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Unit Objectives

Upon completion of this unit, students will:

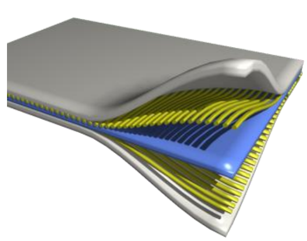
- **Design a custom livery for a fictional commercial airliner and research the importance of a recognizable brand.**
- **Investigate the properties of composite materials and learn about their use in commercial aircraft.**
- **Learn about the various systems that must be managed to manufacture a commercial aircraft from design and ordering through final assembly and testing.**

Background Information:

Airline companies can spend millions of dollars to paint a fleet of aircraft to support their marketing brand. Additionally, complex paint schemes add weight to an aircraft, contributing to the fuel consumption during flight. Companies compare the costs associated with various paint schemes to the income generated from the customer's association with the brand. What many airlines are trying to accomplish is the creation of an emotional attachment to their particular brand. American Airlines was noted for decades for its shiny, polished fuselage exteriors with the AA eagle tail logo. A major rebranding in 2013 saw this airline depart with its long-held brand in hopes of revitalizing the image of the airline. Also, the shiny, polished exterior would be impossible to reproduce on newer, composite-based aircraft and, while saving fuel due to less aircraft weight, resulted in higher maintenance costs to both polish the exterior of the fuselage and apply anti-corrosives to the exposed surfaces which paint naturally provides.

The Royal Society of Chemistry describes a composite material as:

> A material made by combining two or more materials – often ones that have very different properties. The two materials work together to give the composite unique properties. However, within the composite you can easily tell the different materials apart as they do not dissolve or blend into each other.



"Composite 3d" by PerOX - Own work. Licensed under Public domain via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Composite_3d.png#mediaviewer/File:Composite_3d.png

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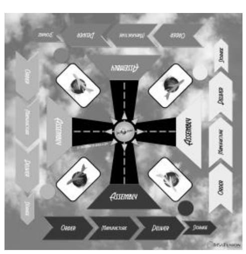
From concrete to plywood to carbon-fiber composite materials used to build commercial jets, composite materials have been manufactured since approximately 1500 B.C. when ancient Egyptian settlers used a combination of mud and straw to create stronger, more durable homes. Since the Wright Brothers built the first Wright Flyer in 1903 from wood and fabric, composites have been a part of the aviation industry. Newer aircraft, such as the Boeing® *787 Dreamliner* and Airbus® *A350 XWB* contain at least 50 percent composite materials. These composite materials are stronger and lighter than traditional materials and provide greater fuel efficiency. They are also non-corrosive and therefore require less maintenance than traditional aluminum-clad fuselages.

Most composite materials are made up of two different *constituent* materials; one is known as the matrix and the other is the reinforcement. The reinforcement provides the strength and stiffness to the composite while the matrix binds the reinforcement into an orderly pattern. Most matrix materials are plastics of some kind, namely resins, and also help to transfer loads especially between discontinuous types of reinforcements such as seen in concrete.

Commercial aircraft use carbon-fiber reinforced plastics (CFRP) in which a thermosetting resin is used with continuous carbon fibers. To create the fuselage sections for the Boeing® *787 Dreamliner*, thin strands of carbon-fiber tape and resin are wound around a rotating mold, building layer upon layer to form a laminate. After being heat-treated in an autoclave at 350°, the thin, barrel-shaped section is removed from the mold. At final assembly, these barrel sections are joined together creating the fuselage of the aircraft. Since multiple companies are providing the various fuselage sections, design specifications must be well-documented to avoid delays or "traveled work" in final assembly of the aircraft frame.



Students are usually introduced to engineering through the engineering design process in relation to designing a product. However, manufacturing and assembly processes and procedures are also the result of engineering design as well. A manufacturing engineer is responsible for researching, designing, and developing the various integrated systems, processes, machines, tools, and equipment necessary to produce high-quality, competitive products.

