

## **Design and Development of Augmented Reality Engineering Expeditions - Innovations in Online Engineering Education**

### **Dr. Araceli Martinez Ortiz, Texas State University**

Araceli Martinez Ortiz, PhD., is Research Associate Professor of Engineering Education in the College of Education at Texas State University. She leads a comprehensive research agenda related to issues of curriculum and instruction in engineering education, motivation and preparation of under served populations of students and teachers and in assessing the impact of operationalizing culturally responsive teaching in the STEM classroom. As executive director of the LBJ Institute for STEM Education and Research, she collaborates on various state and national STEM education programs and is PI on major grant initiatives through NASA MUREP and NSF Improving Undergraduate STEM Education and NSF DUE . Araceli holds Engineering degrees from The University of Michigan and Kettering University. She holds a Masters degree in Education from Michigan State and a PhD in Engineering Education from Tufts University.

### **Dr. Bobbi J. Spencer, Texas State University**

B.J. Spencer, Ph.D.

Dr. Spencer is an Assistant of Professor of Practice and the Construction Science and Management (CSM) Program Coordinator in the Department of Engineering Technology at Texas State University where she focuses on the architectural courses, VDCO, and is the internship coordinator. In 2017, she obtained her Ph.D. in Education from Texas State University with the emphasis on professional education. A registered Architect in the State of Texas, she received a Master of Architecture from Texas A&M University in 2007 where she participated in a study abroad semester at the Universita della Svizzera italiana, Accademia di Architettura di Mendrisio, Switzerland following 23 years of industry experience in architecture and construction.

**Cindy Rojas**

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**Araceli Martinez Ortiz, PhD**

Research Associate Professor, Engineering Education  
LBJ Institute for STEM Education and Research  
Texas State University

**Cindy D. Rojas Annicchiarico**

Masters Degree Student  
Department of Engineering Technology  
Texas State University

**BJ Spencer, PhD**

Assistant Professor of Practice  
Department of Engineering Technology  
Texas State University

**Abstract**

This paper presents a framework for the design of augmented reality expeditions in engineering education settings to motivate student learning of engineering fundamentals and careers. The impact of social distancing has been significant for students of all ages and there is a great need for additional and creative online learning resources. The engineering field has an opportunity to not only motivate and support student learning, but to do so by featuring the very innovative nature of engineering as a tool to develop those experiences. A case study regarding the development of NASA-themed aeronautics virtual tours and virtual field trips highlights the capabilities of various software technologies and offers design considerations. The three developed virtual expeditions serve as an opportunity to engage and educate high school and university students. A research plan to collect student feedback on these experiences is also presented.

**Introduction**

As the need for additional modes of learning grow, virtual reality and augmented reality have arisen as technologies that can be used to create new learning experiences for students of all ages. Virtual tours created with these technologies can be useful approaches to train in different areas such as in aerospace, aviation manufacturing, and testing, particularly in situations where on-site, face-to-face training is a challenge. The term "virtual reality" or "VR", first introduced by Lanier (1986) refers to various technologies that allow people to experience and learn in an immersive experience. While the technology has its limitations, it continues to be further improved to allow more immersive experiences and more realistic settings. In recent years, the

industry sector has also started focusing more on virtual reality development as a means of workforce professional development (Berg & Vance, 2017). Instead of spending on high-cost physical prototypes, various industries also use VR to help design, build, and test early designs (PWC, 2016). In the medical community, VR is used as a training tool to expose high-risk and challenging situations to novice health personnel (Liu et al., 2003). In the construction sector, architects and interiors designers use virtual reality before building, to analyze systems and interactions (Mobach, 2008). In the educational sector, virtual reality is used to demonstrate and facilitate learning in a flexible and efficient manner. According to Yildirim et al. (2020), VR can positively benefit students to develop spatial skills and can increase students' engagement towards learning different subjects, including science, technology, engineering and math (STEM). In consideration of these benefits, this project incorporates active learning strategies and VR as an instructional technology in the context of some of NASA's aeronautics projects.

This project will outline an educational design framework that can be used when creating a virtual reality learning experience. A specific learning experience featuring NASA's Experimental Fabrication Division Branch and its various manufacturing, repair, prototyping and modifications shops will be presented as an example, and a student evaluation survey is also developed as an instrument for evaluating user experience.

