National Aeronautics and Space Administration

STEM LEARNING:

Seeing Sound
Student Activity

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BACKGROUND

Since the 1960s, NASA engineers have worked to reduce aircraft noise that can be generated from many different sources. Although most of that noise comes from engines, other noise-generating airplane components include the landing gear, where the engines and airframe or body meet, as well as "high lift devices" such as wing flaps. Such noise is often described as polluting the air, especially around airports and inside the aircraft itself (passengers sitting near the engines during a plane trip know exactly what aircraft noise feels and sounds like).

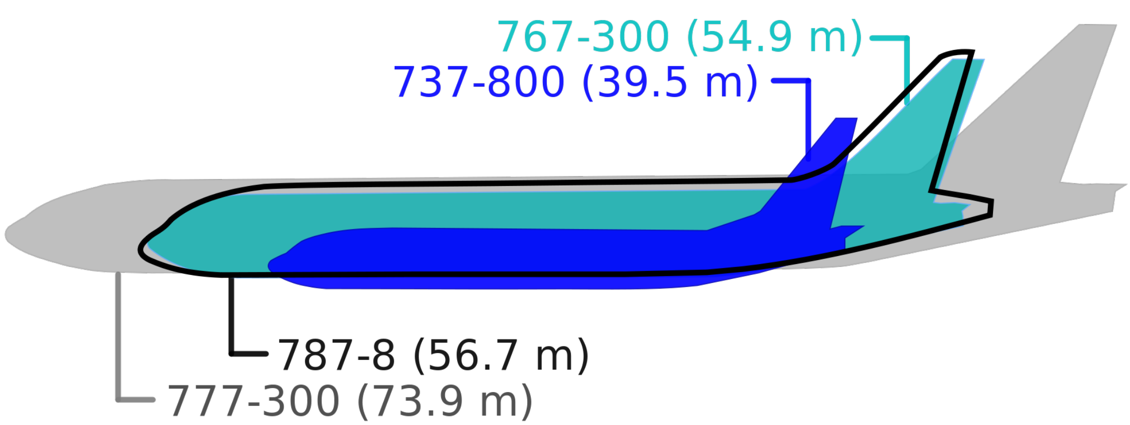
With many different planes taking off and landing each day, and more planes filling the sky, noise pollution from individual aircraft will continue to increase unless something is done. In earlier airplane designs, when engines increased in power and speed, noise mostly increased as well. With newer designs, however, that isn't necessarily the case. For example, even though Boeing's 777s and 787s are larger and have more powerful engines, these newer aircraft are quieter than engines on the smaller 737's. The image below gives you an idea of the size difference in the three planes.

While noise cannot be completely eliminated from jet engines, it can be reduced. One noise-reducing technology NASA helped to develop that is now being used on some commercial jet engines is the chevron.

A chevron is a sawtooth shape designed into the ends of the casing around the outside of the jet engine and/or into the interior engine nozzle itself. (see Figure A). The noise we hear from jet engines mainly comes from turbulent air created by two streams of air – one hot and one cold – mixing at the back of the engine. The air coming out of the jet engine itself is extremely hot, while the air flowing around the outside of the engine case is much cooler. When the stream of hot air leaving the inside of the engine meets the stream of cooler air from outside the engine, the air becomes turbulent and noise happens!

NASA discovered that the chevrons can smooth out the point where the two air streams meet, reducing turbulence and therefore the noise. One NASA researcher described the effect as having two lawn mowers and turning one of them off.

When NASA first started exploring chevron technology in the 1980s, it wasn't easy to figure out which chevon shapes and depths would work the best; especially when engineers didn't have the technology to know exactly how sound waves behaved. James Bridges, one of the engineers involved with aircraft noise research at NASA, describes some of the problems with creating chevron designs: "Early on, we didn't have the advanced diagnostics, instrumentation and insight to know what we



Size comparison of 737, 777, 787.
Image credit: User:Rolypolyman on en.wiki, SVG conversion by Surachit derivative work: Altair78 licensed with Cc-by-sa-3.0, GFDL. https://commons.wikimedia.org/wiki/File:Boeing_787_size_comparison.svg

had done to make it worse instead of better." He outlines the process used to develop early chevrons: "You have an idea and then you cut out a piece of metal and try it. Sometimes the kernel of the idea might have worked out, but the way you did it wound up causing more noise."

