AUBURN UNIVERSITY

SAMUEL GINN
COLLEGE OF ENGINEERING

3D Modeling of Detached Metal Whiskers

Group # 8

ORR

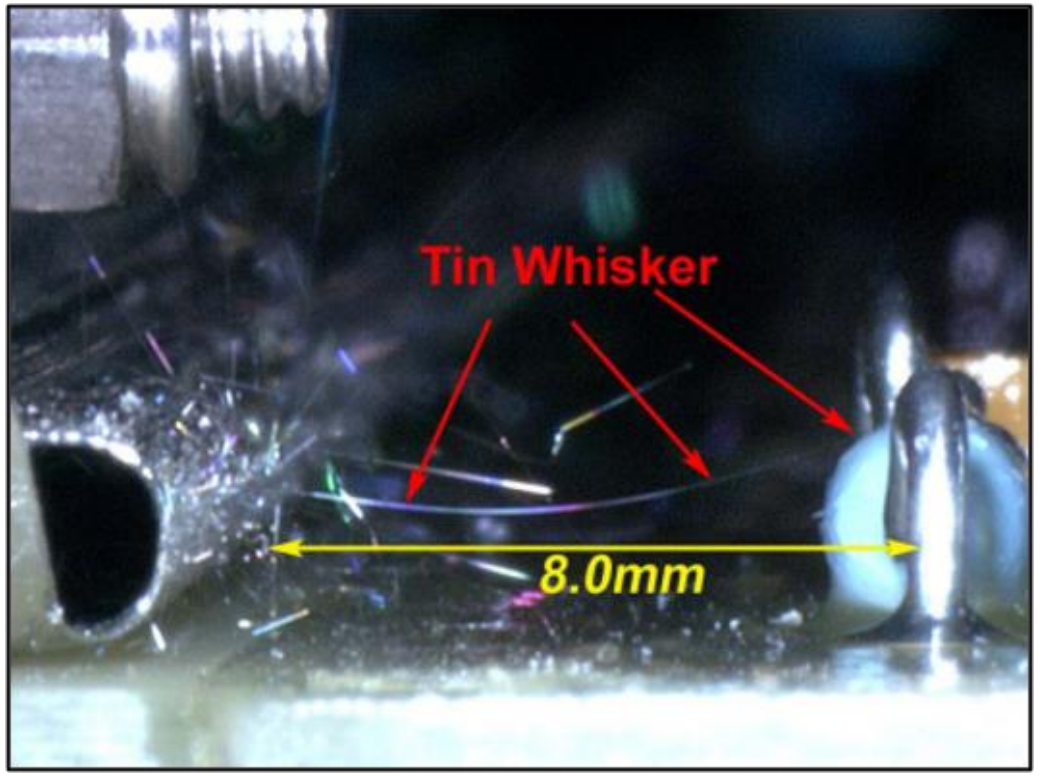
MANAGER: Graham Duke
SCRIBE: Connor Massey
Meredith Osborne, Andrew Smith

List of Abbreviations

NASA	National Aeronautics and Space Administration
MDA	Missile Defense Agency
CCA	Circuit Card Assembly
CAD	Computer Aided Design
MCS	Monte Carlo Simulation
WP	Working Principle
PCB	Printed Circuit Board
UI	User Interface

Introduction / Problem Statement

- What are metal whiskers?
  - Microscopic, metal filaments (tin, zinc, cadmium)
  - Length: few microns to >10 mm
  - Thickness: submicron to tens of microns
  - Create bridges between exposed conductors
- Objective:
  - Risk-identifying simulation of detached whiskers bridging conductors
    - Visual identification
    - Statistical identification



Whisker Bridging

[1]

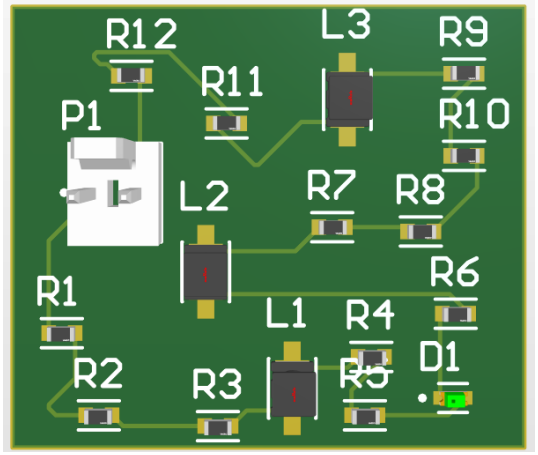
Design Specifications

- Rigid Cylindrical Model of Whisker
- Detached and Airborne Whiskers
- Physical and Statistical Simulation
  - Unity
  - MCS
- Simulate Environmental Effects on Detached Whiskers
  - Variety of forces
  - Gravitational acceleration
- Import User CCA Models
- Range of User Inputs
- Single Script

Design Implementations

CCA Processing

- Overall plan for importing CCAs remained constant
- Altium used for test CCAs
- .mtl and .obj files created from Altium, inserted into Unity



CCA Designed in Altium

Material Identification

- Automated process (CDR – manual)
- Code scans for input material
- Trigger tag applied to all surfaces with material name
  - If whisker contacts ≥ 2 triggers, bridge

Conductive Material Input Box

Design Implementations

Distribution Selection

- Applied principals from CDR
- User selects desired distribution from dropdown menu
- Coded switch statement to change distribution function
  - Mu and sigma processed accordingly

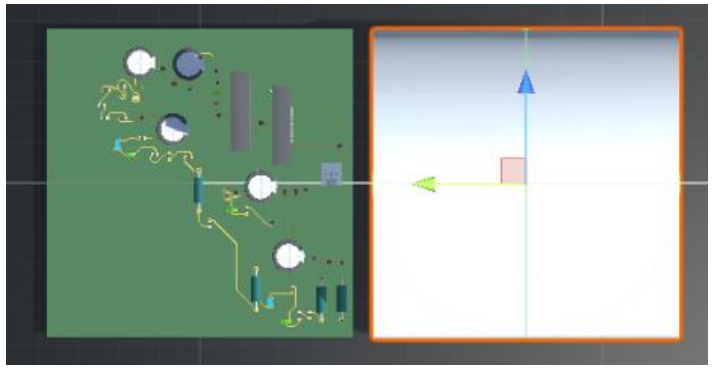
```
private float GenerateLogNormalValue(float mu_log, float sigma_log)
{
    float normalVal = RandomFromDistribution.RandomNormalDistribution(mu_log, sigma_log);
    float logNormalVal = Mathf.Exp(normalVal);
    return logNormalVal;
}

private float GenerateNormalValue(float mu_norm, float sigma_norm)
{
    return RandomFromDistribution.RandomNormalDistribution(mu_norm, sigma_norm);
}
```

Distribution Functions

Whisker Scaling

- Arbitrary unit system in Unity
- Whiskers must be in micrometers (μm)
- Internal code configures inputs to μm
- Proof:
  - Used Altium boards as reference
  - Test inputs to match board dimensions



3” x 3” Board for Whisker Comparison

Design Implementations

Material Selection

- Applied principals from CDR
- User selects one of three preset materials from dropdown menu
- Code applies corresponding material properties to calculate whisker physics
- Calculate the following (per whisker)
  - Mass
  - Resistance
  - Friction Force

```
public Dictionary<MaterialType, MaterialProperties> materialProperties = new Di
{ //density (kg/um^3), resistivity (ohm*um), coefficient of friction (unitless)
    { MaterialType.Tin, new MaterialProperties(7.3e-15f, 1.09e-1f, 0.32f) },
    { MaterialType.Zinc, new MaterialProperties(7.14e-15f, 5.9e-2f, 0.6f) },
    { MaterialType.Cadmium, new MaterialProperties(8.65e-15f, 7.0e-2f, 0.5f) }
};
```

Material Properties Dictionary

Drop Location

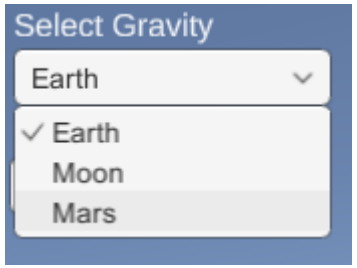
- User inputs X, Y, and Z coordinates to specify a drop location for whiskers
- Spawn area deviates from origin (0,0,0) in positive and negative direction

Drop-Location Coordinate Inputs

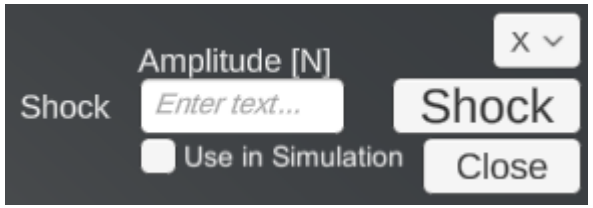
Design Implementations

External Forces

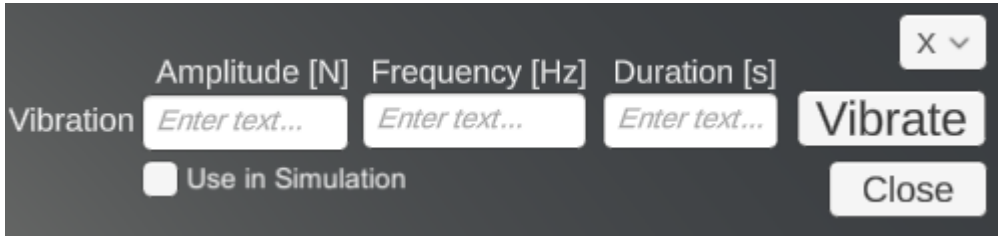
- Three external forces implemented
  - Gravitational acceleration
    - Select between Earth, Moon, or Mars
  - Mechanical shock
    - Half-sine pulse
    - Apply uniaxially (X, Y, Z)
  - Constant vibration
    - Full-sine pulse
    - Apply uniaxially (X, Y, Z)
- Shock and vibration repeated in each iteration



