COREolis VR Artificial Gravity Simulator

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PORTFOLIO ELEMENT A

Presentation and Justification of the Problem

Problem Statement

Develop a virtual reality or augmented reality simulation that will help train astronauts and engineers of the difficulties in a rotating spacecraft 15m in diameter and rotating at a sufficient velocity to produce 1g.

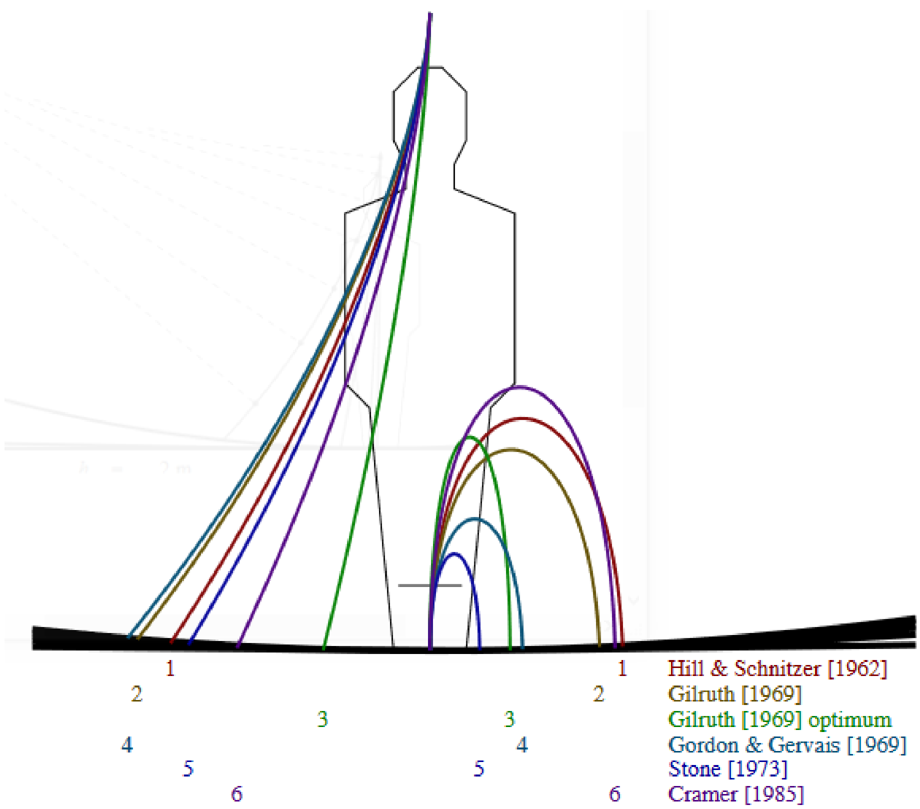
Problem Background

Why this is a problem that needs to be solved (context for problem statement):

- No real world application of toroidal artificial gravity has been attempted
- Various issues with fitness and calibration would be present without proper training for these astronauts
- A simulation would act as a proof of concept for this method of artificial gravity to visualize the problems associated with it

Several difficulties arise when sending astronauts out to space. Whether it's going on a mission to Mars or rotating around the Earth, the effects of the different forces in space on the astronauts can lead to many problems when they return home to Earth. A way to mitigate this problem has been suggested to be to simulate the effects of gravity on the way to Mars. Doing so would be able to minimize the effects zero gravity would have on a person in space. Rotating a ship would be able to create a force that would be relatively similar to that of gravity on Earth.

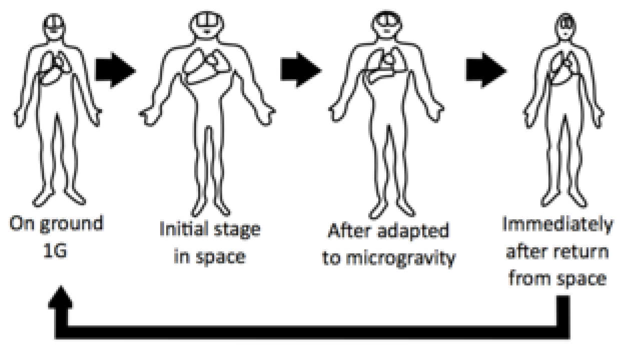
"Artificial gravity at the minimum 'comfortable' radius and tangential velocity proposed by various authors"'
-Theodore W. Hall



Validation of the Problem

Spending a considerable amount of time in space where there is little to no gravity can pose damaging health issues for a person. Astronauts often stay in space for long periods, and the lack of gravity can pose serious issues for them physically. Though, in this current time, organizations do not have the technology to create a system to artificially create a force of gravity on astronauts, many designs and ideas have been proposed to fit this purpose. To test the details and to visualize these designs, a simulation for astronauts would aid in fully realizing what this toroidal landscape would entail. Extended stellar travel would come with adverse health effects for astronauts in this environment of microgravity, and, to counteract this, a system of artificial gravity would reduce the strain of this process.

Effects of Zero G's On the Body



Scholarly Articles

"NASA has learned that behavioral issues among groups of people crammed in a small space over a long time, no matter how well trained they are, are inevitable." (Perez)

"The return from 0g to 1g leads to an inability to maintain an appropriate blood pressure when in an upright position—orthostatic intolerance—and insufficient blood flow to the brain. Astronauts returning from orbit therefore have to rest for several minutes, and the time needed to normalize their blood pressure increases with the time spent in 0g. This could mean that astronauts travelling to Mars—which would take at least one year in 0g—would need considerable time to readapt to gravity after landing there or after their return to Earth, unless we find a technological solution to the creation of artificial gravity on a spaceship." (Setlow)

"Theoretically, Coriolis sickness should not be a problem if the astronauts keep their head still during centrifugation, such as in an artificial gravity sleeper… However, it is foreseen that the crew activity schedule requires the astronauts to combine their artificial gravity training with other forms of fitness. In addition, it is questionable whether an artificial gravity sleeper would be effective in retaining sensory motor functions with the astronaut being asleep.” (Bukley 108)