### **Student Online Learning**

There are many forms in which online education can be delivered. Online teaching can be conducted as a standard or hybrid online course, an interactive webinar, or even a game-based or virtual reality-enhanced learning experience. Online classes are courses taught over the internet. Webinars serve as an online learning event distributed over the internet to a select group of people via their computers. Hybrid courses substitute some portion of the web-based online learning for conventional face-to-face teaching (e.g., video lectures, online discussions, or activities). According to Wladis et al. (2015), online education has become an essential part of university education, especially in community colleges. Since 2010, online enrollment in community colleges has increased by as much as 29% (Allen & Seaman, 2013). Nearly 60% of students in community colleges are enrolled in online courses (Parsad, Lewis, & Tice, 2008). Therefore, the careful consideration of methodology used to teach online classes is vital to accommodate students' need for flexibility and engagement while effectively conveying important concepts, especially in STEM education, which is a sector where there is a shortage representation of professionals. However, according to Jaggars & Xu (2013), some students at the community college level feel discouraged in continuing education due to unsatisfactory experiences with their online courses. So there is an opportunity to improve online teaching, including creating more engaging, interactive online learning experiences, such as by using VR.

There are many benefits of using VR as a tool for teaching STEM subjects: it is an interactive and fun way to learn STEM subjects, provides an engaging way to learn STEM subjects, and offers an opportunity to improve spatial skills (Yildirim et al., 2020). VR allows users to experience concepts or topics that are not easy to access in real-time and in addition, enables learners to experience some aspects of the external world from a novel VR perspective (Wladis et al., 2015).

In higher education, immersive virtual reality has been utilized mainly in laboratory settings. The proposed design of the Experimental Fabrication Division Branch immersive virtual reality will provide an interactive learning experience for high school and university students that will engage and motivate students to learn manufacturing concepts. In this VR experience, students will have the opportunity to learn through different approaches such as with virtual demonstrations, embedded explanatory text, and through educational/motivational videos featuring NASA professionals who encourage students to pursue STEM careers.

### **Hardware and Software Technologies for Virtual Reality in Education**

Technically, virtual reality is an electronic device-generated simulation of a 3-D environment that allows users to interact with a specific virtual experience through electronic devices such as cardboard glasses, computers, goggles, among others. There are different essential categories of VR, such as desktop, immersive, and augmented reality (Zhang et al., 2018). Desktop VR uses a computer monitor as a panel to provide users with a graphical interface (Zhang et al., 2018). Immersion in virtual reality is the feeling of being physically present in a non-physical environment. Perception is generated by surrounding the user of the VR system with images, sound, or other stimuli that provides an engaging, complete atmosphere (Alqahtani et al., 2017). Augmented Reality (AR) applies artificial elements to a live view using a mobile camera (Alqahtani et al., 2017).

The designing of virtual reality involves the use of specific hardware and software and selecting the user interface device. The hardware selection refers to devices such as cameras necessary to create the virtual tour in a software. The software selection is another crucial factor to consider in the designing of virtual reality. Different types of software are used to create a virtual reality experience. The choice of software for the creation of a VR depends on various factors such as cost, interface, ability to insert hotspots and videos, among other attributes further described in the following section.

### **Virtual Reality Hardware for Developers and End Users**

VR experiences, ranging from non-immersive VR, semi-immersive (or desktop), and fully-immersive VR, are categorized according to the level of immersion they offer (Alqahtani et al., 2017). The following descriptions illustrate the various types of VR systems that use different technologies and perform various functions:

#### *Immersion Systems (Fully immersive)*

This form of VR allows the user to wear a data glove and Head Mounted Display (HMD) that monitors the head motions of the user and then switches the visuals accordingly. A data glove is a human-computer interface input device shaped like a glove (Alqahtani et al., 2017).

#### *Non-Immersive system*

A non-immersive interface is often referred to as an augmented reality desktop based on the displayed images as a virtual world window without external equipment such as HMD, and is often referred to as a World System Window. The most commonly used VR system is a desktop system composed of a regular screen monitor to view the virtual world. While these devices have

a lower degree of presence and likely engagement, they can achieve a sufficient level of graphic efficiency, user comfort, and convenience and relatively low cost (Alqahtani et al., 2017). The VR desktop system is the least immersive form and the lowest cost of VR systems. The non-immersive form of VR is the least sophisticated option and is often used in education.