Gravity User Interface

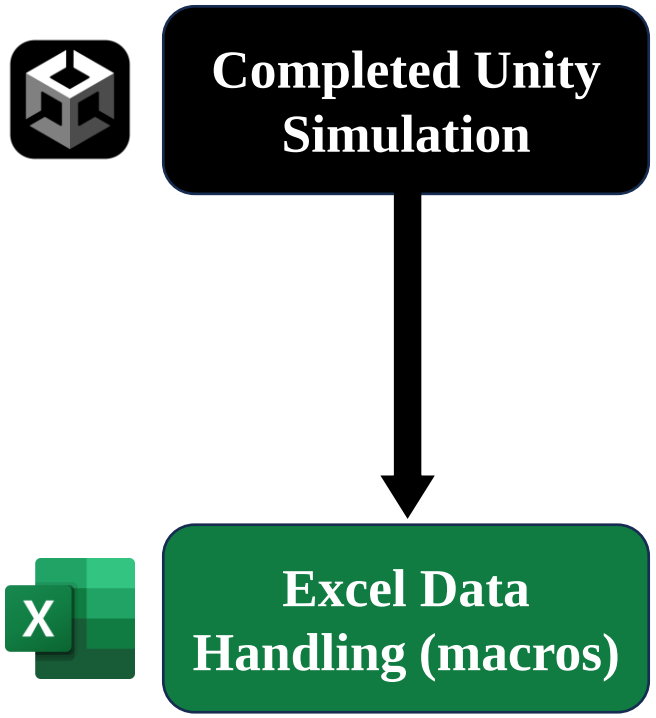


Shock User Interface



Vibration User Interface

Design Implementations



Simulation Results

- Heat map of conductor bridging frequency
- Save simulation results to store length, diameter, resistance of:
  - All generated whiskers per iteration
  - All bridged whiskers per iteration

- Probability calculations (risk assessment)

$$\text{Individual Probability} = \frac{\#\ of\ bridged\ whiskers}{\#\ of\ whiskers\ generated} \cdot 100 \quad (1)$$

$$\text{Overall Probability} = \frac{\#\ of\ bridged\ iterations}{\#\ of\ iterations\ ran} \cdot 100 \quad (2)$$

- Four histograms generated
  - Bridging frequency for length, diameter, length:diameter ratio, and resistance

Method of Operation

Simulation Accessibility

GitHub

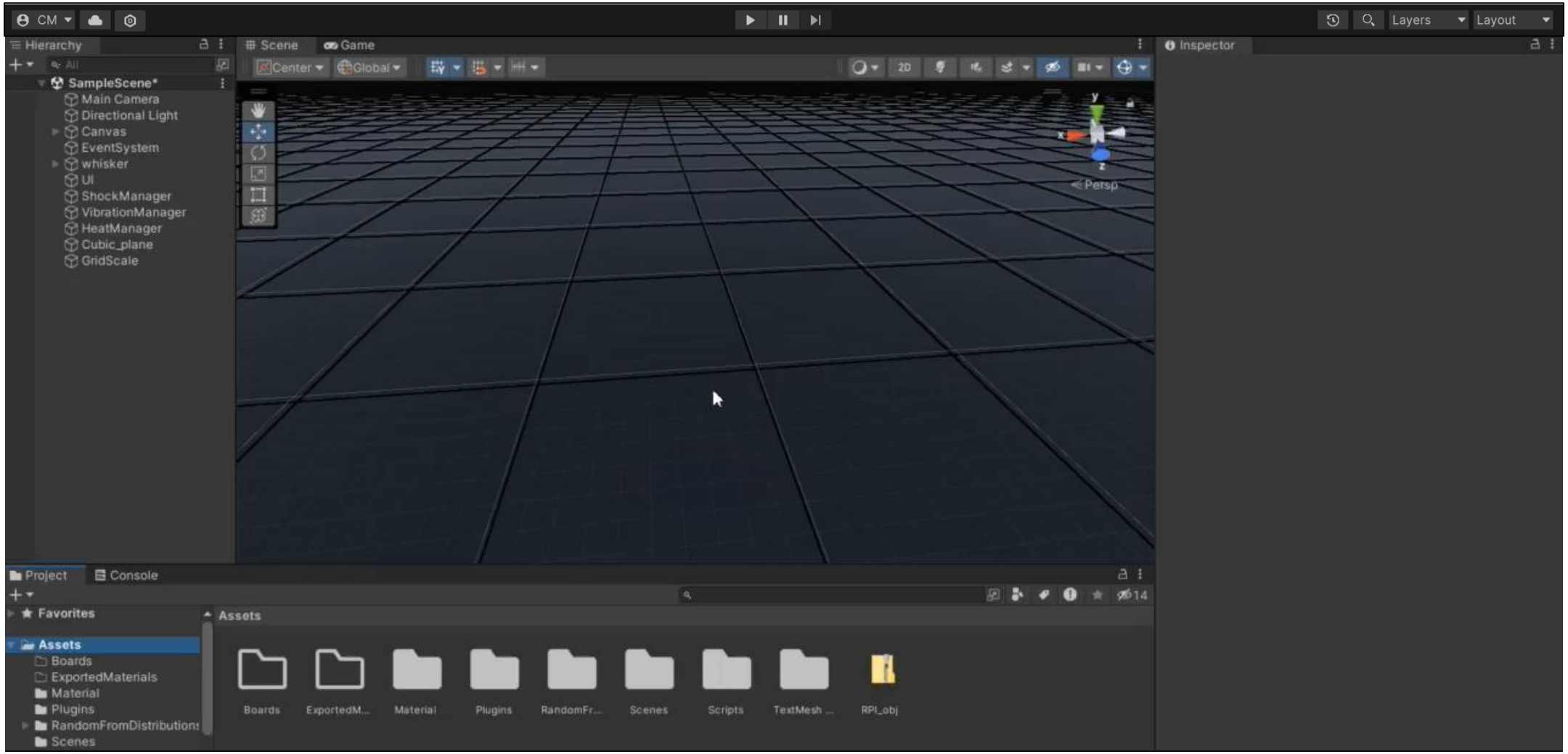
- Version control and software management
- Ease of access to repositories of any size
- Repositories can be cloned to any device through the GitHub Desktop app or downloaded through the website
- Instructions are given in the User Manual

Unity

- Simulation runs entirely off the Unity Game Engine
  - Users must download the Unity Hub and the Unity Editor to begin
- Repositories cloned from GitHub can be added to the Unity Hub, allowing easy access to the simulation
- Unity Editor used to develop and host the simulation