“During space travel, the primary effects of microgravity on skeletal muscles include the deterioration caused by the lack of gravity on slow-twitch muscles, with conversion from slow to fast muscle fiber type; and decreased fiber size in rats (Riley et al., 1990; Jennings and Bagian, 1996). Young rats subjected to 18 days of hind-limb unloading developed an abnormal gait that persisted, suggesting permanent damage to the neuromuscular pathway (Walton et al., 1997). Significant atrophy has been observed in human muscle after only 5 days in space, but the time course of deterioration has not been established.” (Meleshko et al)

Citations

Perez, J. (2016, March 30). The Human Body in Space. Retrieved December 04, 2020, from https://www.nasa.gov/hrp/bodyinspace/
Setlow, R. B. (2003, November). The hazards of space travel. Retrieved December 04, 2020, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1326386/
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Institute of Medicine (US) Committee on Creating a Vision for Space Medicine During Travel Beyond Earth Orbit. (1970, January 01). Risks to Astronaut Health During Space Travel. Retrieved December 14, 2020, from https://www.ncbi.nlm.nih.gov/books/NBK223785/
https://upload.wikimedia.org/wikipedia/commons/8/8b/Space_body_fluid.svg
Hall, Theodore W. *Artificial Gravity Visualization, Empathy, and Design*. 19 Sept. 2006 from https://core.ac.uk/download/pdf/187248978.pdf

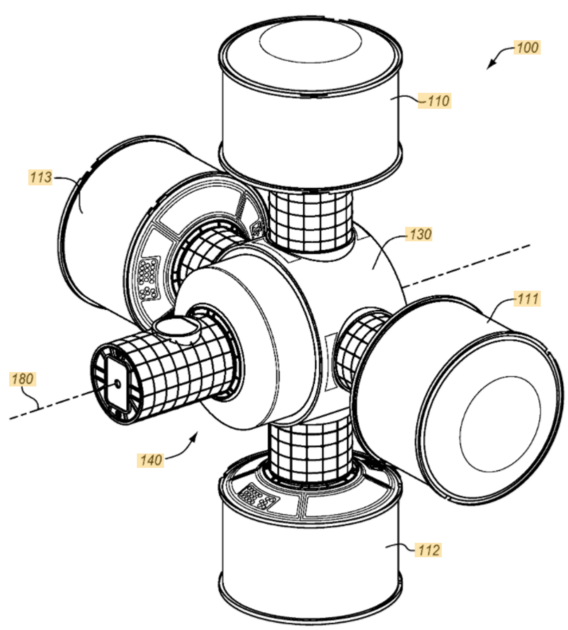
PORTFOLIO ELEMENT B

Documentation and Analysis of Prior Solution Attempts

Introduction

Since a simulation of artificial gravity has not been fully realized, nor has a device for artificial gravity been developed, few patents would meet the exact criteria of our problem. However, many patented aspects of virtual reality technology would aid in our progress as well as designs for tangible artificial gravity solutions. While finding such patents for these mechanisms, we discovered what kind of designs had been created for a future solution to artificial gravity, what advantages these methods would yield, and how they would function in microgravity. This would advance how our digital visualization of these products could progress and feel for the individual.

Patents



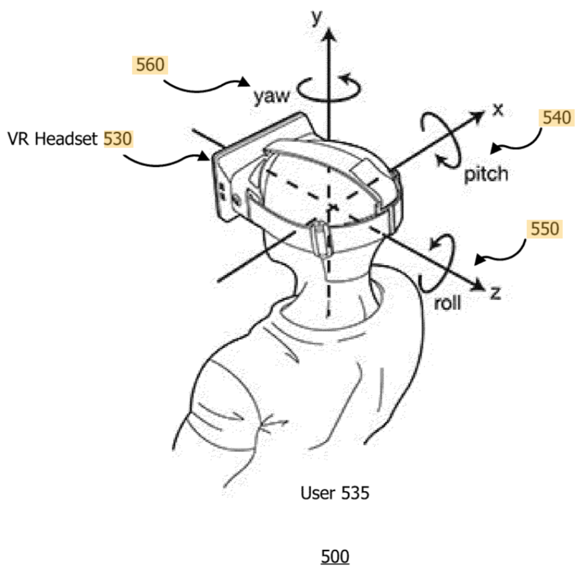
Patent Name: Artificial gravity system with rotating hub that is sealed with rotary seals

Patent Number: US10099805B2

Date of Patent: 16 October 2018

Patent Abstract: A habitation module that provides an artificial gravity environment. In one embodiment, the habitation module includes a core structure having cylindrical sections spaced apart from one another, and a hub that slides over one of the cylindrical sections of the core structure to span a distance between the cylindrical sections. The hub includes a plurality of portals spaced radially around a circumference of the hub, and gravity chambers attach to portals of the hub. A drive mechanism rotates the hub about an axis in relation to the core structure to simulate a gravitational force within the gravity chambers. Rotary seals form an air-tight seal between the hub and the cylindrical sections of the core structure so that the interior of the hub and the gravity chambers may be pressurized.

Pros and Cons: This design consists of a method of artificial gravity without a toroidal structure and instead, a group of cylindrical units connected through a central node rotating at a sufficient enough speed to produce a relative force on the passengers. Though this system would feel more natural for those inside, traveling to other portions of the vessel would prove to be a challenging task as the change in gravity would be extremely disorienting.



Patent Name: Perception Based Predictive Tracking for Head-Mounted Displays
Patent Number: US20140354515A1
Date of Patent: 23 June 2015
Patent Abstract: There is disclosed a method of and apparatus for predictive tracking for a head mounted display. The method comprises obtaining one or more three-dimensional angular velocity measurements from a sensor monitoring the head mounted display and setting a prediction interval based upon the one or more three-dimensional angular velocity measurements such that the prediction interval is substantially zero when the head mounted display is substantially stationary and the prediction interval increases up to a predetermined latency interval when the head mounted display is moving at an angular velocity of or above a predetermined threshold. The method further includes predicting a three-dimensional orientation for the head mounted display to create a predicted orientation at a time corresponding to the prediction interval, and generating a rendered image corresponding to the predicted orientation for presentation on the head mounted display.