#### *Semi-Immersive system*

The third type of VR system is referred to as a hybrid systems. Semi-immersive hybrid systems might include a VR desktop development and additional devices such as data gloves. It retains the simplicity of the VR desktop system, albeit with a high degree of immersion and the use of physical versions. The digitally presented simulated world is set to the known natural environment in semi-immersive mode. The requirement for building a semi-immersive system is display, tracking sensors, and user interfaces. The semi-immersive framework consists of VR and real-world features by embedding computer graphic objects into the reality scene. The input to this form of program is entered and controlled by users such as the mouse, keyboard, modes of contact, glasses, and joystick (Alqahtani et al., 2017).

### **Virtual Reality Software for Developers and End Users**

There are two main types of VR software used in the development of VR learning experiences: toolkits and authoring systems. Many elements (modeling, coding, and then executing) are generated and built in each VR environment and these elements are then combined into a single package (Bierbaum & Just, 1998). The first type includes special programs for library usage that allow a proficient programmer to create a VR application by introducing a set of functions (Toolkits). However, the authoring systems are a simple program created without having recourse to detailed programming, only to graphical interfaces. Five popular software applications were considered to create an interactive 360° virtual tour. These five software packages are briefly described below: *Google Expedition*, *Theasys*, *3DVista*, *Panoskin*, and *Pano2VR*.

*Google Expeditions* is an immersive platform for learning and teaching that lets you to discover AR objects or to “go” on VR trips. Google Expeditions helps teachers to take their classrooms to exciting destinations on augmented reality field trips.

*Theasys* is a sophisticated platform for the 360 ° Interactive Tour. Users can create media enhanced VR experiences using panoramic images taken from any 360 ° cameras or specialist equipment. Theasys includes a sophisticated VR editor software and a range of customization options to create virtual tours.

*3D Vista* is a software that helps to create panoramic images, 360° videos, and professional interactive tours. By attaching custom boxes, hotspot photos, and customized content, 3DVista is an all-round virtual tour solution that enables creative agencies to create professional 360° virtual tours.

*Panoskin* is a user-friendly virtual tour platform that includes cloud-based solutions for the seamless development of virtual tours and client management. Panoskin is a tool for Google

Street View Workflow Ready that allows photographers to create personalized and immersive virtual tours that are released on Google Maps directly.

*Pano2VR* is a versatile virtual tour app that transforms immersive environments from your panoramic or 360 ° images and videos. Gigapixel images are supported by Pano2VR, meaning users can zoom deep into the picture to see stunning details.

Different features are important when selecting a software to create a virtual reality learning experience. These may include: Immersive audio, 3D effects, analytics tracking, hotspot views and panorama uploads. The use of images with horizontally elongated fields of view with specialized software and equipment allows the user to experience a more 3D VR experience. Compared to a 2D image which appears flat, the panorama experience allows the user to feel immersed and engaged by allowing a wider field of view.

### Design Methodology

The methodology for designing the NASA Experimental Fabrication Branch virtual learning expedition included following the eight systematic steps as represented in Figure 1 and described as follows:

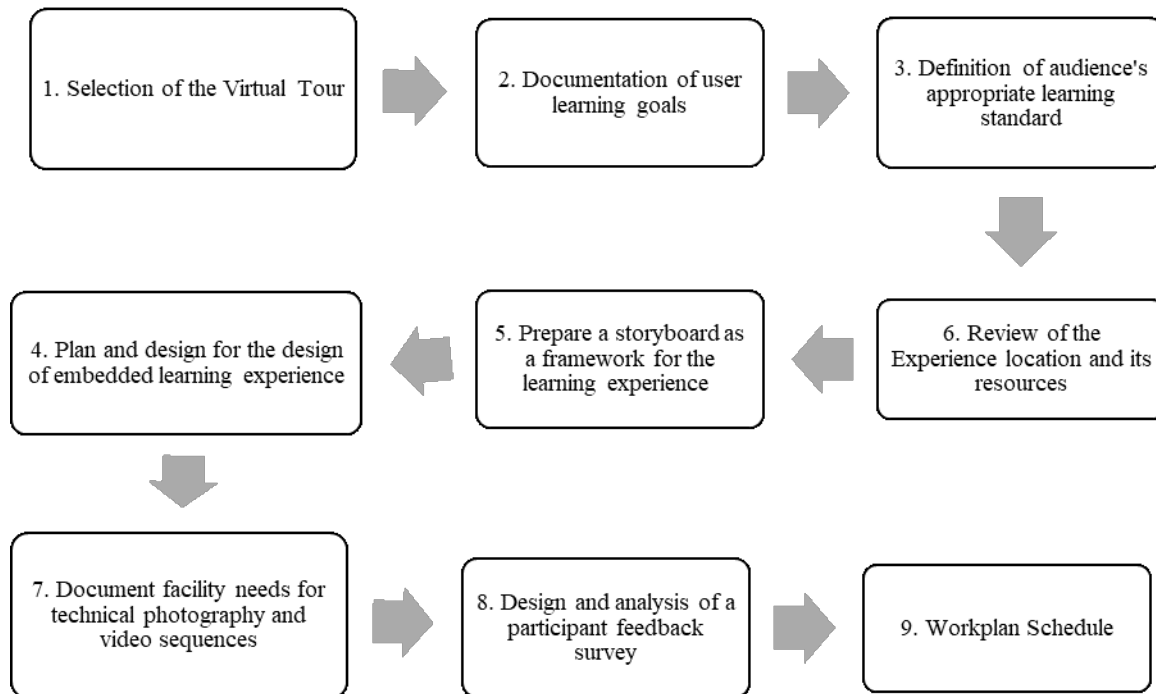


Figure 1. Design Methodology

### Selection of the virtual tour

The selection step may seem obvious, but when designing, if given a choice, there are important elements to consider before moving forward with a particular expedition selection. Literature

should first be reviewed to understand the needs in workforce development that can be addressed by a particular learning expedition. Similarly, the interests of the sponsoring organization (if any) should be considered during this step as well. In this case, our sponsoring organization was the Armstrong Research Center and the Aeronautics Research Mission Directorate. Since workforce literature highlighted the importance of manufacturing, advanced machinery processes and the need for skilled technicians, we decided to focus on the NASA Experimental Fabrication Branch.

## **2. Documentation of user learning goals**

We defined high school and university students as our audience for this VR experience. So, a document of the learning user goals was defined to assure that students would gain the required knowledge during the virtual tour experience.

## **3. Definition of audience's appropriate learning standard requirements**

Additional learning standards in specific content areas of science, technology, engineering or mathematics was identified by searching for these particular set of particular state standards, common standards, or university course learning objectives. In this case, the focus was on physics and mechanics, and careers in aeronautics design and technical testing.

## **4. Review of the experience location and its resources**

This section refers to the additional resources that must be considered, especially if the resources (photos, videos, etc.) are not publicly available and must be requested of the sponsoring organization.

## **5. Prepare a storyboard as a framework for the learning experience**

A storyboard is a graphical outline of the main points of the learning experience presented step by step. The storyboard is outlined and then included – in this case, for the Experimental Fabrication Branch educational virtual reality.

## **6. Plan and design for the development of embedded learning experiences**

During this step, consideration and planning of the software needed to create the virtual experience is carried out. Different software may be assessed in terms of cost, usage, and technical concepts that are important for selecting the software for creating a particular virtual tour. In our case, five different software applications were analyzed. A tentative layout of the virtual reality sequence is proposed by this time in order to assure complete consideration of all necessary factors for this virtual experience.

## **7. Document facility needs for technical photography and video sequences**

During this step, the facility needs are carefully defined and documented in regards to the virtual layout and the needed collateral for each “station”. The information that will be requested includes photographs, videos, or technical information that will serve as inputs for this virtual learning experience.

## **8. Design and analysis of a participant feedback survey**

Assuming that that a product quality or learning research goal is also part of the project, this step allows for the design and development of a specific participant feedback survey. This survey should be carefully developed based on research or product quality questions following robust survey development methodology. The surveying methodology will allow for either foundational user response to the experience or, if a significant sample of user data is collected, complex analysis can be carried out for potential publication. A preliminary survey tool was developed for this stage of the project and is included in the appendix.