Because aircraft manufacturers are always interested in technologies that reduce noise, chevrons took just a few years to move from being an idea to being included in designs for new engines. Years might seem like a long time, but this is relatively fast for modifications to aircraft engines that have to pass very strict testing. NASA also needed time to develop ways to test the results. Without proper ways to measure noise, turbulence, air temperature, and noise-reduction abilities, building and testing chevrons wouldn't have been productive. Another challenge was figuring out how to maintain engine thrust while also reducing engine noise. Since the beginning of chevron development, many different styles and shapes have been tried and used. Earlier chevrons had a more symmetrical shape. As you can see from Figures A and B, the chevron shapes look the same all the way around.

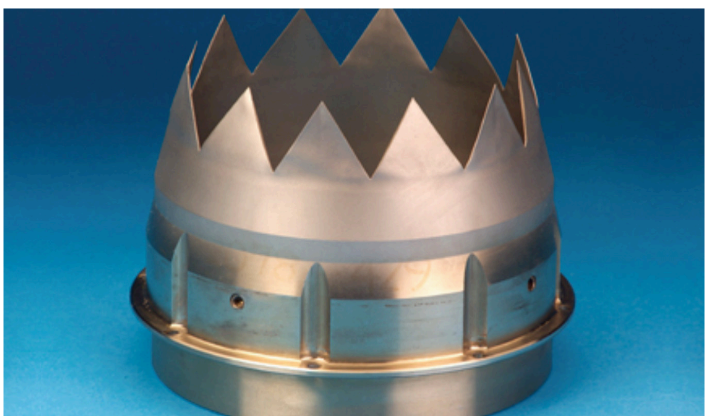


Figure A. An early chevron test article with symmetrical notches.

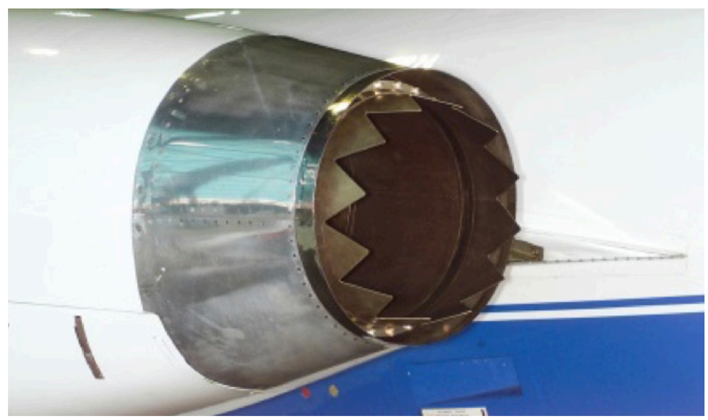
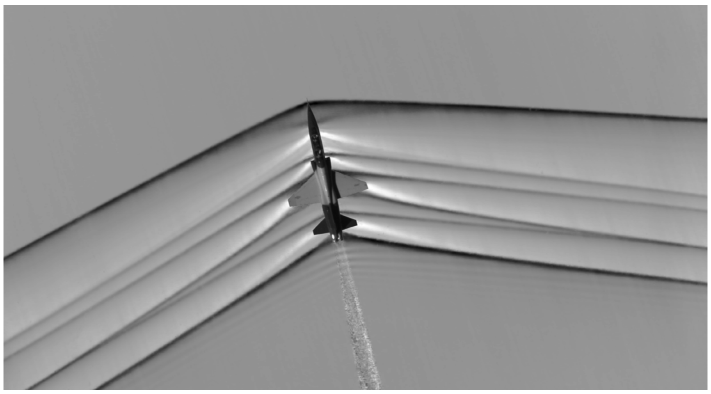


Figure B. An early chevron test article inside an engine nozzle.

Figure C. Final chevron shapes—asymmetrical—in place on engine casing and nozzle.

However, as chevron technology has matured, some newer designs have a less symmetrical shape. Figure C shows chevrons on the engine casing and the nozzle; the chevrons on the top of the casing are deeper than those on the bottom.

THE SCIENCE OF SOUND



Although sound is something most of us take for granted, rarely do we consider the physics involved. Sound comes from many sources – a voice, machinery, musical instruments, computers – but all are transmitted the same way: through vibration.