Pros and Cons: Since this design is a general technology applied by most internal tracking VR headsets, it applies to most devices within our needs and budget. The limitations with this form of tracking entails the loss of body tracking and limits the only interactable portions of the user to their hands (with a controller) and head.

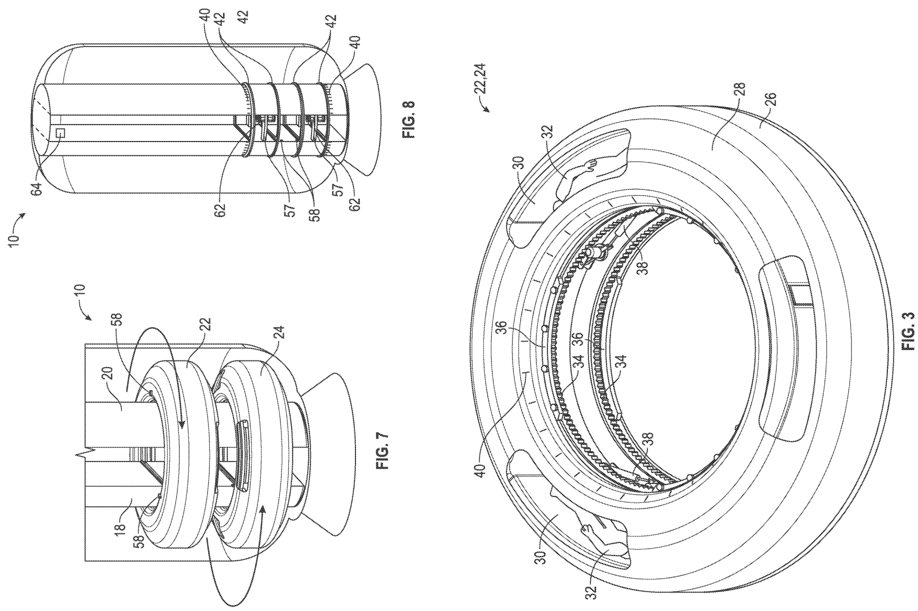


FIG. 8

FIG. 7

FIG. 3

Patent Name: System and Method of Providing Artificial Gravity
Patent Number: US9359091B2
Date of Patent: 15 May 2014
Patent Abstract: An artificial gravity system and method for a spacecraft including a least one pair of rotatable stages wherein each stage is capable of rotating about at least one structural support in the spacecraft and wherein the rotatable stages in each pair of rotatable stages counter-rotate one another wherein each stage is capable of accommodating a plurality of occupants. The stages may be circular and deployable. The system may also include dynamic balance equipment in each stage consisting of a fluid redistribution design utilizing fluid pumping systems, storage- and reserve-volume tank pairs to redistribute fluid throughout each stage for optimal mass balance, stage- and spacecraft-mounted laser-tracking equipment for redundant speed measurement, drive assembly and a brake motor and wheel assembly, foldable structural support arms capable of reducing the radial space of each stage during takeoff, and an inertial measurement unit capable of detecting overall vehicle rotational rates.
Pros and Cons: The presented design contains a large mass of mechanisms and moving parts causing a larger building cost and development time as well as a more likely change of mechanical failure. However, the size of this design would closely reflect gravity on earth as the change in gravitational acceleration from an occupants top and bottom would be much smaller

than a compact design. This would accommodate a large amount of individuals and equipment due to its shape being a torus rather than multiple cylinders.

Summary

While other methods of artificial gravity have been conceptualized, no widespread or public program exists to simulate and visualize this process. The designs of these methods of artificial gravity are too early in development to be realized in reality and only exist within patents and ideas. Since our design is a non-tangible, visual representation and proof of concept for a toroidal design of artificial gravity, it exceeds the current lack of this form of device.

PORTFOLIO ELEMENT C

Presentation and Justification of Solution Design Requirements

Introduction

Due to our affiliation with the NASA organization, specific parameters and specifications were given by NASA engineers for the specific project we are doing. However, we also had to abide by the constraints given by Meridian for the Engineering Design and Development project. These two sets of criteria established most elements of our development including many virtual actions, budget, and needs within the program. While these specific criteria were to be met during designing and constructing our program, objects, background, design, and layout all impact the experience of the player. Although not stated in either our EDD requirements or that of the NASA Hunch program, the non-functioning objects and execution of interaction would be determined by us.

Primary Stakeholders

Users: NASA
Buyers: NASA-Hunch
Sellers: Meridian
Manufacturers: COREolis

Communication with NASA-Hunch

During our interactions with members of the NASA-Hunch program, we were able to understand what priorities would be necessary to develop a product that suits the needs of astronaut testing. While NASA determined what specific interactable objects would be required, with some leniency, we were able to create other objects fitting in this world as well as visuals to absorb the tester and diminish the gap between the individual and the program.

Design Priorities (Highest Priority Top in Descending Order)

Functionality	- Physics
	    - Centrifugal Acceleration
	    - Collisions
	    - Coriolis Effect
	- Player Interaction
	    - Object Interaction
	        - Grabbing
	        - Lever and Control Interactions
	    - Player Climbing

	- Hand Physics and Tracking - Layout

Visuals	- Design
	    - Modeling
	    - Texturing
	- Lighting
	- Post Processing

Conclusion

The product should accurately reflect the forces within a rotating artificial gravity mechanism with precise forces. Users should experience a close to the real process of toroidal motion in this simulation and their interaction with the world should feel as tangible as possible with our technology. While the limit of the controller disconnects the actions of the player from the simulated environment, grabbing and other direct motions are simplified to become user friendly. Forces should seem as they do in our reality due to our physics engine and object will travel as expected in a rotating environment. The controls and locomotion of the player should feel natural and not inhibit their ability to move about and touch their surroundings.