## 9. Creation of a work plan schedule

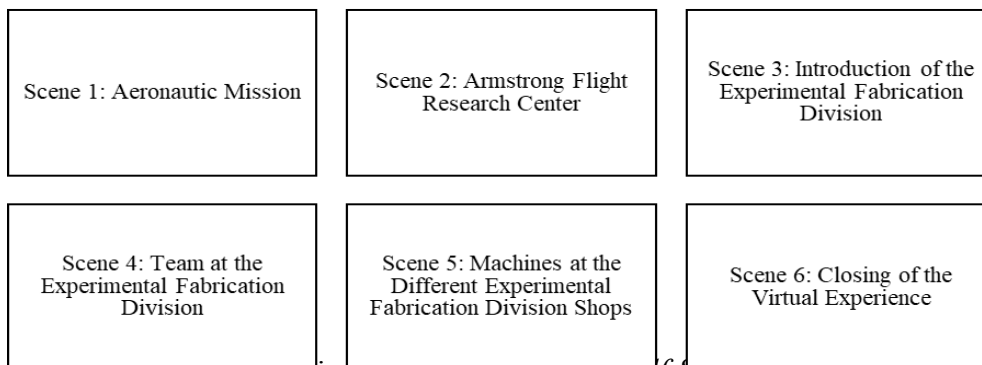
During this step, a very detailed workplan is laid out related to the full project and all its inputs, outputs, and milestones.

### Limitations

This paper presents a project in progress. The augmented reality experience is not yet complete and data from the users will be collected at a later time. Once the VR experience is complete, the survey instrument will also be tested for repeatability. The two important qualities of surveys are consistency and accuracy, so these will be assessed for reliability and validity.

### Design of the Experimental Fabrication Branch Storyboard

The Experimental Fabrication Branch was selected to be designed as the NASA virtual experience from the Armstrong Flight Research Center. The Armstrong Experimental Fabrication Branch is a manufacturing, modification, and repair center. It consists of five shops that provide machining, sheet metal, tubing, welding, and composite fabrication for aerospace and ground requirements. The design of the Experimental Fabrication Branch VR aims to educate and engage high school and university students with different physical mechanical principles that operate in some of the machines in different shops. This virtual tour also includes important aspects of safety considered for the manufacturing, modification, or reparations of the other projects implemented at the Experimental Fabrication Division Branch. The scenes defined for the virtual tour are summarized in Figure 2. The storyboard was designed to highlight NASA's Aeronautic Mission to students, while featuring the Experimental Fabrication Branch and its technologies. The storyboard outlines the experiences planned to allow students to gain a global vision of the importance of manufacturing machines and tools while featuring the cutting edge application of these on NASA R&D aeronautics projects such as x-planes and supersonic vehicles.





## Figure 2

### *Storyboard for the Experimental Fabrication Division*

The first scene provides a global vision of the NASA Aeronautic Vision. This scene intends to provide students with an overview of the NASA Aeronautic Mission. Since the Experimental Fabrication Division is part of the Armstrong Flight Research Center, scene number two intends to present the Armstrong Flight Research Center background, including some of the projects that this research center conducts, supported by the Experimental Division Branch. Scene three introduces information related to the Experimental Fabrication Branch and its different shops. In this scene, students will familiarize themselves with other processes conducted in this division: plastic processes, steel and metal production, and renewable processes. Additionally, concepts related to machining, fabrication, and welding applications are presented in this scene. Also, this scene identifies the importance of accurate documentation in all aspects of manufacturing. Scene four provides information about the Experimental Fabrication Team in terms of career insight and educational background of technicians, scientists and engineers on the team. This scene intends to engage high school and university students to introduce careers related to STEM. This scene presents opportunities, career pathways and reinforces robust interviewing techniques. In scene five, users can access video hotspots that contain videos or images of the most relevant machines in the Experimental Fabrication Branch shops and explanations of their names and functions. The most pertinent machines' functionality is explained in terms of physical and technical principles that are easy to understand for high school and university students- making connections to physical science learning standards. Scene six is the closing of the virtual tour and will present future NASA projects in which the Experimental Fabrication Branch is involved. Table 1 summarizes some of the information that will be included during each scene.