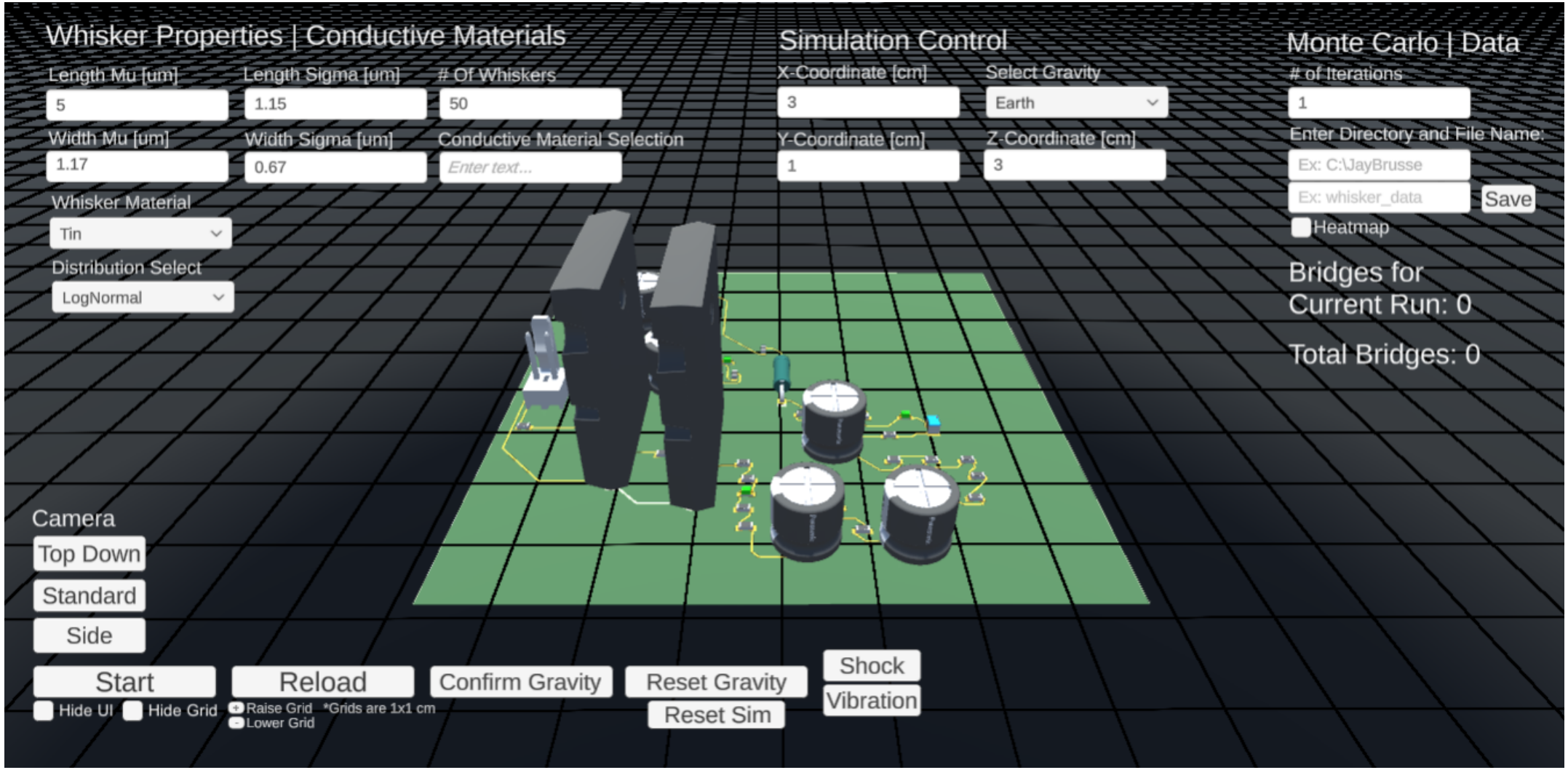
Method of Operation

Importing Board Models



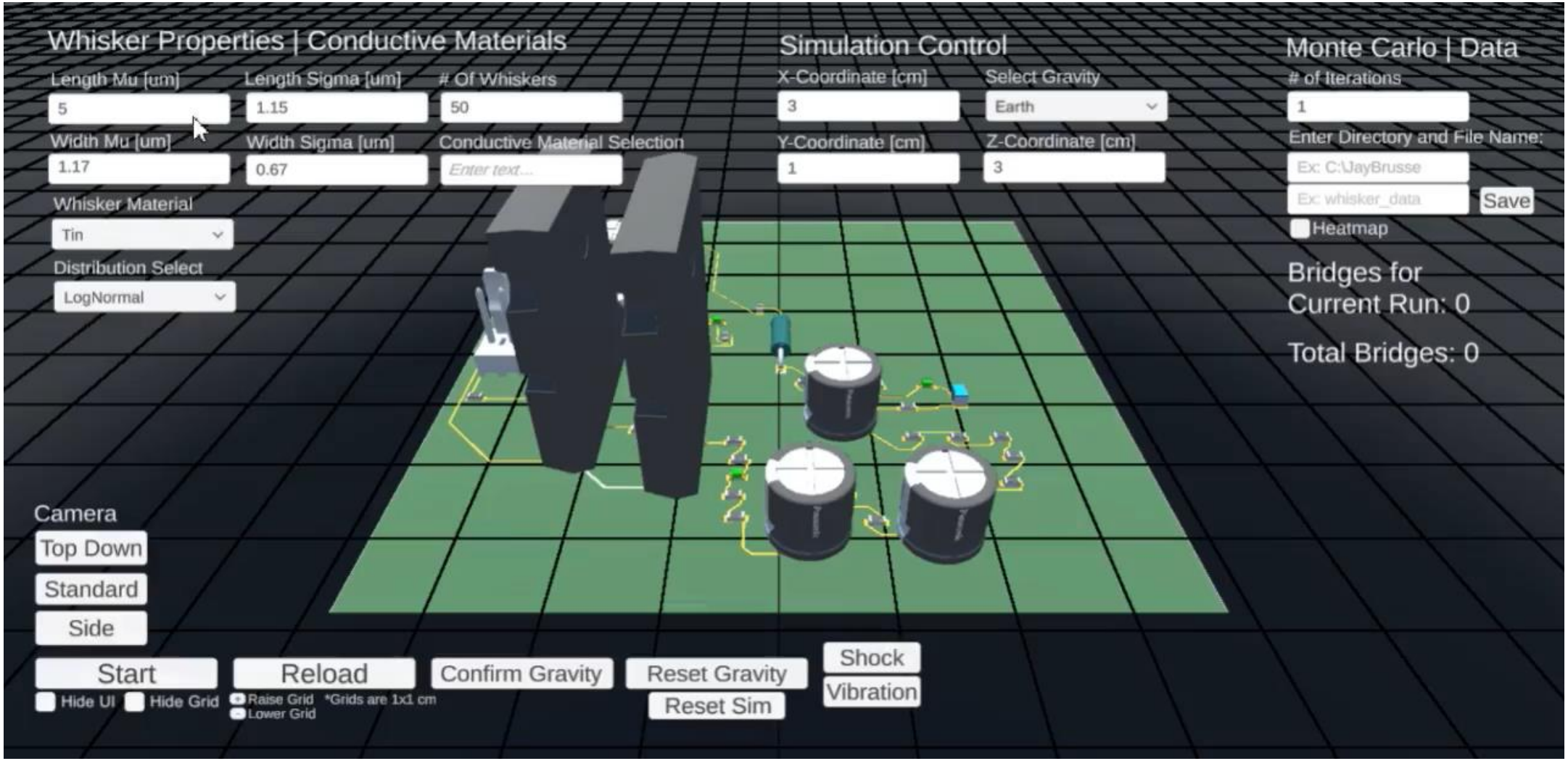
Method of Operation

User Interface



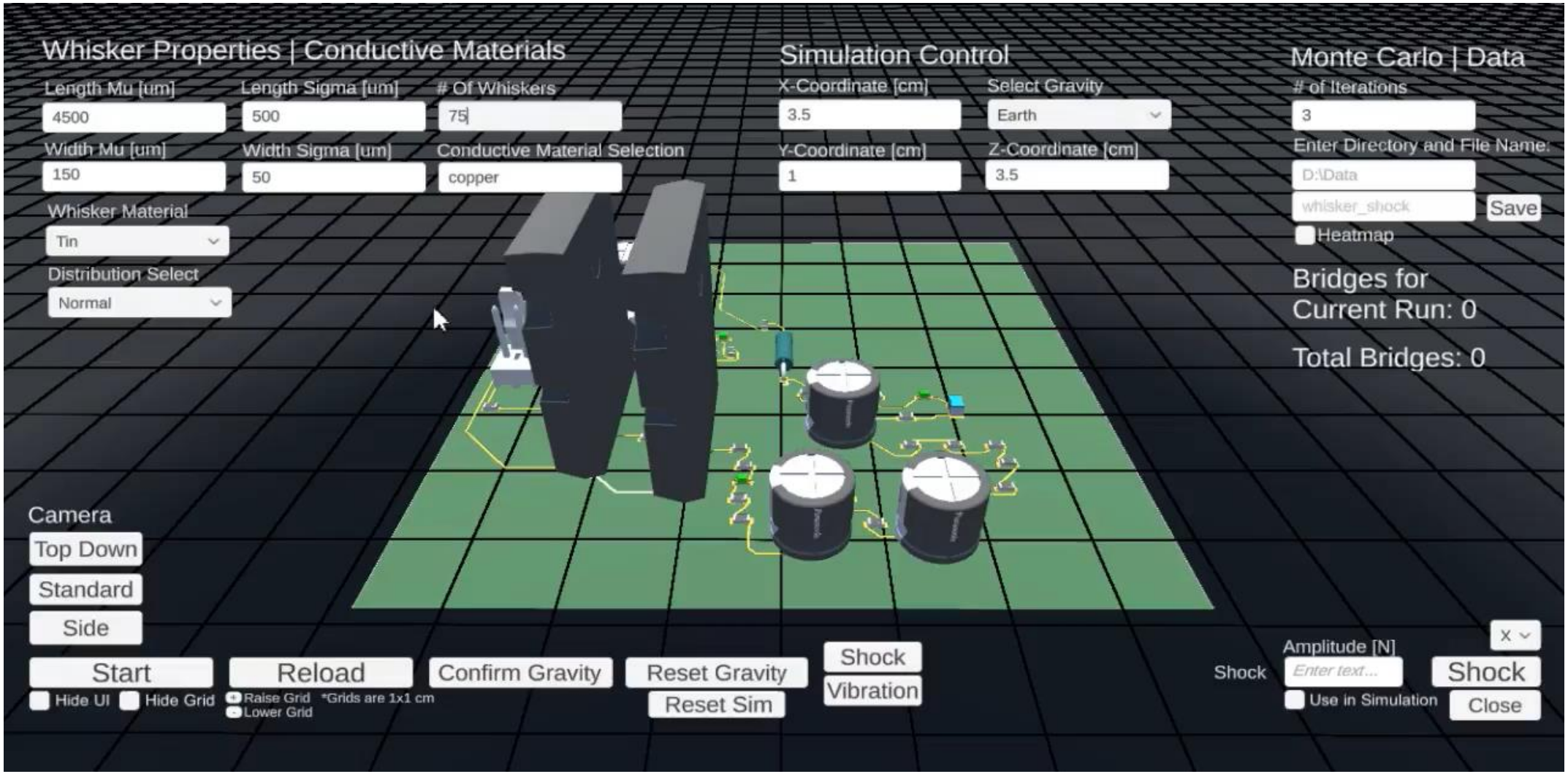
Method of Operation

Running the Simulation



Method of Operation

External Force Application & Heat Map

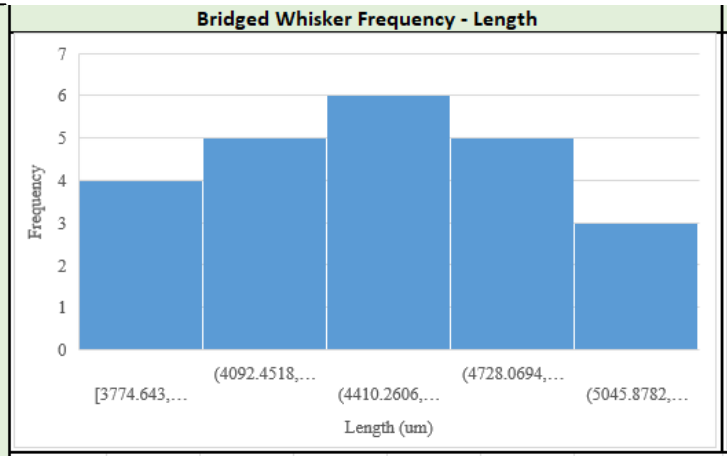


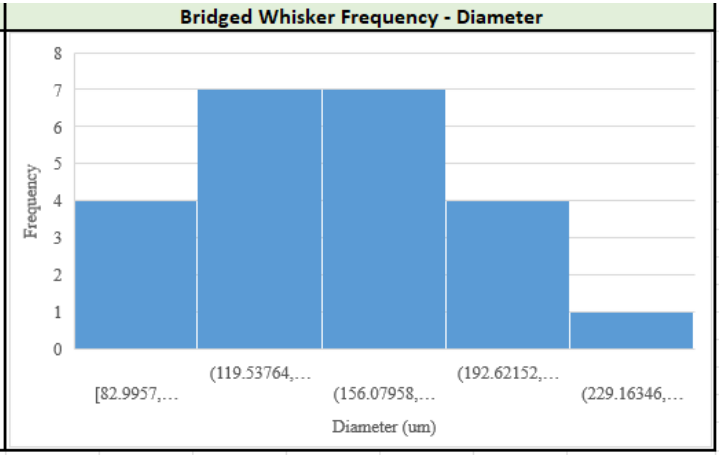
Method of Operation

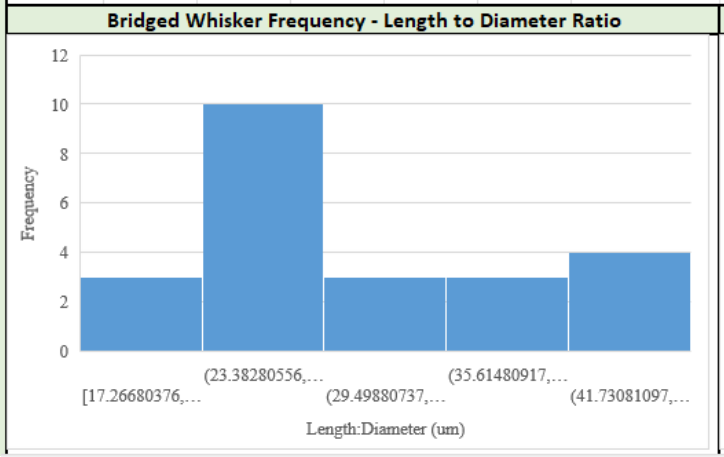
Results Analysis

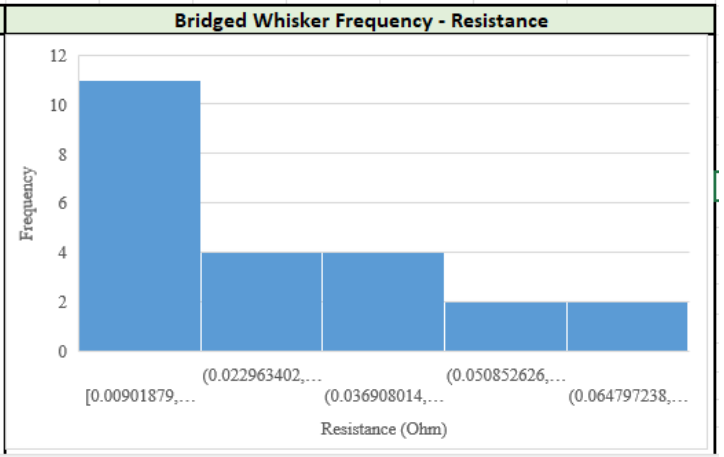
ALT + F8 -> GenerateProb	
Overall Probability	
100.00%	
Individual Probability	
Iter #	Probability
1	10.67%
2	5.33%
3	14.67%

ALT + F8 -> GenerateFreq			
Length	Diameter	L:D Ratio	Resistance
4216.771	121.2332	34.782312	0.0398175
4212.525	165.9083	25.390683	0.0212394
4556.262	206.9365	22.017682	0.0147663
3908.231	82.9957	47.08956	0.0787419
4792.311	111.1245	43.125602	0.0538595
5363.687	197.8514	27.109674	0.0190161
4130.755	147.3153	28.040231	0.0264162
5202.961	139.1005	37.40433	0.037319