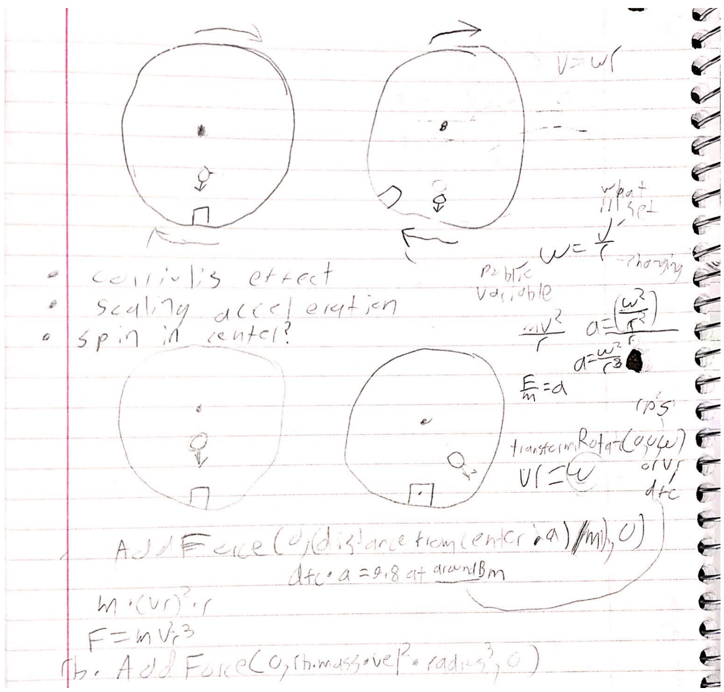
PORTFOLIO ELEMENT D

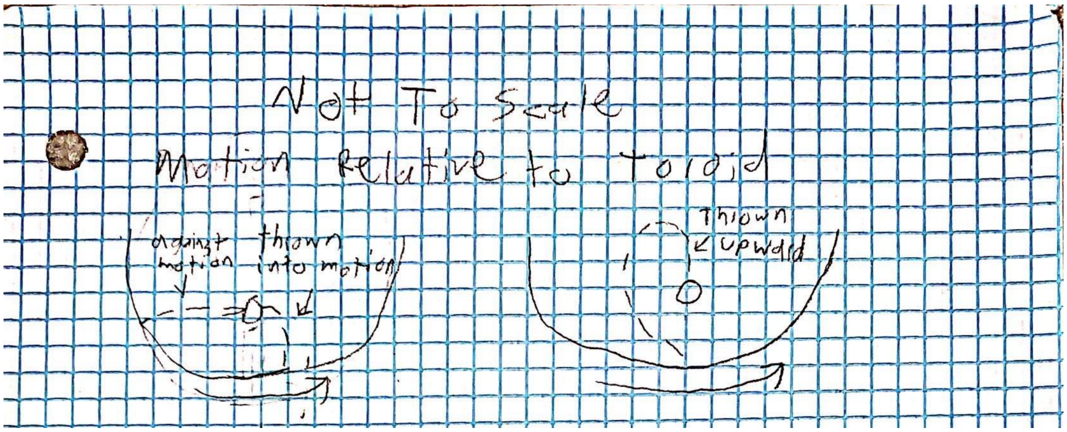
Design Concept Generation, Analysis, and Selection

Design Solution Brainstorming

To begin our development, we first began to analyze the constraints we were given regarding the physics within the structure, the shape and requirements of the toroidal model, and the movement of the player. This required us to further research the physical properties within a rotating toroidal environment to properly simulate this in whichever program we choose. When deciding what game engine to use, our needs were proper physics in a three-dimensional environment, an easy to learn programming language, and options for editing on multiple devices. The free game engine Unity along with the language C# met this criteria since it is a widely used development program with a large amount of documentation, learning resources, and user-friendly code. While most mechanics of the simulation were specified in our constraints, how we execute them within the game engine is variable.

Brainstorming Photos





Headset Decision

Oculus Quest

The on board processing within the Quest allows this headset to display and render mildly intensive graphics at a reasonable quality. Since this headset is able to function without a computer (but is able to connect to a pc for testing and development) or tracking stands and only costs $399, its portability is widely above another other mainstream headset.

The Oculus Quest was chosen due to its cost being within our budget and its superior portability and transportational aspects. Though its quality is less than the rest of the products in our decision, it remains a usable and practical piece of technology supported by many platforms and developers.

Specifications:

NASA Constraints

- 15 m in diameter and 3m wide that connects to two central core modules
- Four ladders leading from the central core to the outer ring
- At least two people capable of running and doing workouts
- 3 baseballs for juggling and throwing to another person
- A hose for watering plants
- Several pillows for growing plants in
- Barbells and a set of weights
- A flying drone
- A shower
- 3 pendulum clocks on the wall at different heights
- Force gages
- Rotation can be changed from positive to negative g
- Show the pathway of a ball being thrown

EDD Constraints

- $500 budget
- August to December time frame for the project

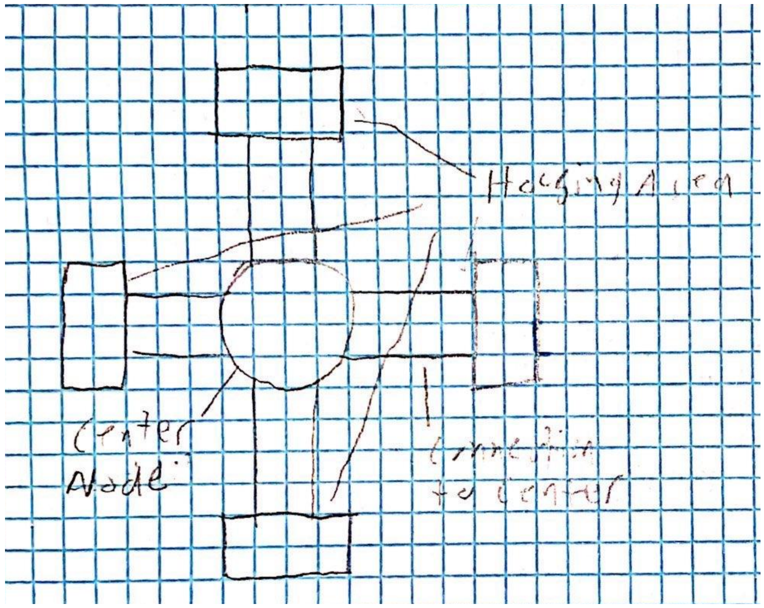
Toroid Decision Matrix

Design 1

The rings within this design maximize space as well as maneuverability with the 4 connections to the central ring to increase the stability of the structure. However, the gravity within this ring would not allow everyday actions due to the lack of substantial force near the center of a rotating toroid.