While developing the Boeing® *787 Dreamliner* aircraft, engineers decided to take a radical new approach to assembling the aircraft. Rather than fabricate and build the entire aircraft in one location, the *Dreamliner* would be a global undertaking, with completed sections of the plane arriving at a final assembly site to be joined and integrated with other systems. The goal was to increase the number of planes completed per month by outsourcing many of the large pieces of the plane. For example, the wings would be produced in Japan, large composite barrel fuselage sections would be produced in Italy, Japan, and the United States, winglets would be produced in South Korea, England would manufacture both engines and landing gear, and many other countries would provide such items as cargo and passenger doors, vertical fins, tail cones, wing edges, and flaps (source: Boeing).

NOTES

This resulted in companies that partnered with the aircraft giant often having to purchase new, expensive, and sophisticated equipment to deal with the innovative manufacturing processes required to complete the various components. Thus, a major responsibility fell to Boeing to manage the huge supply chain and monitor the facilities and manufacturing processes. Critical scheduling software had to be developed to schedule the production and delivery of thousands of parts from around the world. This innovative new manufacturing strategy was not without its problems, and the efficiencies in production, reduced inventory of parts in storage, and quick delivery to customers were not initially realized. (source: Luisada, Claude, *The Boeing 787 Dreamliner*)

Inquiry Overview:

This set of activities will introduce students to the many facets of engineering and design involved in the manufacture of a commercial jet aircraft. In the first activity, students will investigate the importance of an aircraft's livery in representing the brand of an airline as well as consider design choices related to the weight of painted aircraft fuselages versus polished metal's anti-corrosive maintenance requirements. Also, students will have an opportunity to design their own custom livery to represent their "brand" for this curriculum.

Next, students will explore underneath the layer of paint to find new innovations in fuselage construction using carbon composite materials. Students will create a composite structure using craft sticks and glue to see how combining two materials into one can create desirable properties- in this situation related to the strength of the product. Following this activity, a "barrel section" with a diameter of two inches will be produced using fiberglass casting material, a composite of fiberglass threads and resin.

NOTES

Students will observe the interaction of this material with water to create a hardened surface and will attempt to combine their barrel section with other teams' sections to see if the design specifications were met. To conclude this exploration, students will view a video showing the manufacturing of aircraft fuselage barrel sections using carbon fiber tape and will observe samples of carbon fibers that ultimately will form the body of an aircraft!

Finally, students will be introduced to the supply chain and project management issues that are encountered during assembly of a product as immense in scale as a commercial jetliner. Through a board game where students follow seven large components of the jet assembly from ordering through manufacture, delivery, storage, and assembly, students will begin to understand the complexity of integrating many different systems into a cohesive final product and will be introduced to systems engineering as a discipline. Many students think of engineering only in relationship to designing a particular part or product. It is the goal of this activity to broaden their thinking that engineering solutions and integrating systems are also viable applications of the engineering design process.

Additional Activity:

In the Appendix, there is an additional *Design and Engineering* activity on designing an aircraft cabin configuration using a standard, three-class arrangement for First Class, Business Class, and Economy Class seating. Students will attempt to maximize the profit on a commercial airliner flight by manipulating different seating configurations and creating a mathematical model to generate the profit obtained based upon a seating class fare structure. Students will compare their models to other students, and will discuss the pros and cons of each different configuration.

NOTES

ACTIVITY ONE: LIVERY DESIGN (60 minutes)

Objectives and Standards: 7.RP.A; 6.RI.7; 6-8.SL.4; 6-8.WHST.7

The students will:

- Learn about reasons why commercial airlines spend time and money on developing a brand.
- Investigate the process of painting or polishing an aircraft fuselage.
- Design a personal aircraft livery.

