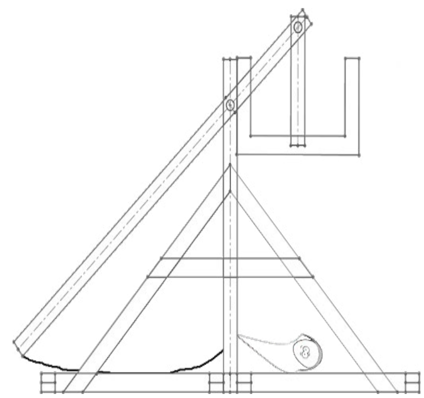
Extension Activities:

- Experiment with other aspects of parachute design such as the effect of apex or top vents or number, length, and arrangement of suspension lines.
- Add constraints or incentives for a parachute with less mass or a design that is more cost-effective (assign cost to supplies, time, labor, etc.)
- Experiment with multiple parachutes instead of one. Boeing uses 3 main parachutes and SpaceX uses 4 main parachutes.
- Experiment with different parachute materials.
- Set up a kiddie pool in the drop zone to experiment with a water landing.



- Design and build a crew capsule to hold multiple Eggstronauts and design a parachute to safely land it.
- Add features to the crew capsule to help soften the impact of landing such as airbags, landing legs, springs, etc.
- Design and build a launch abort system that safely propels the Eggstronaut or capsule away from the launch pad and lands gently with a parachute.

Additional Resources:



NASA's Next Gen STEM Commercial Crew Program
- www.nasa.gov/stem/ccp

NASA's Commercial Crew Program website
- https://www.nasa.gov/exploration/commercial/crew/index.html

Commercial Crew Partner websites
- http://www.boeing.com/space/starliner/
- https://www.spacex.com/crew-dragon

Tracker Video Analysis and Modeling Tool
- https://physlets.org/tracker/

Egg Drop Interactive Simulator
- https://www.physicsclassroom.com/Physics-Interactives/Momentum-and-Collisions/Egg-Drop

Skydiving Interactive Simulator
- https://www.physicsclassroom.com/Physics-Interactives/Newtons-Laws/Skydiving/Skydiving-Interactive

Falling in a Vacuum and with Air Resistance Interactive Simulator
- https://www.compadre.org/precollege/items/detail.cfm?ID=10002

Engineering Design Process
- https://www.jpl.nasa.gov/edu/teach/resources/engineering-in-the-classroom.php

NASA Systems Engineering Handbook
- https://www.nasa.gov/sites/default/files/atoms/files/nasa_systems_engineering_handbook_0.pdf

Web sites may provide teachers and students with background information and extensions. Inclusion of a resource does not constitute an endorsement, either expressed or implied, by the National Aeronautics and Space Administration.