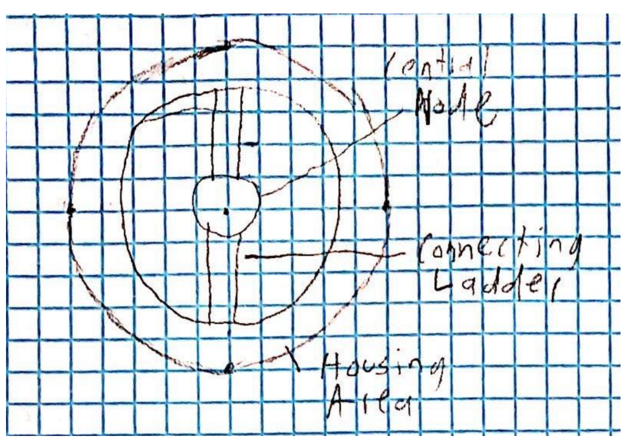
Design 2

Without a wrapping ring-like shape around the toroid, living within these areas would feel more like earth to the users. Less materials, construction time, and space transportation costs are needed for this structure, but very little space is provided for the crew or others inside.



Design 3

As the simplest build, it would be the easiest for our team to 3D model and most efficient for our technology to compute. With plenty of unwasted space, this area would harbor a massive amount of technology and store plenty of people and other components. Without 4 connections, it may be unstable if they aren't thick enough.



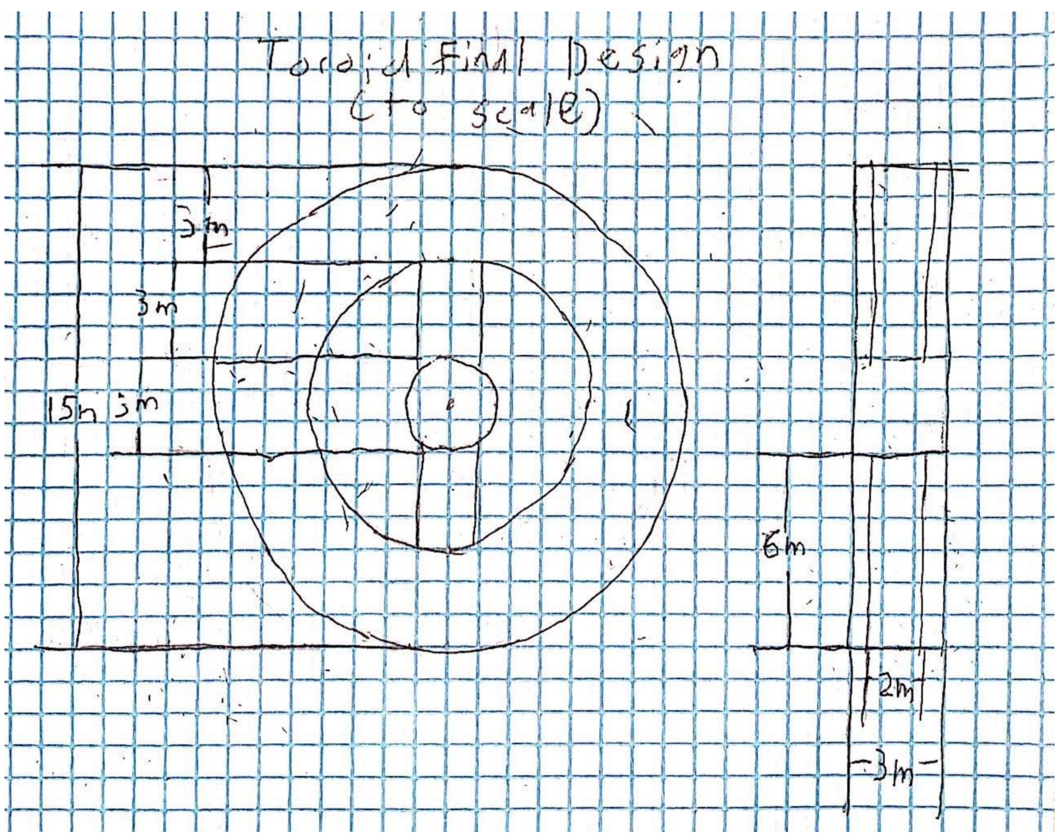
Decision Matrix

Most Favorable = 3 Least Favorable = 1

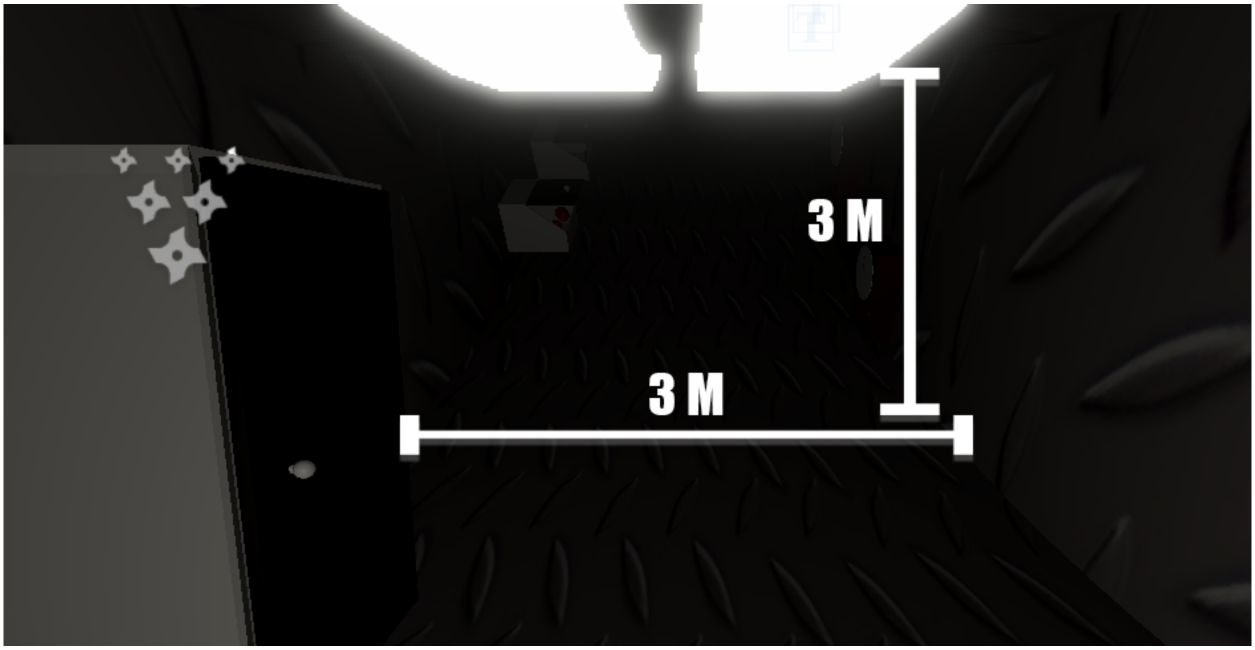
	Space	Simplicity	Structural Stability	Practicality	Total
Design 1	3	1	3	1	8
Design 2	2	2	2	2	8
Design 3	2	3	1	3	9