**Table 1**

### *Important Information to be Considered per Scene*

<p><b>Scene 1: Aeronautic Mission</b></p> <ul style="list-style-type: none"> <li>❖ Videos and resources that engage students in the virtual experience aligned with the Aeronautic Mission.</li> </ul>
<p><b>Scene 2: Armstrong Flight Research Center</b></p> <ul style="list-style-type: none"> <li>❖ 360 Images from the Armstrong Flight Research Center</li> <li>❖ Background information from the go for flight expedition</li> </ul>
<p><b>Scene 3: Introduction of the Experimental Fabrication Branch</b></p> <ul style="list-style-type: none"> <li>❖ This scene will present the different shops at the Experimental Fabrication Division</li> <li>❖ There are five shops: Machine shop, Sheet Metal, Chemical Crib, and Building 703</li> <li>❖ During this scene, the following questions and information must be answered and included, respectively:           <ul style="list-style-type: none"> <li>- Why are there different types of shops?</li> <li>- Why is the machinery there necessary?</li> <li>- Address the importance of testing as a measurement of safety</li> <li>- Mention that the Experimental Fabrication Brand is part of the Armstrong Flight Research Center</li> </ul> </li> </ul>

- Mention some of the projects that these different shops have supported
<b>Scene 4: Team at the Experimental Fabrication Division</b> Information to be shown in this scene: <ul style="list-style-type: none"> <li>❖ Career information</li> <li>❖ Preparation and skills</li> </ul>
<b>Scene 5: Machines at the Different Experimental Fabrication Division Shops</b> <ul style="list-style-type: none"> <li>❖ Relevant machines from the different shops</li> <li>❖ Description, name, and scientific principles from each selected machine</li> <li>❖ Machines operation through a video</li> <li>❖ Images or videos of the selected machines.</li> </ul>
<b>Scene 6: Closing of the Virtual Experience</b> <ul style="list-style-type: none"> <li>❖ Future projects that NASA has been developed</li> <li>❖ Recap information from the initial introduction</li> </ul>

### **Integration of Educational Content**

The Experimental Fabrication Learning virtual tour is designed in a way that all the scenes presented in the virtual tour include educational content in a manner that is entertaining, informational, inspiring, and engaging.

### **Focus on the Experimental Fabrication Division Shop Processes**

#### **Machine Shop**

The capability of the Armstrong Machine Shop is unique, compared to most industrial shops of its size. In the machine shop, tasks arrive in the form of a standard work request, generally originated by a design engineer or operations engineer and coordinated through the maintenance branch. Working from simple descriptions or sketches, engineering drawings, all the way up to blueprints, and Computer-Aided Design (CAD) models accompanying the work request, personnel in the Machine Shop remain with the part until it is completed and can be handed over to the customer. The Machine Shop supports the Aircraft Maintenance and Modification Branch and other organizations at Armstrong that need unique parts for vehicles, facilities maintenance, support equipment, or utility systems.

#### **Sheet Metal Shop**

The Sheet Metal Shop carries out all modification and repair work on aircraft, ranging from creating something as small as an aluminum bracket to which electrical wires will be attached up to replacing or modifying wing spars, fuselage ribs, control surfaces, and large areas of the exterior skin. According to NASA (2020), the following projects have been supported by the Sheet Metal Shop:

- Fabricating the belly-mounted F-104 pylon used to test space shuttle tiles for water resistance and aerodynamic loads.

- Modifying a large Convair 990 jetliner fuselage so it could be used as a landing gear testbed to evaluate space shuttle tires for wear under varying landing and load condition.

### Chemical Crib




Armstrong's 3,200-square foot chemical crib is a highly successful centralized site for dispensing, mixing, labeling, and storing chemicals. The chemical crib also performs vital solvent recycling, liquid reduction, compaction operations, and chemical disposal. The program's benefits have had positive bearings on the nation, and NASA, through a reduction in procurement and disposal costs, reduced potential for workforce exposure, reduced risk of EPA-non-compliance, and an increase in collaborative partnerships.

### Machinery in the Experimental Fabrication Branch shops

The primary machines used in the Experimental Fabrication Division are the sixteen featured on NASA's website. Table 3 illustrates the machines that were selected to be presented in the virtual tour: Computer Numerical Control (CNC) Milling, Electrical Discharge Machine (EDM), and Hydraulic Shear.