3926.428	156.9299	25.020267	0.022127
4609.084	128.3004	35.924159	0.0388593
4003.366	95.61187	41.871015	0.0607769
5043.786	122.6006	41.139978	0.0465702
4538.517	136.732	33.192793	0.0336907
4315.837	156.2732	27.617256	0.0245263
4755.919	179.2377	26.534144	0.0205453
4517.813	215.2865	20.98512	0.0135279
4212.595	176.2689	23.898685	0.0188163
5124.408	178.9008	28.643852	0.0222206
4618.727	96.53155	47.846813	0.0687892
5016.429	191.2884	26.224429	0.0190263
4847.679	200.7805	24.144172	0.0166889
4587.883	265.7054	17.266804	0.0090188
3774.643	123.0862	30.666663	0.0345775







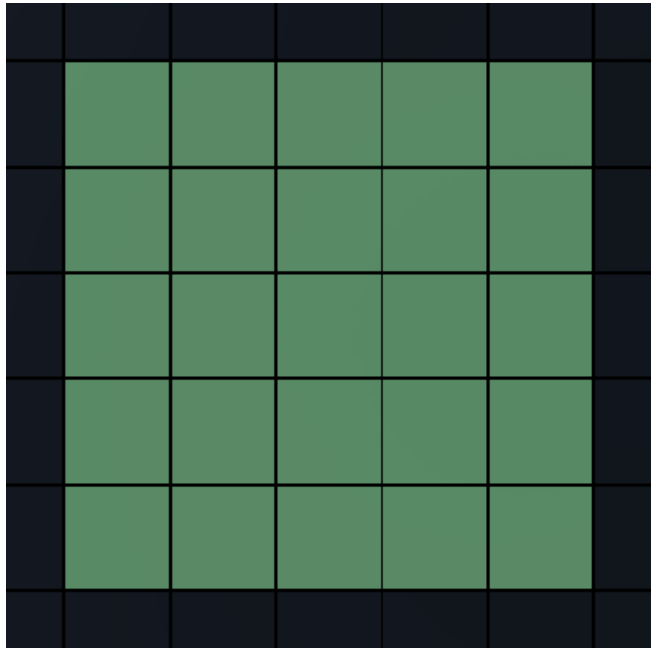


Macro Generated Tables and Histograms

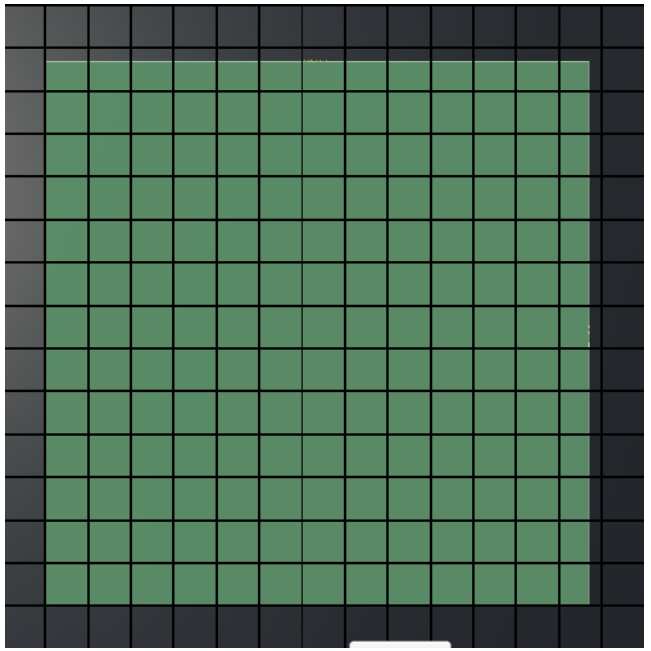
Testing and Analysis

Varied CCA Designs – Board Scaling

- Boards must be scaled to match whisker scale
- Unity uses arbitrary dimensions
- Grid tool implemented
  - 1 cm x 1 cm units
  - Visual reference for whiskers size comparison
  - Toggle on/off
- Unit system independent