Activity Overview:

In this activity, students will first be asked how many different commercial airline companies they can name and what they know about those airlines. Next, students will research with a partner, using a created resource list on Trackstar, their response to the following prompt:

What is an aircraft livery and why it is important to an airline?

Student teams will report out on their discoveries and will then be tasked with designing a name, logo, and aircraft livery to represent their new airline. They will also write a short description on what message they want potential customers to receive simply by observing their fleet of aircraft.

Suggested Inquiry Approach:

ACTIVITY ONE MATERIALS

Per student team:

- 1 – aircraft template
- Colored pencils or markers
- Computer with internet access

1. Ask students if they can name any commercial airline companies (either United States carriers or International carriers). Record on the board or chart paper any student responses.

2. Follow up by asking what they “know” about each of the airlines listed. Place a star or mark any of the responses that describe what the aircraft “looks like” or its paint scheme or logo but do not tell students why you are highlighting those points.

Students will work in pairs for the next part of this activity. Provide each student team with at least one computer with internet access.

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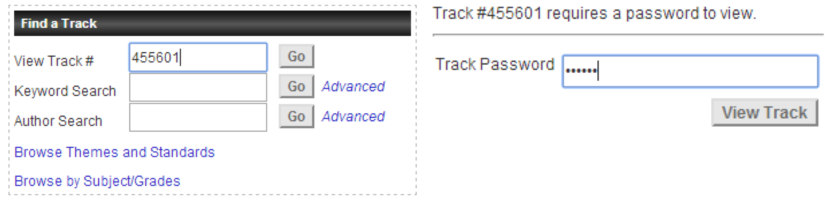
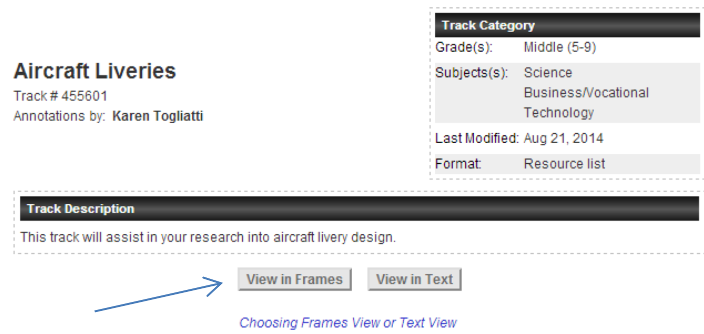
3. Have students navigate to trackstar.4teachers.org and enter the following Track #: 455601. This particular track is password protected and the password is: FUSION. Be sure students type in the password in all caps.



4. Have students select the "View in Frames" button upon opening the track.



5. Students will visit several of the sites listed in the track in order to answer the inquiry prompt:

   What is an aircraft livery and why is it important to an airline?

   Direct students to respond to the inquiry prompt in the appropriate section of their student pages and to record supporting details for their response. Allow students 15-20 minutes for research and to organize their response and then have each partner team share their research. Important questions to ask students at this point are as follows:

   - **What are the various types of aircraft livery that have been used on different aircraft?**
   - **Why is spending millions of dollars on designing an aircraft livery important to an airline company?**
   - **What is the impact of painting the fuselage (the aircraft's main body section that holds crew and passengers or cargo)?**
   - **How might an airline counteract the fuel consumption issues due to painting the aircraft?**
   - **What problems might an airline have if they decide to polish the fuselage instead of painting?**

NOTES

6. Next, student teams will generate a corporate name for a new commercial airline and will design a logo and livery for their new fleet of aircraft. An aircraft template is provided for students to design and color their new livery scheme. Students should also prepare a written explanation of the message their brand should send to potential customers.