**Table 3**

*Selected machines to be presented in the virtual tour (images from NASA, 2021)*

<b>Machine Name:</b> Computer Numerical Control (CNC) Milling	<b>Machine Name:</b> Electrical Discharge Machine (EDM)	<b>Machine Name:</b> Hydraulic Shear
<b>Shop:</b> Building 703 Fabrication Shop	<b>Shop:</b> Machine	<b>Shop:</b> Metal
		

### Building Fabrication Shop Machine - Computer Numerical Control (CNC) Milling Machine

The Fabrication shop has unique computer numerically controlled (CNC) milling capabilities, including a vertical machining center 30 x 16 x 20 in., 21-position tool changer with three-axis capabilities. The process of milling uses a specialized rotary cutting tool to remove material from a workpiece surface. The process can be used for cutting holes or notches, as well as for

sculpting a three-dimensional piece. Unlike drilling or traditional cutting, the tool in a mill can perform countless unique, small cuts to remove material from a surface in chips.

With CNC technology, machinists and engineers can control vertical milling machine operations using sensitive computer systems. These systems collect design information directly from drawings, which is converted into codes, and then translated into operational commands through the system. Milling operations are performed very precisely. CNC milling machines at the Experimental Fabrication Branch held very precise tolerances to  $\pm 0.0002$  inches. A CNC vertical mill machine has cylindrical cutters oriented vertically on a spindle axis. This is especially useful for plunge cuts and drilling. Some vertical machining centers can be manipulated on up to five axes to fabricate custom shapes, slots, holes, and details in three-dimensional parts.

The CNC mill found at the Experimental Fabrication Branch has a 5-axis press brake, rated at 175 tons that can bend up to 1"-thick steel plate. The press brake is also capable of bending parts up to 12' in length. All the necessary support equipment is also on-site such as brakes, shears, saws, and lathes.

### **Machine Shop – Electrical Discharge Machine**

An Electrical discharge machining (EDM) is a non-traditional machining process based on removing material from a part using a series of repeated electrical discharges between tools, called electrodes, and the amount being machined in the presence of a dielectric fluid. The EDM looks like a massive bandsaw. Instead of a saw blade, the computerized machine uses a 0.010 brass wire carrying an electrical current to cut any material that will conduct electricity. The electrical discharge burns the metal to make a smooth, clean-cut while the computerized machine automatically guides the wire without the aid of a human operator.

The machine shop's EDM machines use one of the most accurate manufacturing processes available for making small odd-shaped angles, detailed contours, or cavities in hardened steel and exotic metals like titanium. Because of its versatility in cutting small, delicate, and complex items, EDM has become an integral part of making prototype and production parts for space, industry, and commercial applications.

### **Metal Shop – Hydraulic Shear**

There are four primary methods used to shape sheet metal: bending, shearing, rolling, and spinning. The shearing method is performed by two blades, one fixed in the shear bed and the other moving vertically with little or no clearance. Shear action moves progressively from one side of the material to the other. The angular configuration of the blades is called the rake. Both rake and clearance are a function of the type and thickness of the material to be cut.

Hydraulic shears are a type of shearing machines that are driven or powered by a hydraulic cylinder. Hydraulic presses can generate extremely high forces to cut metals or other materials. In the metal shop, one of the most used units is a hydraulic shear that can cut a piece of metal up to five-eighths of an inch thick and as much as eight feet wide.

### Virtual Tour Layout

A layout of the virtual site was developed as a guide for the development of the Experimental Fabrication Division Branch VR, and it is illustrated in Figure 5. A site plan with real measurements will be required to assure that appropriate technology and photo breadth requirements can be calculated.

**Figure 5**

*Layout of the Experimental Fabrication Division Tour*



### Design of the survey participant feedback

Once the virtual tour is preliminarily finalized, user feedback data will be collected using a virtual tour feedback survey. This survey was adapted from an online learning experience feedback form (Martinez Ortiz, 2020) and modified for the particulars of the virtual reality experience. The survey developed is provided in the appendix section and includes different aspects of the virtual tour. After participants take this survey, an analysis of the information will be conducted through analytical tools such as Qualtrics to study the possible improvement in the virtual tour, as well as impact upon student learning and motivation leading to a more effective learning virtual experience for high school and university students.