Blank 5 cm x 5 cm Board

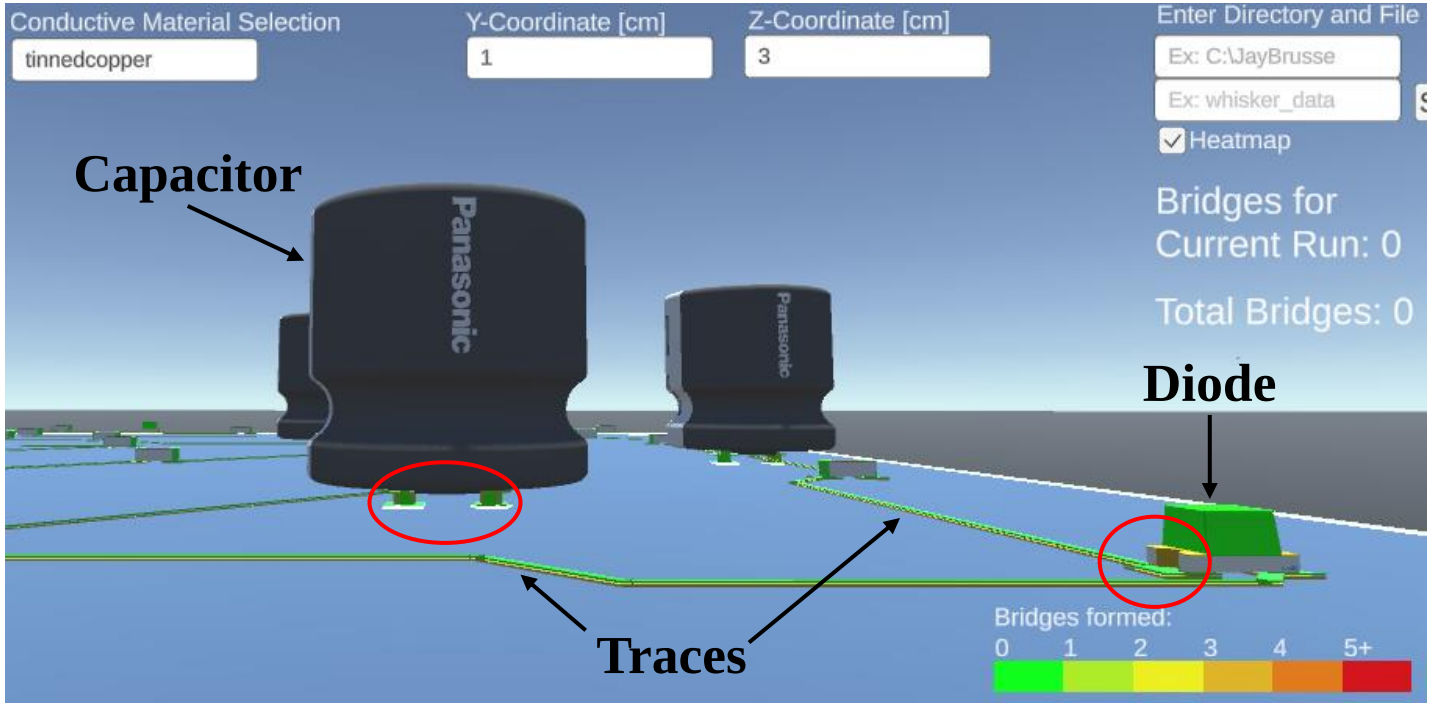


Blank 5 in x 5 in Board

Testing and Analysis

Varied CCA Designs – Conductive Material Input

Exposed Conductive Materials



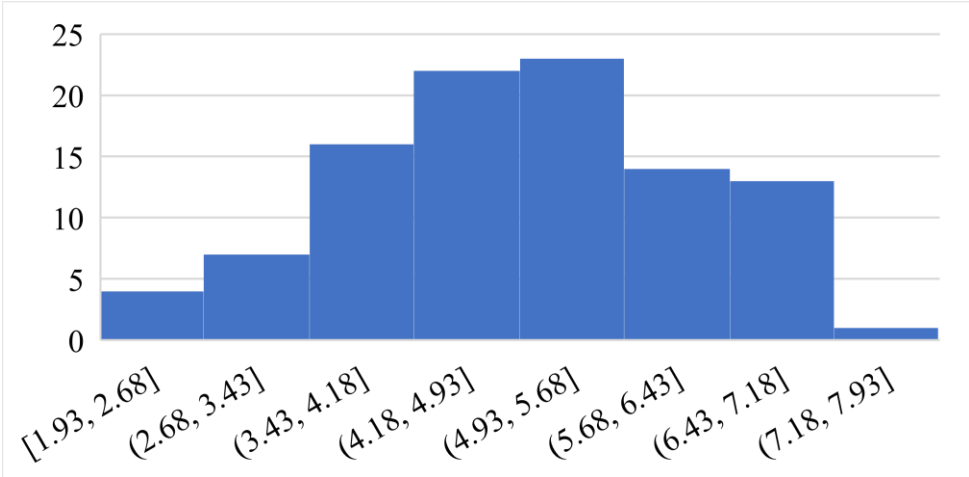
Simulation Material Identification

Testing and Analysis

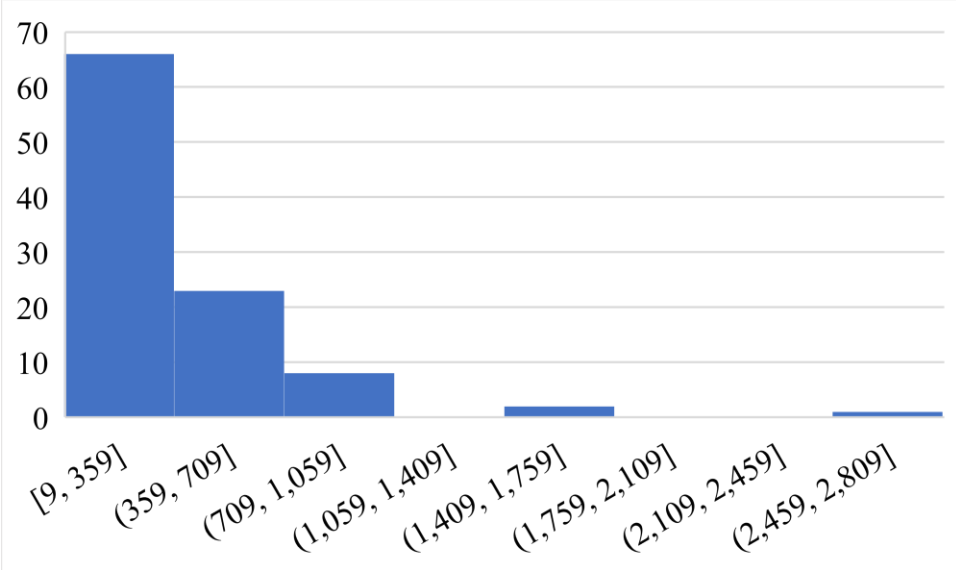
Distribution Validation

Normal Distribution Inputs

Lognormal Distribution Inputs



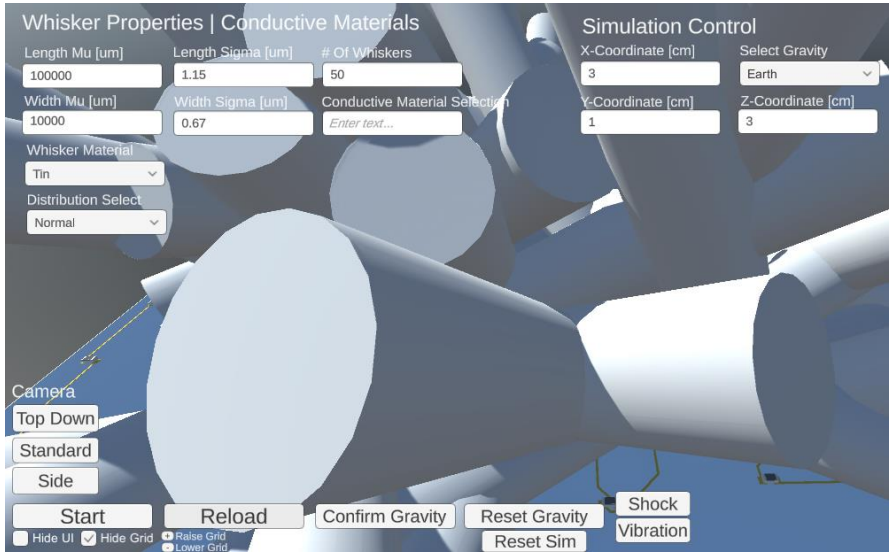
Length Normal Distribution



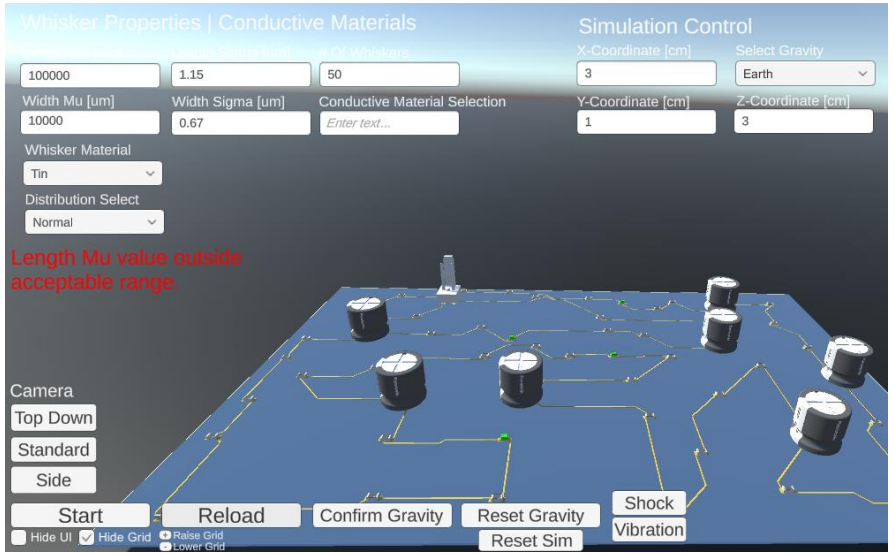
Length Lognormal Distribution

Testing and Analysis