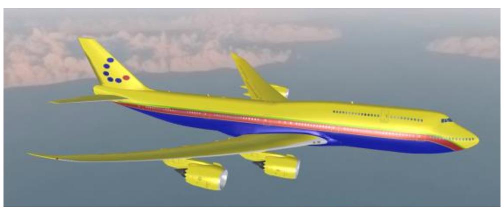
DEBRIEF Activity One:

- **What message will your brand and livery send to potential customers?**
- **What design considerations did you and your partner discuss in order to reach a decision on your company name, logo, and livery design?**

EXTENSIONS:

Visit the following website at http://www.paintconfigurator.com/ to choose from several planes to color and design. Registration is required to save the designs and should be discouraged. However, students can create the liveries online to view and can print screen (ALT+-Prt Scr) to save to a word document.

https://designyourown.newairplane.com/ is a Boeing® Company website that allows eligible users to design a custom livery for a 747-8. This could be done as a classroom demonstration activity.



A fun airline logo quiz can be found at http://airlinelogos.aero/quiz

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Activity Two: Investigating Composite Materials (120 minutes)

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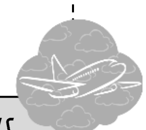
Objectives and Standards: MS-ETS1-1; SEP 1-4, 6, 7, 8, 6.RI.7, 6-8.RH.7, 6-8.SL.4, 6-8.RST.7, 6-8.RST.9

The students will:

- Compare the strength of two individual component materials to their strength when combined as a composite.
- Use a fiberglass composite to simulate a manufacturing process given a product specification.
- Investigate and discuss the use of composite materials in the aircraft industry.

Activity Overview:

For this activity, student partner teams will use popsicle sticks and wood glue to initially discover how combining two materials can result in a material that it stiffer and stronger than either material separately. Next, student teams will use a composite material, fiberglass casting tape, to construct a model "barrel section" of an aircraft fuselage using various "manufacturing" techniques and methods to achieve the stated design specifications. Student teams will then compare their manufacturing techniques with other teams by attempting to combine independently "manufactured" barrel sections to create a uniform fuselage. Discussion will focus on the importance of detailing product specifications when using multiple manufacturers and suppliers. Finally, students will be shown samples of carbon composite fibers and will watch several short video segments detailing the manufacture of carbon composite barrel sections used in the fuselage of the Boeing® *787 Dreamliner* commercial aircraft.



Activity Two Materials

Per student team:
5 – craft sticks
Wood Glue
Styrofoam Cup
Kite string
Weights
Masking tape strip
Orange Duck tape strip
8" Fiberglass Cast Material
Hand lens
Water
Wax Paper
"barrel" forms (index card, foam or balloon)
2 – pairs safety gloves
Computer - Internet Access
Carbon fiber samples

Suggested Inquiry Approach:

Part 1: (45 minutes)
STUDENT SAFETY NOTE:
Please use protective eyewear when breaking any craft stick during strength or stiffness testing.

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You may choose to pre-glue sets of craft sticks for teams prior to the activity.

Students will work with partners for this part of the activity. Begin the inquiry by asking students to examine craft stick and a sample of wood glue. Provide hand lenses and encourage students to describe both of these materials in as much detail as possible.

Next, students will investigate a single craft stick using student-derived procedures to test both the stiffness and strength of the stick. Allow students time to generate their own method to test the strength and stiffness of the craft stick. There are materials available, such as Styrofoam cups, kite string, weights, and masking tape that students can use in their testing design. If students are having difficulty, some questions you can pose are:

- **What would you measure to determine if one material was "stiffer" than another? How could you measure deflection?**
- **If you were measuring strength, could you add weight until the material fails, or could you measure deflection with constant weight?**

Following student testing, ask teams to share their data and observations. Then, compare the composite material of craft stick and glue to both samples that were not composite in nature. The following questions can be raised at this point:

- **How did the beam made of craft sticks and wood glue compare to the single craft stick and double craft stick assembly in both stiffness and strength?**
- **If the beam is considered a "composite" material, what do you think the word "composite" means in this sense?**
- **Why do you think engineers and scientists would try to create composite materials out of other materials? What are some of the potential advantages? What about some disadvantages?**

Part 2: (60 minutes)

STUDENT SAFETY NOTE:

<u>Please use protective eyewear and gloves when handling cast material.</u>

Safety Data Sheet

Safety: Please review all safety practices when using the fiberglass casting material as stated on the Material Safety Data Sheet. Please ensure students use vinyl gloves and goggles when handling the uncured product.