In the most basic sense, when a sound is created it causes the molecule nearest the source to vibrate. Since this molecule is touching another molecule, it causes that molecule to vibrate too. This continues, from molecule to molecule, passing the energy on as it goes. This is also why at a rock concert, or even being near a car with a large subwoofer, you can feel the bass notes vibrating inside you. The molecules of your body are vibrating, allowing you to physically feel the music.

As with any energy transfer, each time a molecule vibrates or causes another molecule to vibrate, a little energy is transferred to the atoms and molecules the wave touches, which is why sound gets quieter with distance and why louder sounds, which cause the molecules to vibrate more, travel farther. The loudness of a sound is measured in decibels, or dB, with sounds above 120dB having the ability to cause permanent hearing loss to humans.

Jet plane at takeoff	110-140dB
Loud rock music	110-130dB
Chain saw	110-120dB
Thunderstorm	40-110dB
Vacuum cleaner	60-80dB
Normal voices	50-70dB
Whisper	20-50dB
Purring cat	20-30dB
Falling leaves	10dB
Silence	0dB

The loudness of a sound is more of a human perception and interpretation than a scientific quantity or property. However, volume can be measured in terms of the amount of energy that travels over a specified distance within a specific period time. This is measured in watts per square meter, where a watt is energy/time (joules/sec). Another important point of note is that it takes 10 times as much energy to produce a noise that sounds only twice as loud as another. Correspondingly, in order to halve the noise something produces, we have to reduce its energy by a factor of 10.

Learn More About NASA's Research on Sound

NASA web story on chevron research:
https://www.nasa.gov/topics/aeronautics/features/bridges_chevron_events.html

NASA video on chevrons with researcher James Bridges (2010):
https://www.youtube.com/watch?v=xnjIFKNalCg

NASA Prepares for Quiet Supersonic Flights over Galveston, Texas
https://www.nasa.gov/aero/nasa-prepares-to-go-public-with-quiet-supersonic-tech

NASA Starts to Build Quiet Supersonic X-Plane
https://www.nasa.gov/lowboom/new-nasa-x-plane-construction-begins-now

NASA Researchers Explain Sonic Boom and How to Make it Quiet
https://youtu.be/zAlh7NJ49ak

What a Sonic Boom Shockwave Looks Like
https://www.nasa.gov/image-feature/stark-beauty-of-supersonic-shock-waves

NASA Tests Tech to Make Airplanes More Quiet
https://www.nasa.gov/press-release/nasa-technologies-significantly-reduce-aircraft-noise

BUILD A CHEVRON ACTIVITY

INTRODUCTION

NASA research engineers like Danielle Koch (see page 9) study acoustics, and different ways to make jet engines quieter. If you've ever been at or near an airport, you know how much noise pollution comes from jet engines, especially as they take off and prepare to land. Lessening the noise from jet engines can help reduce the impact aircraft have, which is something NASA's Aeronautics Research Mission Directorate works on every day.

Today, you will become an acoustics engineer as you work on reducing the noise that comes from a Thunder Drum, which will simulate a jet engine. Your task will be to build a "chevron," which is an attachment or specific shape that is part of the trailing end of an engine to reduce noise coming from a jet engine. NASA engineers developed the chevron, which is used on engines today. The chevron changes how sound waves from hot air inside the engine mix with the waves from the cooler air on the outside of the engine. The mixing of the hot and cold air cause turbulence, which in turn causes increased noise. The Thunder Drum you will be using today will not be using hot or cold air, but will be using sound waves coming out of the end of the drum.

WARM-UP

As you listen to the demonstration of the Thunder Drum, make a drawing below of what you think the sound waves look like that are being generated by the wire spring. Include arrows that show the direction the sound waves travel. Be sure to include the sound waves that are both inside the drum as well as the waves when they leave the drum. Describe the sound that's created with the Thunder Drum. Include details such as pitch, loudness, etc.