Design three met the most needs of our simulation, and would fit best in a virtual creation of artificial gravity. While it may not be the most viable real life structure to house equipment and people, it is able to simplistically display functions and processes within its environment.

Annotated Drawings



Final Annotated Drawing



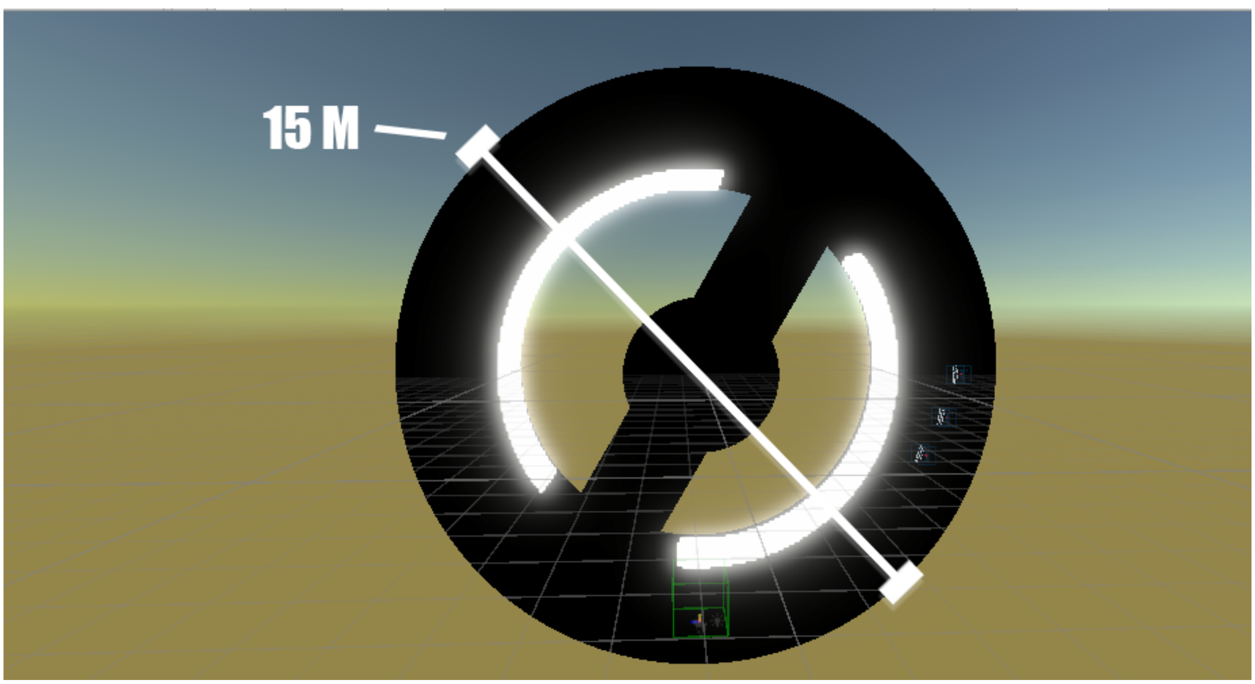


Image Resources

Oculus Quest:
https://static0.colliderimages.com/wordpress/wp-content/uploads/2019/06/oculus-quest.jpeg

PORTFOLIO ELEMENT E

Application of STEM Principles and Practices

Introduction

As a simulation, many aspects of engineering, design, and art unify to alter the effectiveness of the final product through the accuracy of physics to the modeling of objects and terrain. This dynamic range of concepts allows for a diverse range of specialties within our team as well as a broad field of knowledge required to compile these different areas of work. While STEM principles mainly govern our workflow and many aspects of this project, their impact combines with other separate studies.

Science and Engineering Concepts for Research

STEM Principles

STEM Principle 1: Physics **-** Coriolis and Centrifugal Forces

While many aspects of physics are embedded in the program Unity (such as collisions and motion), the unique forces within a toroidal mechanism to produce artificial gravity must be designed using knowledge of their precise amount and direction in a three-dimensional environment. To produce an accurate physical world, these concepts must be translated into the game engine correctly.

STEM Principle 2: Design Process

The format and sequence of the design process guide many functions within our development such as specific elements within the engine, creation of the player environment, and the whole of the project. This way of work determines and ensures a stable and secure method of production and alteration for this product.

