3D Design in Aerospace

Objectives

Students will:

- Learn about the ways 3D design is used in Aerospace and other STEM fields
- Learn the basics of 3D design using the Tinkercad tutorials
- Design a multi-purpose tool that could potentially be used in space

Suggested Grade Level

4^{th} – 12^{th}

Subject Areas

Space Science, Engineering Design

Timeline

45 – 60 minutes

Standards

- **3-5-ETS1-1** Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- **MS-ETS1-1** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- **MS-ETS1-2** Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
- **MS-ETS1-3** Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
- **HS-ETS1-2** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering

21^{st} Century Essential Skills

Critical thinking and problem-solving, creativity, innovation, communication and collaboration, flexibility, initiative, technology literacy

Background

3D printing has moved from the realm of science fiction into the everyday lives of human beings all around the world, impacting the way we live, work, and play along the way. There are many examples of 3D printing in action in today's society. From students designing prosthetic limbs for their limb different peers, to surgeons printing vertebrae for patients with broken backs, to houses being printed in areas suffering from natural disasters constructed completely from concrete, all the way to delicious chocolate bars!

As we prepare to go, 'Back to the Moon, and on to Mars,' astronauts will experience time delays unlike ever before. In fact, the astronauts that will one day walk on the surface of Mars will experience a time delay of 20 minutes for their desperate plea for help to reach Earth, and then another 20 minutes for NASA to send a solution back to Mars! That 40-minute delay in reaction time could mean the difference between life and death for those astronauts that are 93 million miles away from home. With the power of 3D printing, astronauts will be able to design solutions to unexpected problems, so it comes as no surprise that NASA is a major proponent of 3D printing. Believe it or not, there is even a 3D printer in space right now, testing out 3D printing in a microgravity environment on the International Space Station.

Learning is most definitely not a linear process. In fact, it is as much about the process, as it is about the destination. It has been said that, "Mistakes are the portal of discovery." (James Joyce) 3D printing offers a very real opportunity for hands-on engineering, allowing true STEM education to permeate the depths of all content areas. 3D printing allows students to bring their ideas to life. And when those ideas need to be re-considered, they can go back to the drawing board and try again. There is absolutely no better way to introduce students to the engineering design process, then with a trusty 3D printer by your side.

One of the first industries to invest in large scale 3D printing was the aerospace industry. Aerospace – the branch of technology and industry concerned with both aviation and space flight – has been evolving and adopting the technology as early as the 1980s.

The proof is in the numbers: The aerospace and defense industries contributed 16% of 3D Printing's $4.9+ billion global revenues in 2015. A more recent report by Research and Markets found a growth rate of 23% between 2017 and 2021 for the 3D printing in the sector

As commercial air travel has increased, the demand for new aircraft has led to orders of nearly 38,000 new aircraft over the next 20 years. As a result, equipment manufacturers, designers and suppliers need cost-effective solutions to produce these aircraft as quickly and efficiently as possible.

Due to the typically short runs of aircraft parts, the aerospace industry uses additive manufacturing for a great deal of its production. The technology can produce intricate parts that are more resilient and lightweight compared to those made using traditional techniques, which is an obvious bonus. n fact, EOS, one of the leaders in industrial 3D printing of metals and polymers, states that additive manufacturing can produce weight reductions of between 40-60%.

To put this in perspective, the average corporate aircraft travels 75,000 miles per month. A single component that is designed and manufactured with 3D printing (and is therefore lighter), reduces air drag by 2.1%, which in turn reduces fuel costs by 5.41%. By cutting fuel and limiting emissions, 3D printing can subsequently help to *minimize* the environmental impact of air travel. In an age of heightened environmental awareness, this couldn't be more on trend in terms of long-term company strategy and consumer desire. In addition, 3D printing can produce hundreds of thousands of parts without relying on expensive tooling changes involved with traditional manufacturing processes. "Tool-less" production requires less energy, since modified parts or upgrades can be produced as needed, alleviating the need for costly storage. Aerospace parts often include internal channels for conformal cooling, internal features, thin walls and complex curved surfaces. 3D printing processes can create highly complex and lightweight structures with high stability, whilst allowing for the consolidation of multiple parts into a single component. This leads to: Cost reduction, reduced waste, raster production times, greater consistency, better surface finishes across aircrafts.

3D printing is implemented at each stage of the design workflow in the aerospace industry. Here is how it works: Designs will often start off as 3D printed concept models demonstrating various aircraft. SLA and material jetting are used to create highly sophisticated and to-scale models which help to clearly convey the final concept. 3D printing is readily adopted in the prototyping phase within the aerospace industry. Vice President of Operations for North America at PrintForm, Bill Artley explains: "From a full-size landing gear enclosure printed rapidly with low-cost FDM, to a high-detail, full-color control board concept model, there is a 3D printing process suited to every prototyping need." Prior to production, tooling for injection molding, jigs/fixtures and thermoforming can be manufactured quickly and at lower cost thanks to 3D printing. While 3D printing in the aerospace industry used to be used for the prototyping phase alone, it is now used more than ever for the manufacturing of end parts too, since larger industrial printers can print quickly using a variety of materials. Aircraft parts can be tailored to suit particular government or company requirements thanks to 3D printing, whether it's a specific cabin interior design or functionality tailored towards the unique purpose of a particular aircraft e.g. cargo plane, passenger aircraft or helicopter.