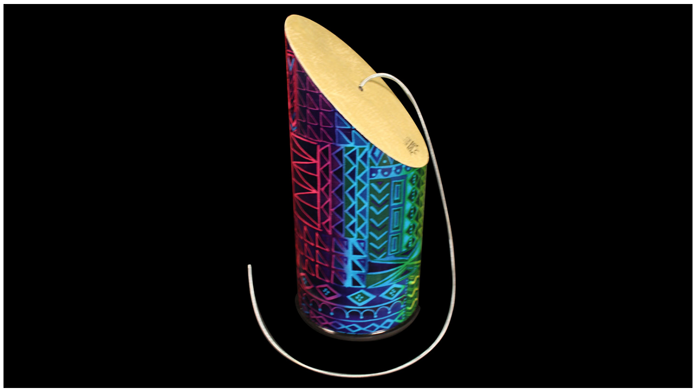
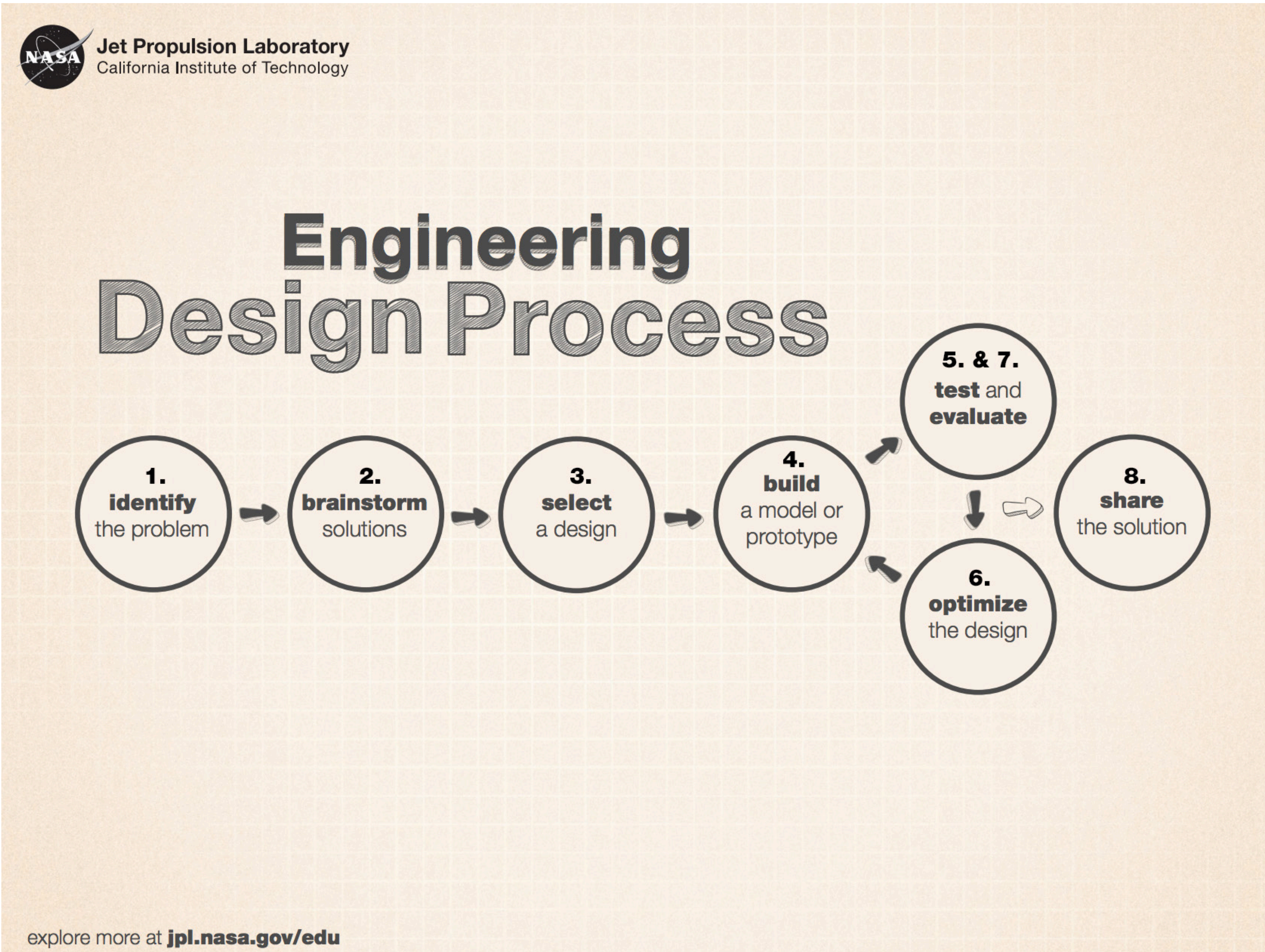


Image: Thunder Drum



To build the chevron, follow the **Engineering Design Process**:

1. IDENTIFY THE PROBLEM

Based on the introduction you just read and the warm up you completed, identify the problem you need to solve.