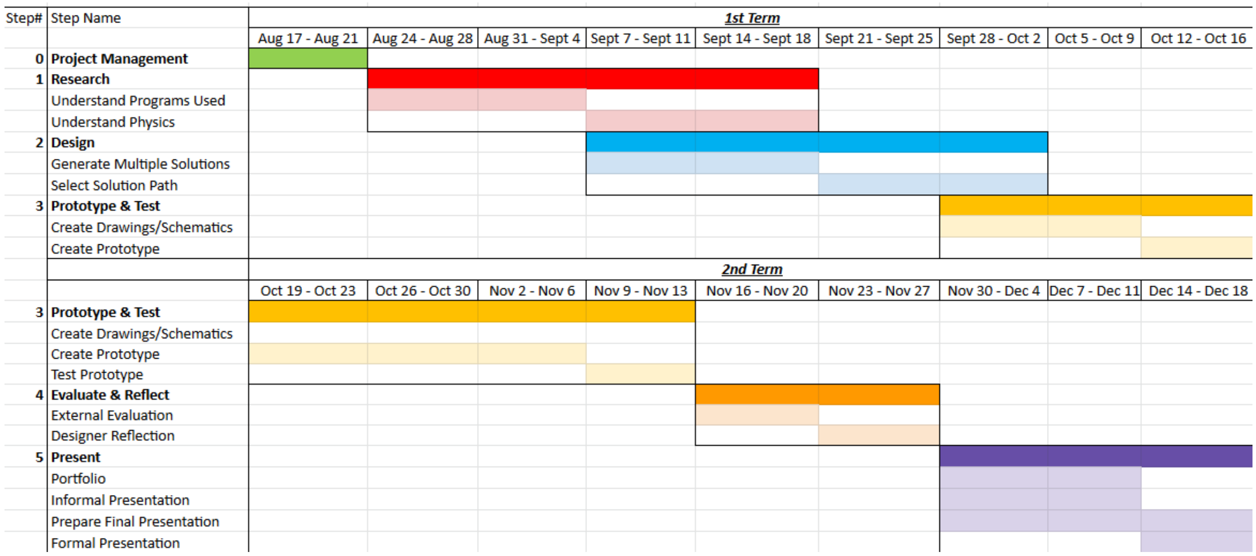
STEM Principle 3: Programming and Scripting

Though the specific scripts used in this project were developed in C#, general knowledge of programming principles and organization were key for optimization and fully understanding the tools within this engine.

STEM Principle 4: Technology Education

Through user-friendly button mapping as well as a simple array of showcases within the project, new users are able to control the simulation with little to no explanation. Our "README" tutorial provides additional instruction for beginner instruction.

Gantt Chart



Expert Input

Allison Westover

Ms. Westover was the main consultant for this project; she was there to answer any questions to the commissioners for the project for us. She was able to connect us to other experts within the NASA-Hunch program for aid.

Glenn Johnson

To help us better understand specific needs of the NASA-Hunch program for our development, Mr. Johnson guided us to tweak or fix different aspects of our project and emphasized certain broad areas of our work. This morphed many different elements of our design as well as the presentation of our final product.

Mark Thomas

Through his physics and mathematics experience and close proximity, we were able to contact Mr. Thomas about physics principles to further our understanding of specific physics principles. Using this knowledge, we were able to translate these concepts into our program due to this experience.

Project Stages

Research Stage

The intermediate use of physics involved in the process of artificial gravity requires specific knowledge of how those pseudo-forces act relative to the individual experiencing them. Basic knowledge of C# along with the components within the Unity game engine was needed to proceed with development. Our needs for a three-dimensional environment required an outlet for modeling as well as knowledge pertaining to this process.

Design Stage

Through our criteria, we were able to develop a toroidal model along with a layout for the components to be interacted with by the player. The physics programming through which objects and the player are affected by must act as artificial gravity would if attempted in reality.

Creation Stage

Our team developed our program through the use of Unity, Blender, and Microsoft Visual Studio Code. Importing models directly from Blender and importing Unity Libraries into VS Code allowed quick transferring of files and models to each program.

Testing Stage

Our team checked for bugs and exploitations often, as Unity allowed us to bug test and re-import lost files. Through Unity's game scene, we are able to edit portions of the system in real-time as well as bug fix different aspects from this tool.

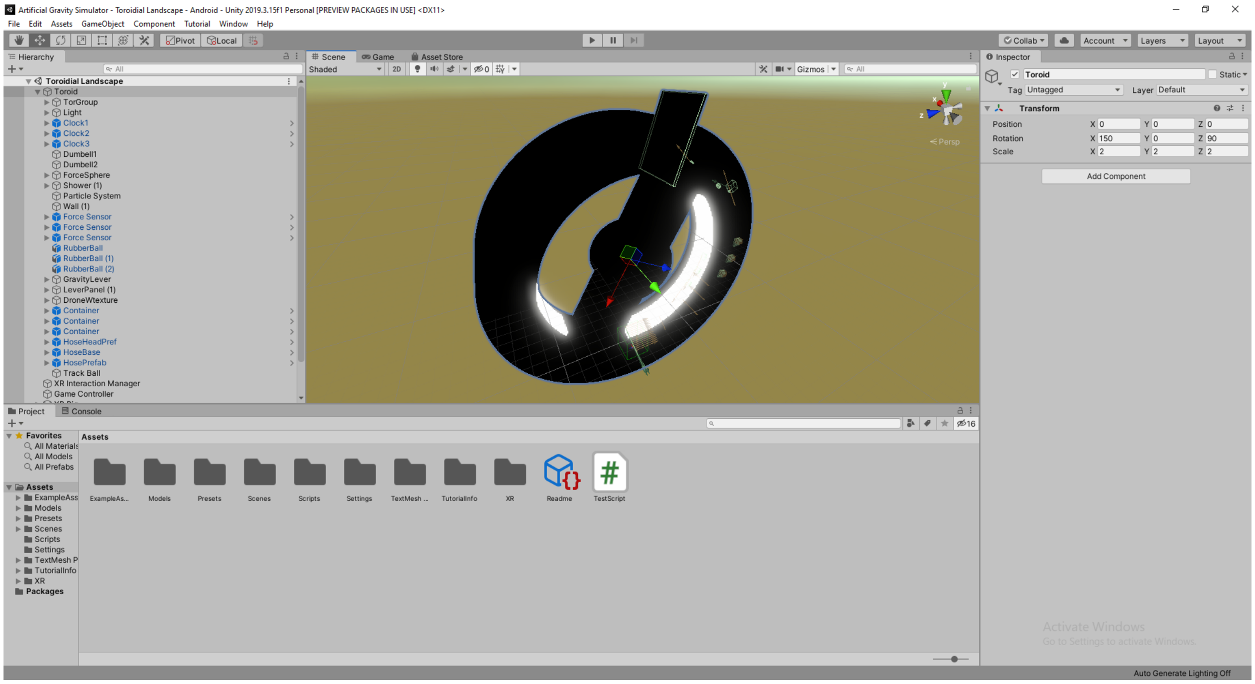
Review Stage

After all major mechanics were developed, we refined specific elements of our physics system, such as optimization, as well as created more objects outside of our defined criteria. While these were not an addition to functionality, they increased the immersion of our simulation as well as improved the realism of the proposed mechanism of the toroid. Post processing techniques as well as lighting and texturing were employed to visually express a more vivid environment for the user.