The four main areas in which 3D printing is used in the aerospace industry are as follows:

1. Jigs and fixtures: hundreds of fixtures, templates and gauges can be 3D printed, leading to a 60-90% cost reduction.
2. Surrogates: the placeholder parts that are used during production or training to represent components that are later installed in final assemblies. NASA and several air force bases commonly use surrogate parts on a frequent basis.
3. Mounting Brackets: 3D printing is used to manufacture structural, low-volume metal brackets that mount complex lifesaving systems to the interior walls of aircraft.
4. Prototypes: 3D printing can produce prototypes that allow designers to get a greater understanding of the form and fit of a part before production commences. It is useful for aerodynamic testing since prototypes are often fully representative of the final part. It can also be used to manufacture interior components such as door handles and intricate cockpit dashboard designs.

3D printing is also being used to make lighter and more efficient engines and turbine parts, lighter plane seats and even drones, to name but a few.

The aerospace industry uses 3D printing to manufacture end-use parts, prototype, alleviate supply chain constraints, limit warehouse space, cut storage costs and reduce wasted production materials. It is also using the technology to explore groundbreaking innovation, via reducing commercial airplane travel emissions, constructing in space and even bio printing in space.

As the aerospace industry continues to see the value of 3D printing, we can expect more companies to begin developing on-site 3D printing operations and investing in the technology. Indeed, on-site printing capabilities offer groundbreaking real-time design, processing, trial, and implementation of customized components.

The software for 3D printing is also rapidly evolving, which will have an even greater impact on aerospace manufacturing processes.

If you want to see science fiction at work, visit a modern machine shop, where 3D printers create materials in just about any shape you can imagine. NASA is exploring the technique – known as additive manufacturing when used by specialized engineers – to build rocket engines as well as potential outposts on the Moon and Mars. Nearer in the future is a different milestone: NASA's Perseverance rover, which lands on the Red Planet on Feb. 18, 2021, carries 11 metal parts made with 3D printing.

"It's like working with papier-mâché," said Andre Pate, the group lead for additive manufacturing at NASA's Jet Propulsion Laboratory in Southern California. "You build each feature layer by layer, and soon you have a detailed part."

Curiosity, Perseverance's predecessor, was the first mission to take 3D printing to the Red Planet. It landed in 2012 with a 3D-printed ceramic part inside the rover's ovenlike Sample Analysis at Mars (SAM) instrument. NASA has since continued to test 3D printing for use in spacecraft to make sure the reliability of the parts is well understood. As "secondary structures," Perseverance's printed parts wouldn't jeopardize the mission if they didn't work as planned, but as Pate said, "Flying these parts to Mars is a huge milestone that opens the door a little more for additive manufacturing in the space industry."

Vocabulary

3D printing, prototype, manufacturing, multi-purpose, design, evaluate, process

Materials

- Computers with internet access
- Graph paper (optional)
- Examples of 3D printed items (optional)

Lesson

1. Students will go to www.tinkercad.com and create a log-in. (tip: have students prepare an account at home with their parents prior to this assignment)
2. Direct students complete the tutorial lessons provided by TinkerCad by clicking on the 'learn' tab.
3. Allow students to 'tinker' or explore with the program and tutorials.
4. After tutorials, make sure students are familiar with the basic design features (placing and moving shapes, resizing, grouping, moving the plane, etc)
5. Assign students a design challenge on Tinkercad. They are the first astronauts to colonize Mars and must design a **multi-purpose tool** that will assist in building a habitat on Mars (similar to a wrench, screwdriver, HVAC unit, etc).
6. Students may first design their tool on graph paper.
7. Have students share their inventions. If time allows, and 3D printers are available, students can 3D print their prototype.

Extensions

- Incorporate the use of ratios and scale as students create a new project.
- Write an expository essay on how to create something on Tinkercad.
- Compare and contrast AR and VR. How are 3D images (AR) different/similar to Virtual images (VR)?
- Design a prototype for a tech-transfer product, designed for use in space but beneficial to life here on Earth.

Resources

Baldwin, J. (2019, August 27). 3D Printing In the Aerospace Industry. Retrieved from https://blog.grabcad.com/blog/2019/08/27/3d-printing-in-the-aerospace-industry/

From mind to design in minutes. (n.d.). Retrieved from https://www.tinkercad.com/.

Goldberg, D., Turney, D., Dorfman, P., & Holland, K. (2018, December 21). History of 3D Printing: It's Older Than You Think [Updated]. Retrieved from https://www.autodesk.com/redshift/history-of-3d-printing/.

Greicius, T. (2020, October 19). NASA's Perseverance Rover Bringing 3D-Printed Metal Parts to Mars. Retrieved from https://www.nasa.gov/feature/jpl/nasas-perseverance-rover-bringing-3d-printed-metal-parts-to-mars

Loff, S. (2015, February 25). International Space Station's 3-D Printer. Retrieved from https://www.nasa.gov/content/international-space-station-s-3-d-printer

Reichental, A. (2018, January 23). The Future Of 3-D Printing. Retrieved from https://www.forbes.com/sites/forbestechcouncil/2018/01/23/the-future-of-3-d-printing/#42ccceda65f6.