Numerical Input Handling



Improper Whisker Input Results



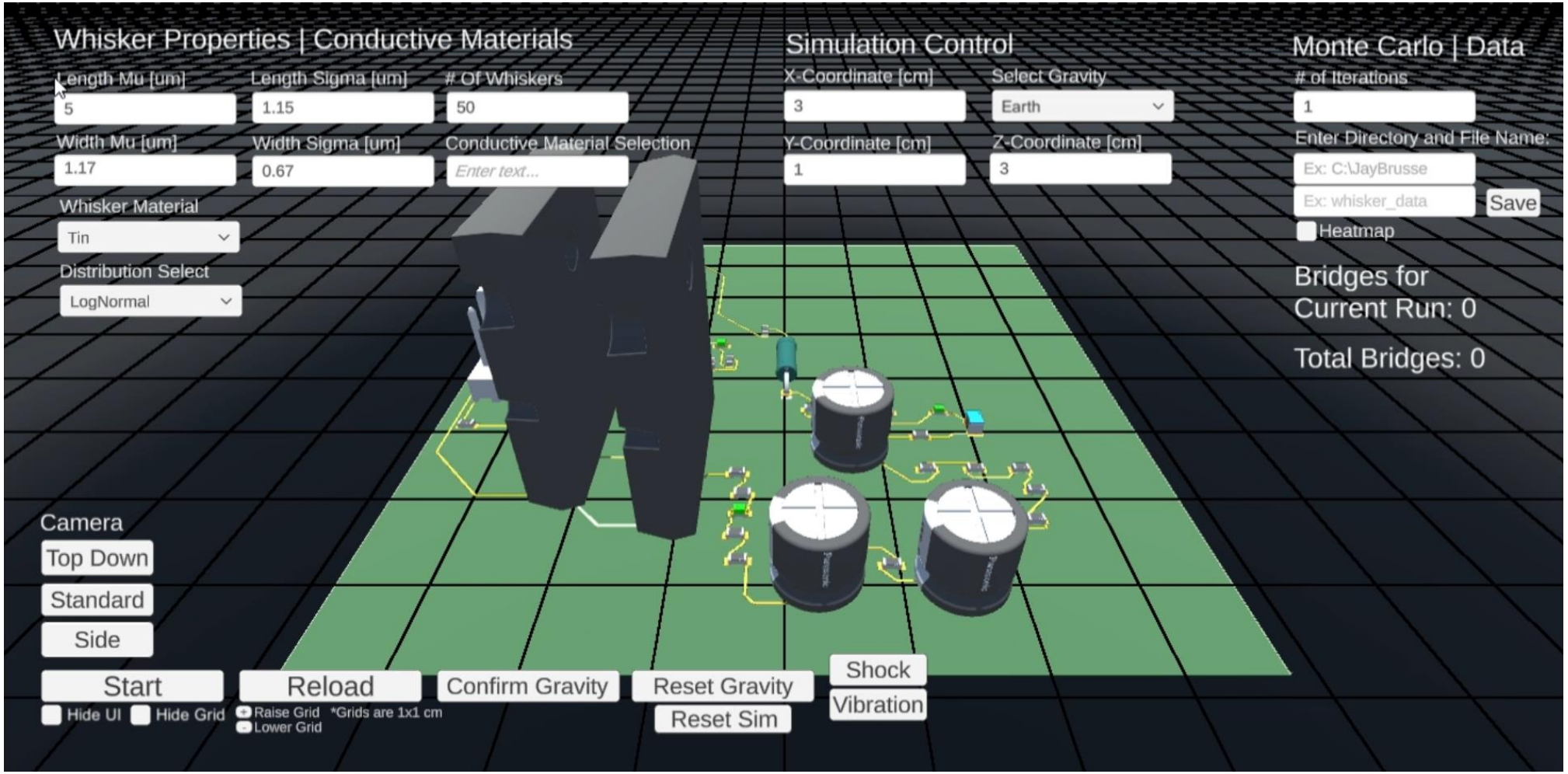
Error Handling for Improper Inputs

- Performance issues
  - Close spawning
  - Rapid collisions
  - Slowed response
- Requires force shutdown

- If-else Statements
  - Prevent actions
  - Error message
- Ensures user does not have to exit scene

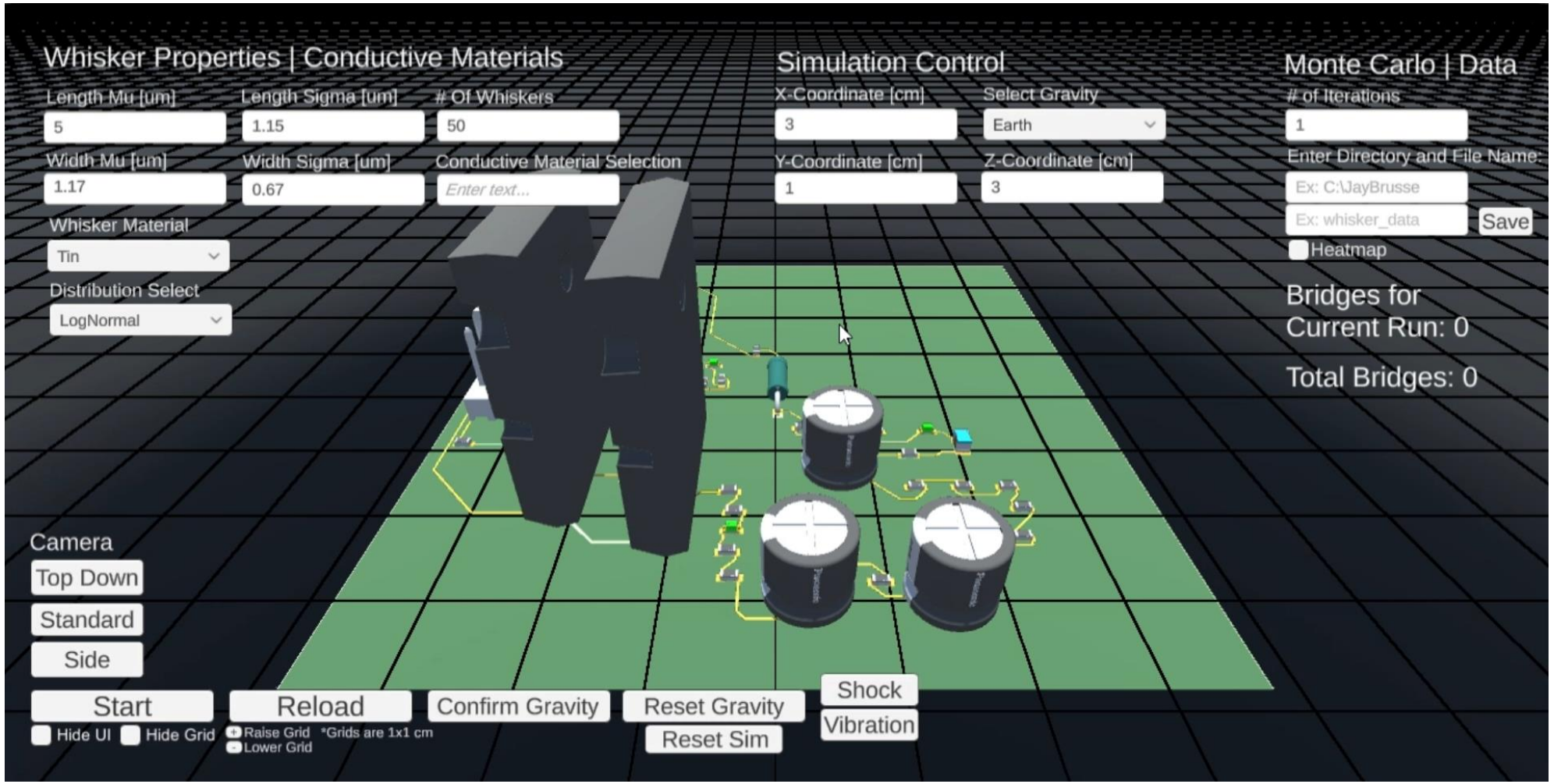
Testing and Analysis

External Force Effects – Perpendicular Force



Testing and Analysis

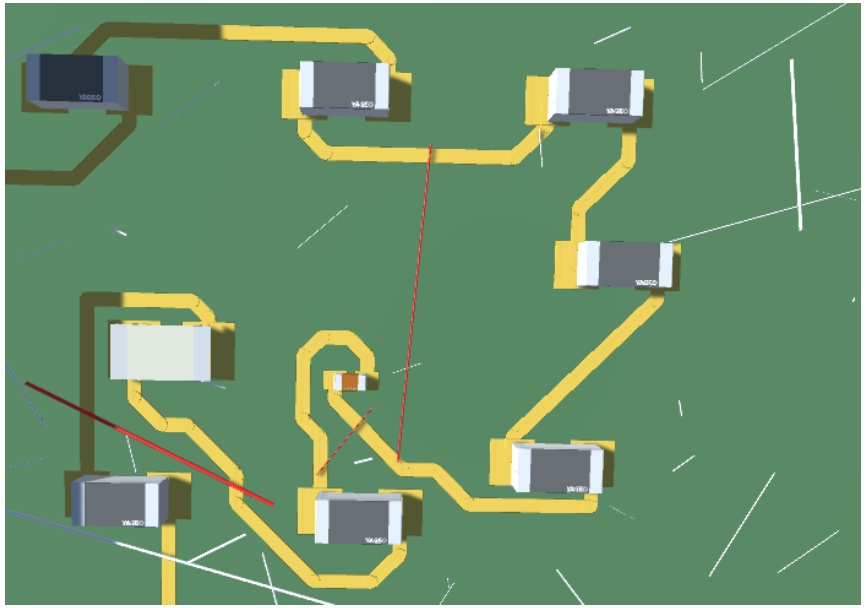
External Force Effects – Parallel Force



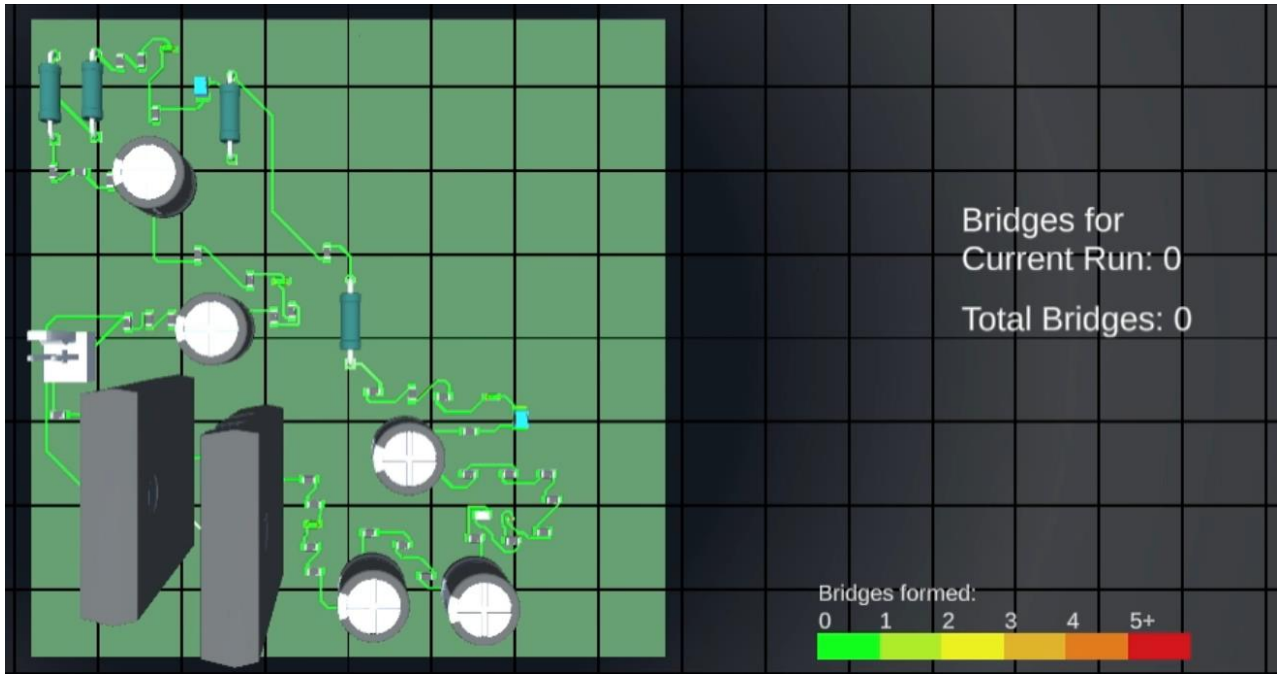
[2]