Students will again work in teams to create a structure using a composite material. The structure they will be building is a 2-inch tall by 2-inch diameter cylinder. They will be forming the "barrel" section around a mold of their choice; cardstock, balloons and foam pieces are provided. The composite material they will be using is fiberglass casting tape that contains knit fiberglass as the reinforcement and a water activated resin is the matrix. This material should harden within 3-5 minutes after being activated by water, but will also begin to harden when it is exposed to moisture in the air.

TEACHER NOTE: Do not open the fiberglass casting material until students are ready to use the material as it will harden prematurely. Wear safety gloves when cutting the material and put waxed paper or another table covering down. Eye protection is also recommended.

1. Allow students to read the background information and the product statement on their student pages. Be sure they understand what is being asked of their team prior to designing a manufacturing process.

2. Students may use any available classroom materials to design a process to manufacture the barrel section. You will be provided with 2" diameter foam sections which students may use as a mold (extraction may be difficult), or they may blow up a long balloon to the proper diameter and form around the balloon and then let the air out prior to hardening of the casting material (exact diameters may be difficult). Waxed paper may be used as a liner so that the casting material does not stick to the form. Students may also roll cardstock (index cards) tubes to the correct diameter and line with waxed paper.

3. Once students have formed the barrel section, provide them with an area of the classroom where they can either spray water on the section to activate the resin or rub water along the surface of the casting material to activate the hardening process. Encourage students to make observations during this time as their barrel section cures.

4. The next phase of the activity challenges the students to now combine their formed barrel sections with those of two other groups. They will use masking tape or orange Duck tape along the <u>inside diameter</u> of the sections to form their combined fuselage sections. What the "quality-control inspector", namely the teacher, will be looking for are no gaps, smooth transitions between sections, and all sections the same diameter and shape.

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You may choose to complete Part 3 while barrel sections are drying.

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Following the completion of this part of the activity, the following questions may be asked:

- **Were the specifications detailed enough for the combined fuselage sections to fit together "exactly" with no gaps or differences in shape and diameter?**
- **Why is it important to be detailed in your requirements when using multiple suppliers of the same product?**
- **What recommendations would you make to the major airline company for future production of the barrel sections?**

Part 3: (15 minutes)
For this part of the activity, begin by passing around the sample of carbon fiber material to students. Tell students that this is the material with which newer commercial aircraft are constructed. Ask students the following questions:

- **Do you think this material would be the matrix or reinforcement material in an engineered composite? What property would the carbon fiber give to the aircraft fuselage?**
- **What would need to be combined with the carbon fiber to create a composite?**

Next, have students navigate to the following website:
http://media.star-telegram.com/Multimedia/News/8june/080629Dreamliner/index.html

Click on the Carbon-fiber process to learn about how the barrel sections for the Boeing® *787 Dreamliner* are constructed. Be sure students also click on the short video showing the carbon-fiber tape application to a rotating mold and the heat treatment of the fuselage section in a giant autoclave. An article describing how the first Boeing® *787 Dreamliner* barrel sections did not join correctly can be found at http://www.seattletimes.com/business/boeing-finds-787-pieces-arent-quite-a-perfect-fit/

DEBRIEF: ***ACTIVITY TWO:***

- **What have you learned about composite materials in this unit?**
- **Why are composite materials being studied and used by manufacturers of commercial jet aircraft?**
- **What other applications are there for composite materials?**
- **Why are detailed product specifications and manufacturing instructions important?**

NOTES

EXTENSION:

For more information on composite materials, visit the following page at the Royal Society of Chemistry: *http://www.rsc.org/Education/Teachers/Resources/Inspirational/resources/4.3.1.pdf*

This article from Boeing details the projected advantages of using carbon composites in the design of the *787 Dreamliner* aircraft. *http://www.boeing.com/commercial/aeromagazine/articles/qtr_4_06/article_04_2.html*

This website at Drexel University introduces students to materials science concepts. *http://www.materials.drexel.edu/materials/*

NASA 360 video on Composite Materials *https://www.youtube.com/watch?v=tZhH2B-EI1I*

Videos about carbon composite materials in aircraft:

https://www.youtube.com/watch?v=FTUw0OWWMLU

https://www.youtube.com/watch?v=wXxn-8OA8Ac&list=PLvVyhWpfrZv8zBciIWgXsTzABgkVhxiT4&index=1

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Activity Three: Putting It All Together: Modular Jet Assembly (120 minutes)

Objectives and Standards: NGSS Crosscutting Concept: Cause and Effect, Systems and System Models, SEP 8, 6-8.RH.7, 6-8.SL.4

The students will:

- Learn about the many decisions that are made when designing and manufacturing a commercial aircraft.
- Use a board game to learn about the manufacturing supply chain for a large, commercial jet aircraft.
- Understand that new technologies or processes often need to be invented in order to successfully manufacture a new product.

Activity Overview:

In this inquiry, students will first be introduced to the manufacturing and assembly process of a large commercial jet aircraft through viewing several videos and interactive websites. Then, students will play a board game designed to teach them about the supply chain and manufacturing process. Potential problems that engineers and production planners face on an often daily basis in assembling such a complex product are highlighted.

Suggested Inquiry Approach:

Begin this activity by showing the following video on the assembly of the Boeing® *787 Dreamliner* at ***https://www.youtube.com/watch?v=f07HpUAuWgk***

This video provides an overview of the many challenges faced by engineering and project managers when designing and integrating various components in a product as massive as a commercial aircraft. Another video, located on the content classroom at learning.imsa.edu, entitled *737 Assembly* shows a more traditional assembly process using aluminum-clad fuselage skins.

Activity Three Materials

Per team of four:

1 – game board and directions
30 – ORDER cards
30 – MANUFACTURE cards
30 – DELIVER cards
30 – ASSEMBLY cards
4 – Two-color counters
1 – Color-coded die
4 – different colored planes
4 – different colored cut-apart plane templates
Student Pages

NOTES

Students can also access *http://old.seattletimes.com/multimedia/news/business/building-the-dreamliner/boeing-787.html* for an interactive look at building the *Dreamliner*.

Next, students will form teams of four and receive a game board, directions, playing pieces, a die, four two-color counters, and cards to play the game of ***So You Want to Build a Jet?***. Review the directions to the game with students (a PowerPoint presentation is provided with the directions on the content classroom at learning.imsa.edu) and answer any questions that students may have about playing the game.

Allow students to play the game for 45 – 60 minutes, recording on their student sheets various problems that could occur (as well as potential positive developments) as the seven parts of the plane they will be building are assembled. Students should also be encouraged to discuss potential solutions to some of the problems as they arise. What would they do if they were the manufacturing engineer?

DEBRIEF: Activity Three:

Following completion of the game, ask students to talk among their teams and summarize the information they learned while playing the game. Have student teams debrief by various stages of the process (Order, Manufacture, Deliver, and Assembly), the potential issues that could arise and their proposed solutions to those issues. Also, ask students why having many components in storage (excess inventory) would not be beneficial to the final assembly process.

EXTENSION:

The Alliance for Innovative Manufacturing at Stanford University provides an inside look at the manufacturing process for an airplane on their website "How Everyday Things are Made." Click on the airplane link on the left navigation panel to launch the video: http://manufacturing.stanford.edu/hetm.html