First you need to list the "rules" you must follow. What are you allowed to use to solve the problem? What are the limits to your solution? If you are building something, what materials can you use? Is there anything you're not allowed to use? How long do you have to complete the task?

2. BRAINSTORM POSSIBLE SOLUTIONS

Brainstorm some ideas, designs, materials, and anything else you can think of. Don't worry about keeping this section neat and tidy; the more ideas you have, the better.

3. SELECT A DESIGN

Use the brainstorming ideas you just created and select a design you are going to develop. Make a drawing of your design. Include a materials list, any measurements you'll need, and any other information that might be helpful. Also, write one sentence explaining why you are choosing this design. Engineers are often asked to "justify" their design and your one-sentence explanation is your justification.

4. BUILD A PROTOTYPE

In this step, build your prototype. This is what you will attach to the Thunder Drum to try out your design. Write down any problems or notes that might be important if you had to build the same prototype again or if someone else had to build it.

5. TEST AND EVALUATE

Test your prototype and record your results. How did it perform? If you have the oscilloscope or decibel meter (or both), include your findings.

6. REFINE THE DESIGN

What needs to be improved? Draw and re-design your chevron. Include details about shape, materials, etc.

7. RE-TEST YOUR DESIGN

Note your results of the re-test. Was it an improvement from your original design? Why or why not? Again, if using an oscilloscope or decibel meter, include those findings. If you are not able to build and/or re-test your design, describe what you think will be different about this design.

8. SHARE YOUR FINDINGS

An important aspect of engineering design is presenting your findings. With your instructor's guidance, put together your problem, design, and results to share with the rest of the group. Be prepared to defend the choices you and your team made, and also be ready to describe what limitations, errors, and ideas you have for moving forward with the design.

MEET DANIELLE KOCH

"Nature Knows Best" host Danni Washington visits NASA engineer Danielle Koch in the aero-acoustic laboratory to explore noise levels from aircraft and how one solution involves materials that mimic sea sponges.

https://www.youtube.com/watch?v=VjDUfHzwTx8
Video Credit: Steve Rotfeld Productions

Danielle Koch, Mechnical / Aerospace Engineer, Acoustics Branch NASA Glenn Research Center

WHAT I DO

I am a **research engineer** in the Acoustics Branch at the NASA Glenn Research Center in Cleveland, OH. I am one member of a team of engineers who are working to make jet engines quieter. If you have ever been near an airport you know how loud the airplanes are when they take off and land. As air travel becomes more and more popular, airports are becoming busier and the neighborhoods around the airports suffer from increased noise pollution. Many communities spend lots of money to improve the quality of life for the people who live near airports through programs that provide sound insulation to their homes. Some airports are helping these communities by also enacting stricter noise limitations. Imagine what life would be like if the airplanes didn't make so much noise in the first place. That is exactly what we are doing here in the Acoustics Branch at NASA Glenn.

Before you can make an airplane quieter, you must first find out what part is making the most noise. At NASA Glenn we are concentrating on two main parts of the engine that we know make a lot of noise—the fan at the front of the engine and the jet at the back of the engine. We are trying to understand how noise is generated and are trying to redesign these parts to make the engine run more quietly. We do this in two ways: experimentally and computationally.

Experiments are conducted here at NASA Glenn in two state-of-the art facilities—the 9- by 15-Foot Wind Tunnel (http://facilities.grc.nasa.gov/9x15/index.html) and the Aero-Acoustic Propulsion Laboratory (http://facilities.grc.nasa.gov/aapl/). In these experiments aerodynamic measurements are taken of the airflow through the fans and jets with pressure and temperature probes, as well as non-intrusive measurement systems such as lasers. Acoustic measurements are also taken microphones placed around the test article.