Programs Used

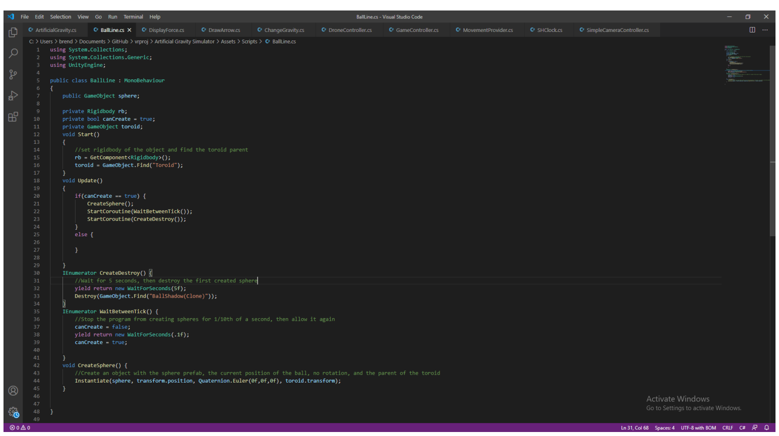
Unity

This user friendly game engine utilizes accurate physics, 3D space, VR capabilities, and an outlet for addons to morph to our desired workflow. Along with the entry level code of C#, this program requires our needs to fully simulate an artificial gravity environment.



Microsoft Visual Studio Code

Along with an add-on for C#, this program helped develop code for the Unity game engine using the programming language C# and also aided in troubleshooting errors within this code.

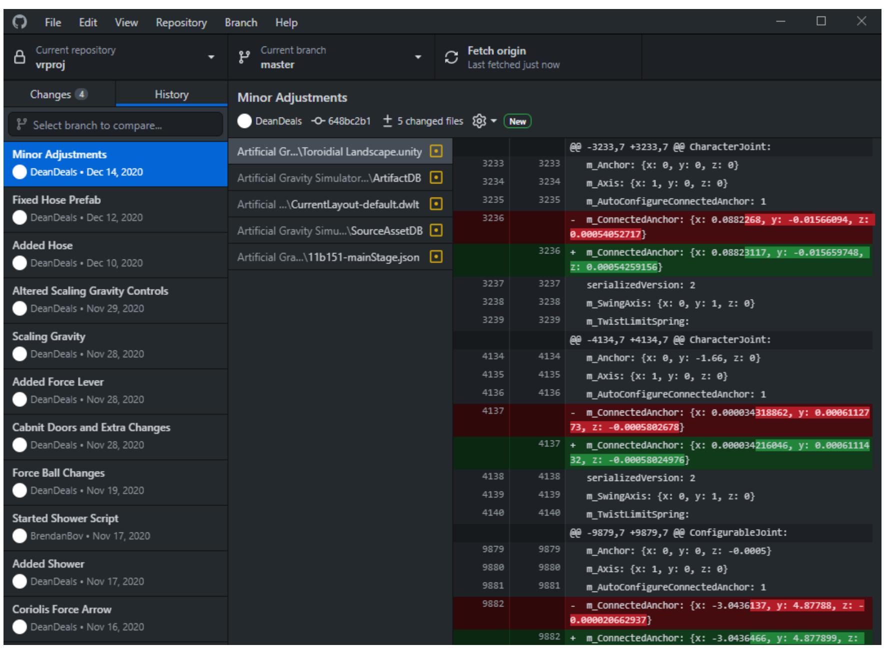


Blender

Blender enabled the free creation of digitized 3D models to be exported into Unity. Rendering in a lighted environment, texturing, texture baking, and material application were all employed to create the final product.

GitHub/GitHub Desktop

To communicate and share data with our members, we uploaded our Unity project through GitHub and downloaded and controlled our file history through the desktop app of this service. This allows us to document each step of our development through version control and frequent recording.



PORTFOLIO ELEMENT F

Consideration of Design Viability

Introduction

The amount of technology in this project was primarily limited to different softwares as no physical product has been developed. With no other competition for this product, the market data available is limited to products that serve reasons further from that of our own. Since our budget was limited to $500, most of this was dedicated to the hardware on which we would develop our product rather than the production cost of the software we created.

Products used

Oculus Quest

While the processing of our virtual environment will be, in some cases, on an external computer, the display of our program will always take place on this device. The Oculus Quest serves its purpose as an affordable piece of technology with average processing power and display. Its ability to track head and hand movements without any external tracking mechanisms allows it to portably and effectively spread the usage of this technology.

Market Analysis

In the current marketplace, no software is as easy and readily available as our team's. Our software is compatible with many different virtual reality headsets and would be completely free to distribute, and the only cost would be in the individual user's headset. When creating physical artificial gravity mechanisms, the experience is much more practical, but the low price of virtual reality outweighs this experience.

Product Distribution

To run on the Oculus Quest, our product can be run through an exported Unity build. For external device driven headsets such as the Vive and Oculus Rift, this exported Unity build can be executed on any device of the user's choice.

Conclusion:

As a software, the production of this system requires little resources as well as no effort to transport across many users. The slim market alongside no cost of production makes the market of this system practically non-existent. This simulation meets the specific goals of the NASA-Hunch program for an immersive simulation of artificial gravity while maintaining usability on multiple devices and ease of use for less powerful hardware.