Testing and Analysis

Bridging Registration



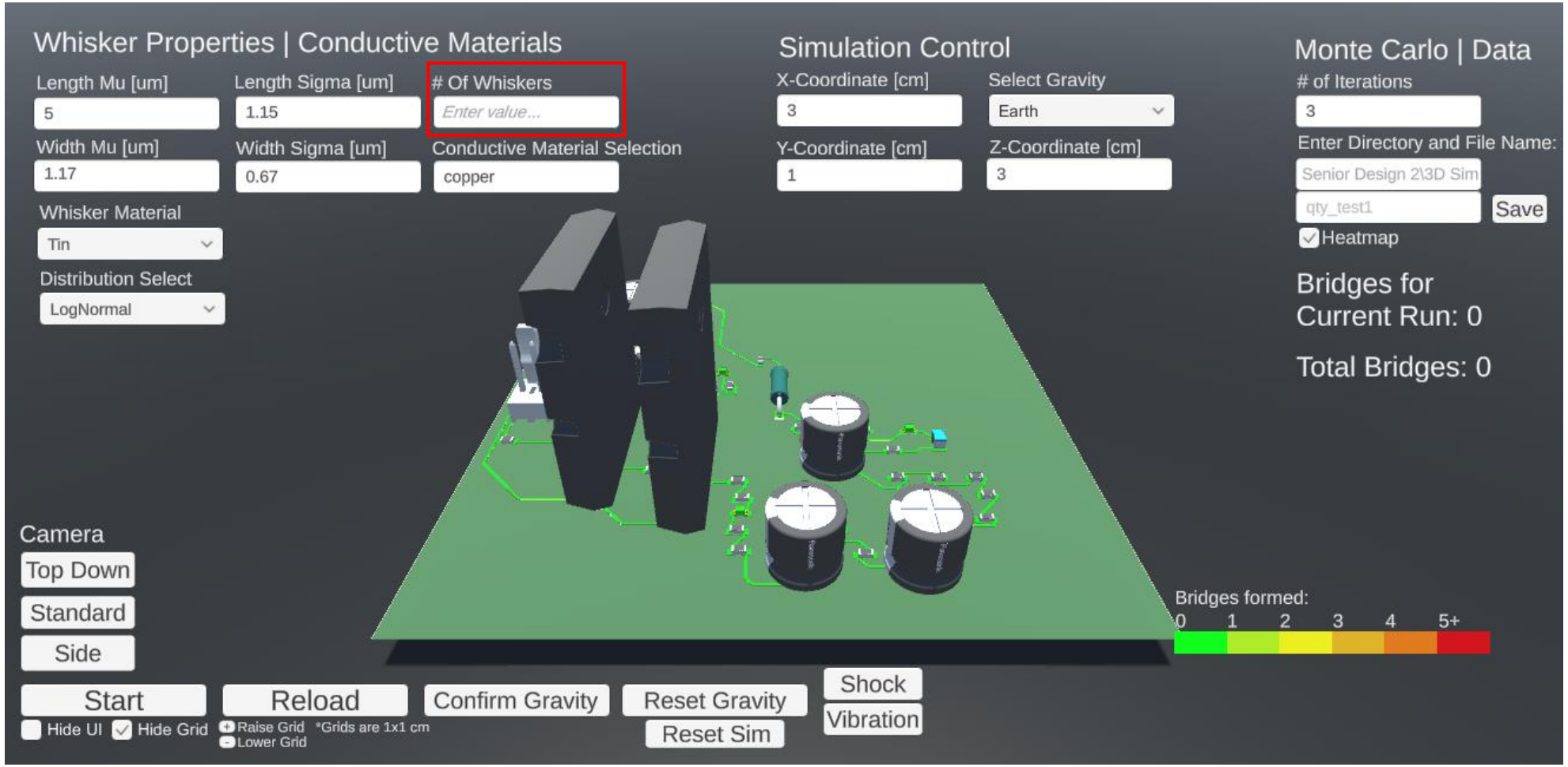
Bridging Contact



Heat Map Test (10 Iterations, 2x Speed)

Testing and Analysis

Results Assessment



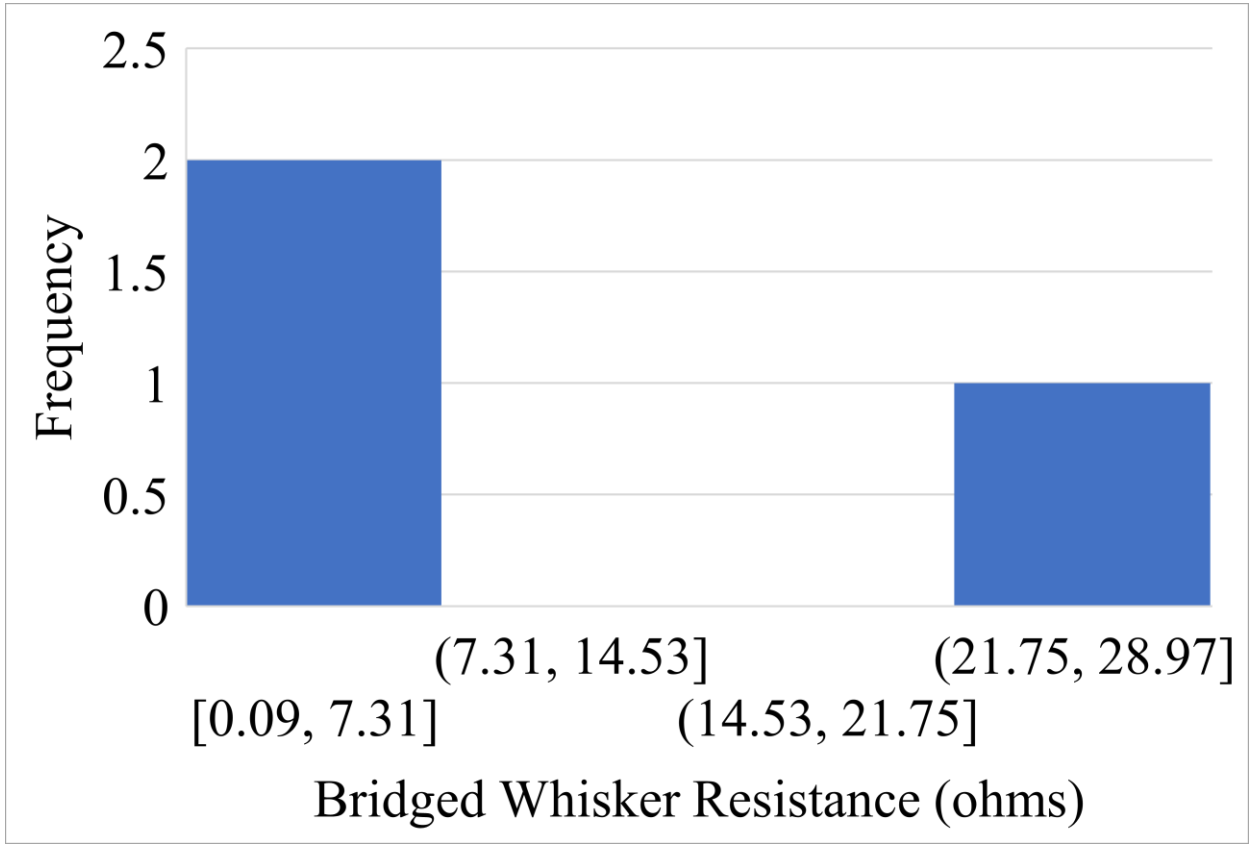
Test Initial Inputs

Testing and Analysis

Results Assessment – Small Whisker Storm (Qty: 50)

ALT + F8 -> GenerateProb	
Overall Probability	
66.67%	
Individual Probability	
Iter #	Probability
1	2.00%
2	4.00%
3	0.00%

Small Quantity Bridging Probability



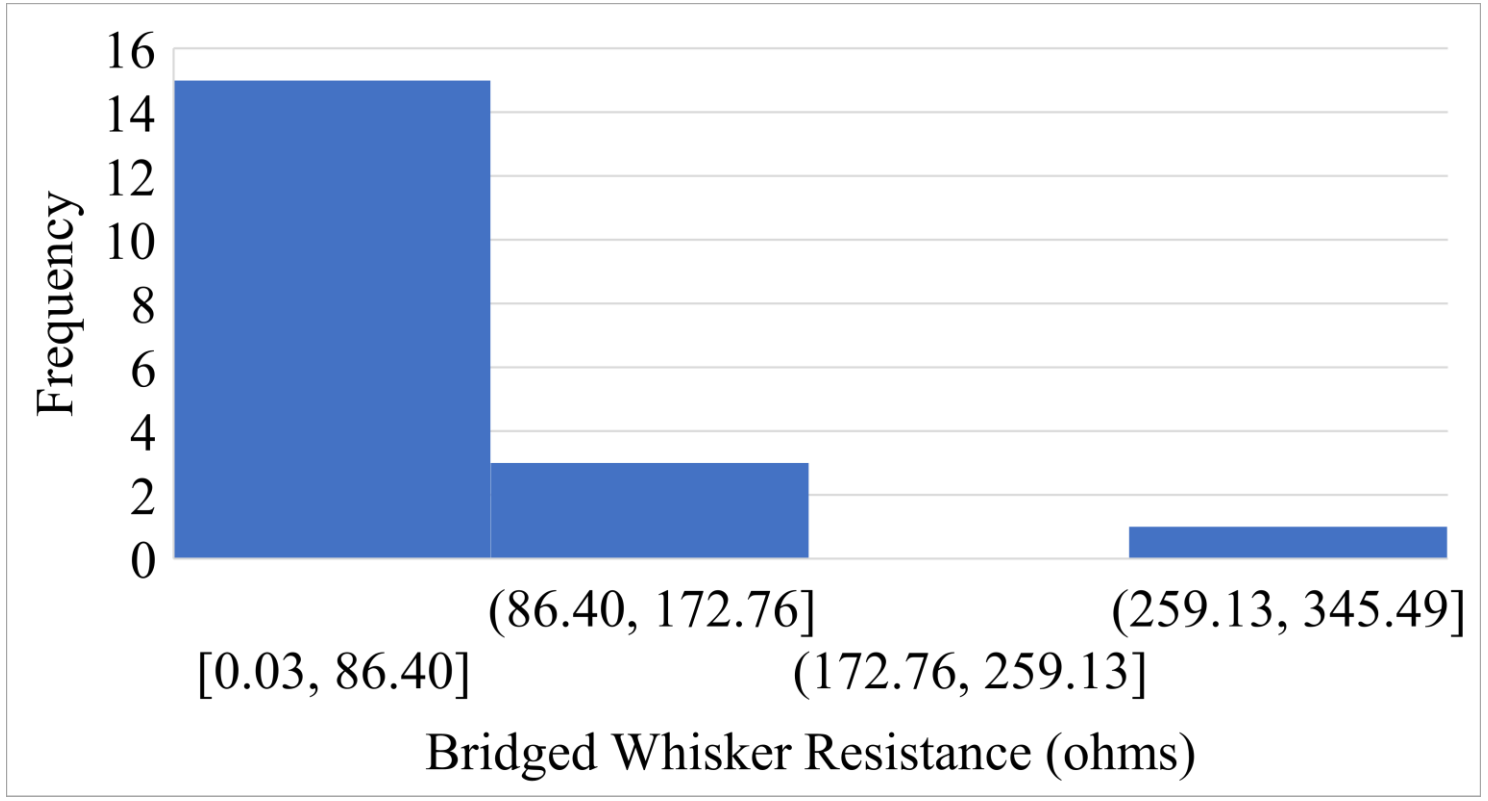
Small Quantity Bridging Resistance Frequency