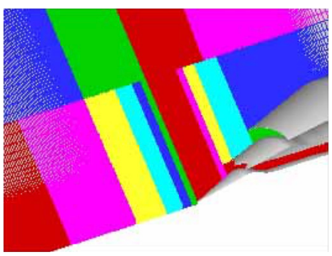
We use **computational fluid dynamics** (CFD) to calculate the flow through virtual models of the fans and jets. CFD is a way to use computers to solve the fundamental equations of fluid motion. We also use computer programs to calculate the noise coming from the engine. We then compare the predicted results to the experimental results. Sometimes we compare experimental results to predictions to prove the theory is correct. Sometimes we use predictions to decide what to test next.

WHICH BRINGS US TO MY PART

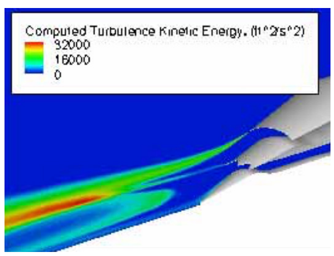
I spend my day working at a computer to generate the aerodynamic predictions for fans and jets that other engineers use to generate the acoustic predictions. There are many things that I do to generate an aerodynamic prediction for a jet. First, our team decides to study a particular nozzle. Nozzle hardware, like that shown in the picture below, is built, installed in a facility, and tested. Next, I am given a computer file containing a description of the nozzle surface (its coordinates), which I use to create a virtual model of a portion of the nozzle, like that shown in the next picture. That model is actually a grid or mesh used for the flow calculations. I then create other necessary computer files describing the nozzle and the flow conditions before running the computer program that calculates the properties of the flow field.

When the calculation is complete, I often create charts of my results, some of which look like that shown in the third picture. I then give my results to someone else who uses them as input into an acoustic code. After we are finished, we draw conclusions from our results and publish technical reports that document our findings. Often we present our findings at local, national, and international technical meetings.

Real Nozzle Hardware



Computational Grid of Nozzle Hardware



Calculated Aerodynamic Results

HOW I GOT HERE

I grew up in Pittsburgh, PA as the oldest of four children. My parents are both teachers and strongly encouraged us to get a good education. I always got good grades in school, and English and science were my favorite classes. It wasn't until the summer of my junior year in high school that I even considered going to college to become an engineer. I attended a one-week summer camp at St. Vincent College in Latrobe, Pennsylvania called "Challenge."

During that week a course in aviation was taught and, at the end of the course, the instructor (who was also a private pilot) took us for a ride in a small four-seater airplane. During one flight I was even allowed to co-pilot for a while. It was so exciting! For the first time I really understood how science and math could be combined to do some really cool things. When I returned home from the program I distinctly remember telling my parents (out on our back porch) that I wanted to become an aerospace engineer. After my parents were convinced that I was serious, they helped me to apply to schools with programs in mechanical and aerospace engineering. I decided to attend Case Western Reserve University (CWRU) in Cleveland, Ohio. My tuition was paid through a combination of scholarships, loans, grants, and contributions from my parents and me. I participated in the work-study program at CWRU that helped me earn both money and experience—I worked in one of the labs in the Department of Mechanical and Aerospace Engineering. I also spent one summer in college as an engineering intern at General Motors in Ypsilanti, Michigan.

I received a Bachelor of Science degree in fluid and thermal engineering sciences in 1990. Immediately after graduation I was thrilled to be hired by NASA Glenn as a test operations engineer and work with a team of people to conduct aerodynamic experiments on jet engine components (turbines). While I was working full-time, I went back to Case Western part-time to earn my master's degree in fluid and thermal engineering sciences. This time, NASA paid my tuition. Through my thesis work, I was introduced to the field of computational fluid dynamics. After graduation in 1998, I transferred into the Acoustics Branch.

PERSONAL BACKGROUND

I had a lot of encouragement as a young student that really helped to get me where I am today. I have many people to thank for that—my parents, family, teachers, friends and co-workers. Although I didn't know it at the time, one of the best things my parents did for me was to send me to an all-girls high school. I said "send me," because it was definitely not my idea. None of my grade-school friends were going there, and I was just plain mad that my pleas to attend another co-ed school were seemingly ignored. Not soon after I started school, though, I realized my parents made the right decision and really enjoyed going there.