### Workplan schedule

A work plan schedule is designed to complete the NASA Experimental Fabrication Branch learning Virtual Reality. This work plan schedule is in the appendix section.

## Conclusions

Virtual expeditions are a useful tool for training in different areas of aerospace and aviation manufacturing and testing, particularly in situations where in-site, face-to-face training is a challenge. In the education sector, virtual experiences represent an attractive technological tool that improves students' active learning. In this project, a virtual NASA expedition learning experience of NASA's Experimental Fabrication Division Brach, a manufacturing, repairing, and modification facility dedicated to supporting the aeronautics projects at the NASA Armstrong Research Center, is developed in terms of the design of the experience and the evaluation of different types of software resources.

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**APPENDIX A****VIRTUAL TOUR FEEDBACK SURVEY**

**Please mark the item below that best describes you:**

- |  |   |
|--|---|
| <input type="checkbox"/> High school Student   | <input type="checkbox"/> Teacher            |
| <input type="checkbox"/> Undergraduate Student | <input type="checkbox"/> University Faculty |
| <input type="checkbox"/> Graduate Student      | <input type="checkbox"/> Other              |

**Please mark the Online Resource that you are providing feedback on today:**

- Resource 1- Experimental  
Fabrication Branch
- Resource 2- X-57 Maxwell  
Electric Propulsion Airplane Design
- Resource 3- The Armstrong  
Flight Loads Laboratory



**Please rate each item below:**

1. Did you know about virtual reality technologies prior to taking this virtual experience?  
 Yes  
 No

Comment:

2. If you answer yes to question 1, what type of virtual reality devices have you use?  
 Oculus Rift  
 HTC Vive  
 Samsung Gear VR  
 Google Cardboard  
 Treadmills and Haptic Gloves  
 Other, Which One (s) \_\_\_\_\_

Comment:

3. How was the photo/ video presented in this virtual experience?  
 Excellent  
 Very good  
 Good  
 Fairly good  
 Not good

Comment:

4. Was the science, technology, engineering, or mathematics major concept(s) in this resource clear to you?  
 Very clear  
 Clear  
 Somewhat clear  
 Not very clear  
 Not clear

Comment:

5. To what extent was this resource helpful to you in developing a better understanding of the NASA mission or product?  
 Very helpful  
 Helpful  
 Somewhat helpful  
 Not very helpful

Not helpful

Comment:

6. To what extent did the resource help you gain insight in how to explain the engineering and design concepts in application in the real world?

Very helpful  
 Helpful  
 Somewhat helpful  
 Not very helpful  
 Not helpful

Comment:

7. To what extent did this the resource help you develop a better understanding of STEM careers at NASA?

Very helpful  
 Helpful  
 Somewhat helpful  
 Not very helpful  
 Not helpful  
 Not Applicable

Comment:

8. Was the length of this resource appropriate?

Time was just right  
 Time was too long  
 Time was too short  
 Not sure  
 No answer

Comment:

9. Was the resource engaging and effective in relaying the key information about the NASA facility or product and the science and engineering practices employed by NASA STEM professionals?

Very engaging and effective  
 Engaging and effective  
 Somewhat engaging but not effective

- Not engaging but was somewhat effective
- Not engaging or effective

Comment:

10. How easy was to navigate the virtual experience?

- Very easy
- Easy
- Somewhat easy
- Not very easy
- Not easy

Comment:

11. What part do you they like the most from this virtual experience?

Comment:

12. What aspect was challenging or can be improved?

Comment:

13. Did you learn about the technologies used in this virtual experience?

Comment:

14. Please share any other comments that would help improve the resource:

Comment:

**Thank you for providing your feedback as we strive to improve our products to better serve the needs of students, educators and public at large.**

## APPENDIX B

*Workplan schedule for the competition of the Experimental Fabrication Branch virtual tour*

Activities	Completed	Pending	Estimated Time				
			December	January	February	March	April
Selection of the virtual tour	X						
Documentation of user learning goals		X					
Definition of audience's appropriate learning standard	X						
Review of the Experience location and its resources	X						
Prepare a storyboard as a framework for the learning experience	X						
Planification and designing of the development of embedded learning experiences		X					
Documentation facility needs for technical photography and video sequences		X					
Design and analysis of a participant feedback survey		X					
Creation of the Experimental Fabrication Branch learning virtual reality		X					