Testing and Analysis

Results Assessment – Large Whisker Storm (Qty: 500)

ALT + F8 -> GenerateProb	
Overall Probability	
100.00%	
Individual Probability	
Iter #	Probability
1	1.80%
2	1.00%
3	1.00%

Large Quantity Bridging Probability



Large Quantity Bridging Resistance Frequency

Further Development

Simulation Errors & Suggested Improvements

Ideas for Further Development

Source of Error	Proposed Solutions
Exposed Traces	• **Short Term –** Remove traces (Un-route Tool) • **Long Term –** Research different processing and/or collider process to see if possible
Component "Grouping"	• Research working with different file types
Uniform and Constant Cross Section	• Research different modeling capabilities in Unity to see if solutions possible • **Potential –** Poly Shape tool
Whisker Resistance	• Research different modeling capabilities in Unity to see if solutions possible • **Potential –** Vectors

[3,4,5]

Further Development

Simulation Errors & Suggested Improvements

Ideas for Further Development

Source of Error	Proposed Solutions
Shock Accuracy	• Research different modeling capabilities in Unity to see if solutions possible • **Potential –** Using time differential (2D version)
File Type Issues - .obj	• **Short Term –** Replace component for one of similar makeup • **Long Term –** Research different processing and/or file types • **Potential -** Flipping Normals
Material Names	• Use different software • Research different post processing for names to see if possible
Rigidity	• Research different modeling capabilities to see if solutions possible

[6,7]

Conclusion

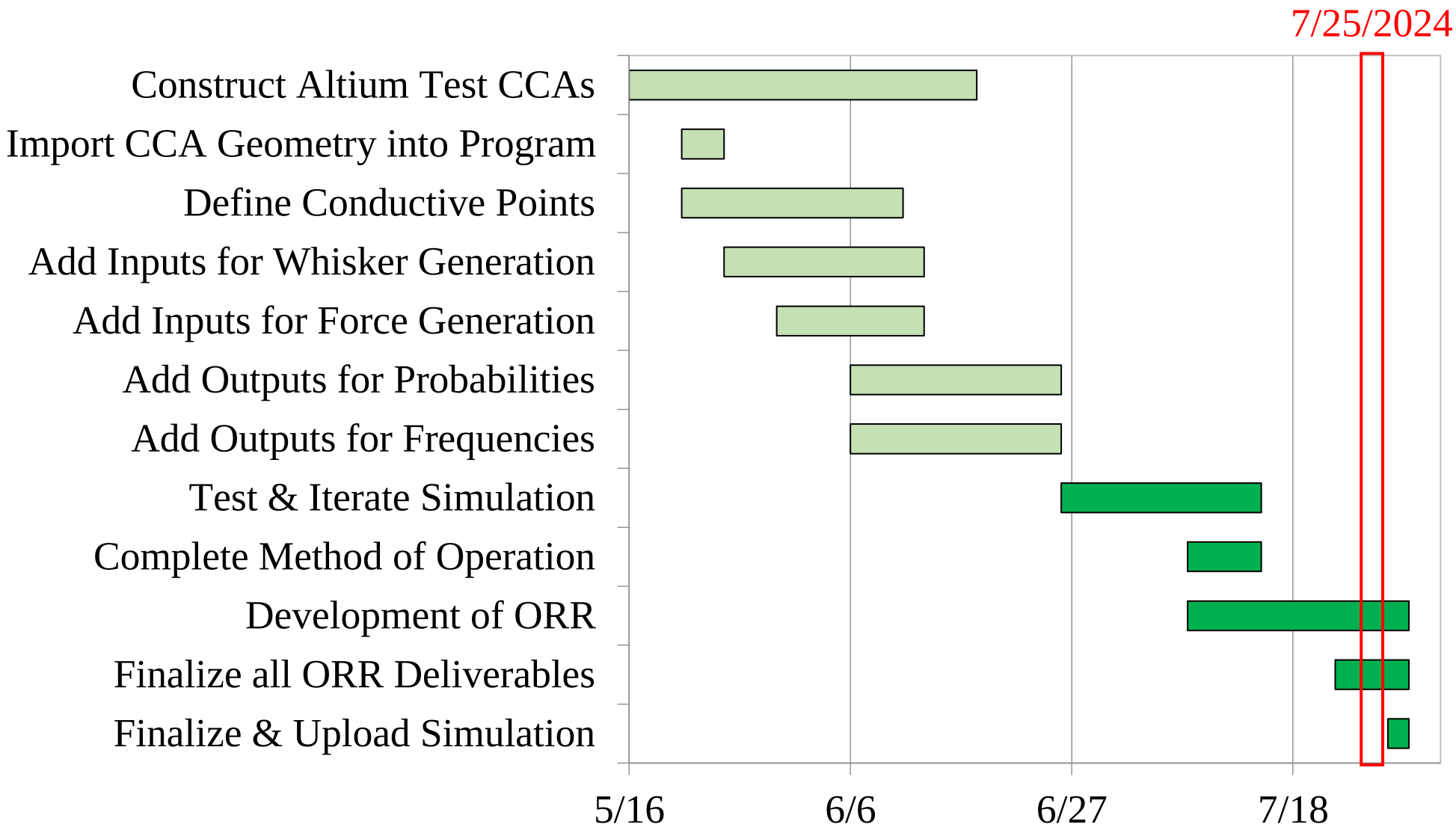
Design Specifications Met

- CCA importing & interaction
- Normal and lognormal dimensional distribution
- Drop location of airborne whiskers
- External forces through sine waves
- Physical results – heatmap
- Statistical results – probability & frequency histograms
- Single script – C#
  - ≈1500 lines of code

Continued Development

- Team 1 suggestions
  - Explore file types
  - Improve material ID
  - Realistic whiskers
- Team 2 improvements
  - Physical boundaries
  - Node & whisker ID
  - Enhanced data tracking

Gantt Chart


7/25/2024
Construct Altium Test CCAs
Import CCA Geometry into Program
Define Conductive Points
Add Inputs for Whisker Generation
Add Inputs for Force Generation
Add Outputs for Probabilities
Add Outputs for Frequencies
Test & Iterate Simulation
Complete Method of Operation
Development of ORR
Finalize all ORR Deliverables
Finalize & Upload Simulation
5/16
6/6
6/27
7/18

References

1. Panashchenko, L. (2012) *The Art of Metal Whisker Appreciation: A Practical Guide for Electronics Professionals, NASA.* https://nepp.nasa.gov/whisker/reference/tech_papers/2012-Panaschenko-IPC-Art-of-Metal-Whisker-Appreciation.pdf (accessed Feb. 1 2024).
2. "Tablecloth whip-off Trick," Steve Spangler, https://stevespangler.com/experiments/tablecloth-science-trick/#:~:text=Plain%20and%20simple%2C%20Tablecloth,the%20object%20to%20move%20it. (accessed Jul. 23, 2024).
3. P.M. Games, "Probulder Unity | drawing 3D shapes with polyshape tool," Youtube, https://www.youtube.com/watch?v=lr9cU0ejY8U (accessed Jul. 23, 2024).
4. "Modifying existing routes," Altium Documentation, https://www.altium.com/documentation/altium-designer/modifying-existing-routes-pcb#routing-aware-move-component (accessed Jul. 22, 2024).
5. Wintersbane, Finding vector3 position of GameObject – Questions & Answers – Unity Discussions, https://discussions.unity.com/t/finding-vector3-position-of-gameobject/148031 (accessed Jul. 24, 2024).

References

6. Ekta-Mehta-D, “Electric shock wave effect 2D – Questions & Answers – Unity Discussions,” Unity Discussions, https://discussions.unity.com/t/ electric-shock-wave-effect-2d/71778 (accessed Jul. 24, 2024).

7. “Why do my object files look weird when imported to unity?,” Stack Overflow, https://stackoverflow.com/questions/72842393/why-do-my-object-files-look-weird-when-imported-to-unity (accessed Jul. 23, 2024).

Questions?

A special thanks to our advisors…

Dr. Donna Havrisik
Jay Brusse
Bill Arnold
Tim Mondy
Dr. George Flowers
Jake Botello