I attended St. Benedict Academy in Pittsburgh from my freshman till my junior year in high school. The Academy closed due to declining enrollment, and I had to transfer to North Catholic High School for my senior year. North Catholic was co-ed, and at the time there were more boys than girls there—it was quite a transition. While I received an excellent education at both schools, I believe that the time that I spent at St. Benedict was crucial to my eventual engineering success.

Having attended both an all-girls and a co-ed high school I can attest to the power of peer pressure. I believe the confidence I now have stems from the time I spent learning in an all-girls environment. This might not be true for everyone, but it made a tremendous difference in my life. I think I was more willing as a student to participate more fully in my classes without the pressure to fit into any stereotypes.

You need to have confidence so that you can overcome the obstacles that will come in your way. Obstacles come in many different forms and at many different times. Sometimes you may have trouble in an important class, sometimes you might have trouble finding ways to pay your way through school, sometimes you may not have anyone to cheer you on. It is important to hang in there and try to overcome these things in your way. The projects that we work on here at NASA are ones that have not been solved yet. It takes confidence to try new approaches and to convince others that, even though you aren't 100 percent sure if your ideas will work, that they are at least worth the try. If everything you try works out—great, it is time to celebrate. But more often than not, we learn most from our failures and confidence helps us to pick ourselves up and try again when at first we don't succeed.

Outside of work, faith and family are most important to me. I've been blessed with a wonderful husband and several young children who keep us very, very busy. I work part-time now that I have a growing family. Keeping a balance between my work and my family is the biggest challenge I now face. Raising our children ourselves at home is something important to us, and my husband and I have been fortunate to have careers that are flexible enough to allow us to arrange our work schedules to do that. You can be an engineer and a mother, too!

ADVICE

Take time to reflect on what you like to do, what you are good at, and try to think how these things can be combined into a career. It will be easy to be enthusiastic about your job if you are doing things you like to do. Take every opportunity to learn about different careers. Work as an intern, volunteer, or co-op. As you can see from my example, a little awareness can change your life forever. The Internet can be a great source of information. Use it to learn about careers that may interest you. Sometimes your hobbies can give you a clue to the types of careers you might like. I've enjoyed all types of arts and crafts since ever since I was a child: crochet, painting ceramics, sewing, and making wreaths. Through crafts, I got to learn how to put things together, so it is no surprise to me now that engineering is so appealing.

If you are in grade school or high school and think maybe (just maybe) you may want to be an engineer, I strongly encourage you to take all the science and math classes in high school that you can. You should be taking physics and calculus by your senior year so that you will be prepared for the classes you will be required to take in college. All the engineers I know use a computer, so it will help to take as many classes as you can that can help you to become familiar with programming and using various applications. Engineering is definitely more than math, science, and computers; all of the things you learn in school can be used at work as an engineer. Skills you learn in English class will help you to write better technical reports and give better presentations. Classes in art or woodshop can teach creativity and develop your hands-on skills. The fun you have playing in school sports or in the band will help you to be good at working with others in a team. Life is about learning, and learning doesn't end when you graduate.

If you are a newly graduated engineer and think that someday you may want to have a family, I encourage you to find out as much as you can about flexible job schedules and maternity/paternity leave policies as early as you possibly can. Some jobs are more flexible than others. Telecommuting is one way to add flexibility to your work schedule, but not all jobs are well suited for a telecommuting arrangement. If you want to take off a lot of time when your child is born, you may have to save your vacation time years in advance. A little planning can make a big difference.

If you are a parent or teacher, please help the children in your life recognize their own talents and explore careers that use these talents. There is room for everyone in the field of aeronautics and space, just not for those who are good in math and science. People who enjoy working with their hands could look into pursuing careers in the trades. Machinists, electronics technicians, mechanics, and electricians are among those workers who are so important to the research we do here at NASA. Others may excel at technical writing, public relations, management, or accounting.

It has been very exciting to work at NASA. I am honored to work with such a group of talented people here at Glenn. It is very rewarding to be able to contribute to the research on these challenging projects while balancing my responsibilities both here at work and with my family at home. I think NASA is a special place that really helps to broaden our knowledge of the wonders on this planet and beyond, while making our lives a little better (and a little more quiet).

National Aeronautics and Space Administration

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NP-2018-07-2607 HQ