Godot Cable Models

Sponsor:

Los Alamos National Laboratory

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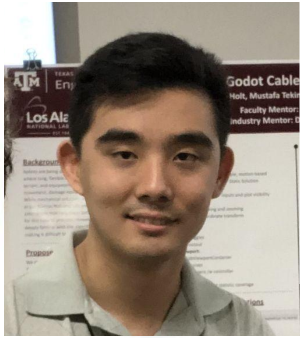

Johnathan
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ROADMAP

01

Intro + Motivation

Explore use of engineering solutions to cable state predictions

02

Requirements & Design

Use FEM to model cable behavior and compare with alternate solutions.

03

Implementation

Using the Godot game engine and using C#

04

Evaluation

Based on the satisfaction of engineers and real-world comparisons.

05

Wrap-Up

Based on the satisfaction of engineers and real-world comparisons.

01

Introduction + Motivation

What's the issue?

- Nuclear waste cleanup efforts
- Dry retrieval machinery has bulky cables

Our contacts at Los Alamos are interested in algorithmic approaches to better programmatically understand cable behavior.

- Simulate deformation of cables for future applications.

What is our Cable Model Program?

- Exploratory tool
- Analysing and comparing strengths and weaknesses of cable algorithms
- 2 algorithms tuddied:
  - Mass-spring and explicit approaches
  - FEM approaches

Mass-Spring Approach

What	How	Result
Simple, intuitive, efficient Used in animations and video games	Small deformations with each time step. Internal forces defined using springs and masses. After many time steps, the structure will settle into stability.	Quickly evaluate the final position of a cable. Not precisely accurate, but it is a viable solution for many applications.

Finite Element Methods

What

Powerful Analysis Framework for Engineering.

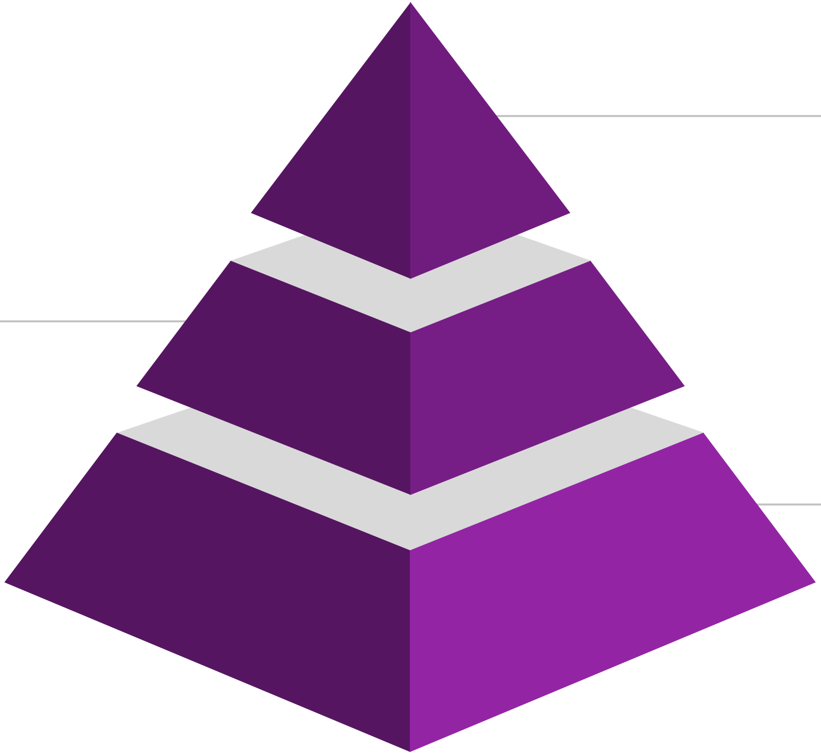
How

Structures are defined as nodes and elements. Final structure state is solved mathematically by balancing internal and external forces.

Result

A precise and provably accurate solution to a complex problem.

Innovation. Originality. Novelty.



Complex Algorithms

1 By comparing these algorithms side-by-side, we can see the upsides and downsides of each approach.

Demonstrates Complex Behavior

2 Our cable model will demonstrate a cable behavior that is complex, realistic and useful.

Targeted Tool

3 Other engines and tools for evaluating this type of behavior exist, but are too generalized to satisfy our sponsor.

02

Requirements & Design

Acceptance Criteria / Definition of Success

- I can clearly see how a cable behaves under its own weight
- I can change cable properties and instantly see the result
- I can compare the original (resting) shape and the deformed (loaded) shape
- The app feels responsive and intuitive — I don’t need instructions
- The visuals are smooth and readable, even with extreme settings
- The interface gives me confidence in results

Requirements

Catenary Curve Generator

- Computes and displays the ideal resting shape of a suspended cable

Finite Element Simulation

- Simulates how the cable deforms under applied forces using physics-based methods

Live Visualization

- Both the original and deformed cable shapes are drawn and updated in real time

User Controls

- Adjustable input fields for start/end points, mass, length, and number of segments

Interactive Camera

- Click and drag to pan, scroll to zoom — with a coordinate system mapped to meters

Comparable Visuals – Each cable plot can be shown or hidden on demand

Design

- **UI Setup**
  Controls for endpoints, mass, length, and segment count
- **Plotting System**
  Modular cable plotters (Parabola, Abs, FEM)
- **Coordinate Mapping**
  Scaled world (1 unit = 1 meter) with zoom/pan support
- **Catenary Generation**
  Uses variation on $y = a \cdot \cosh((x - x_0)/a) + C$ to model the resting shape
- **FEM Simulation**
  Applies force increments, computes displacement and stress
- **Visual Output**
  Draws both original and deformed cable for comparison

Design details

- **Data Design**
  Cables are defined by endpoints, mass, length, and segment count. Results are stored as point arrays and force matrices.
- **Functional Structural**
  Plotters follow a shared interface. The Coordinator handles user input and delegates plot generation.
- **Functional Dynamic**
  User actions trigger real-time updates. Plot visibility toggles, and FEM simulation runs on demand with incremental convergence.

03

Implementation

Technology

Godot 4
 Game engine used for rendering, UI, and event handling.

UI System
- parameter adjustments
- viewport controls

Custom Physics Solvers (C#)
 FEM: Truss connected non-linear structure.
 Mass-Spring: Semi-implicit hookian mass-spring system.

Implementation Details

The following slides walk through how our system works -
key algorithms, visuals, and user interactions.

Expect:

* Responsive, fast plots
* Support our custom physics
* Interactive controls
* Clean UI + visuals

General Use Case

1

Inputs

1. Cable Length
2. Endpoints
3. Mass
4. External Force

2

Process

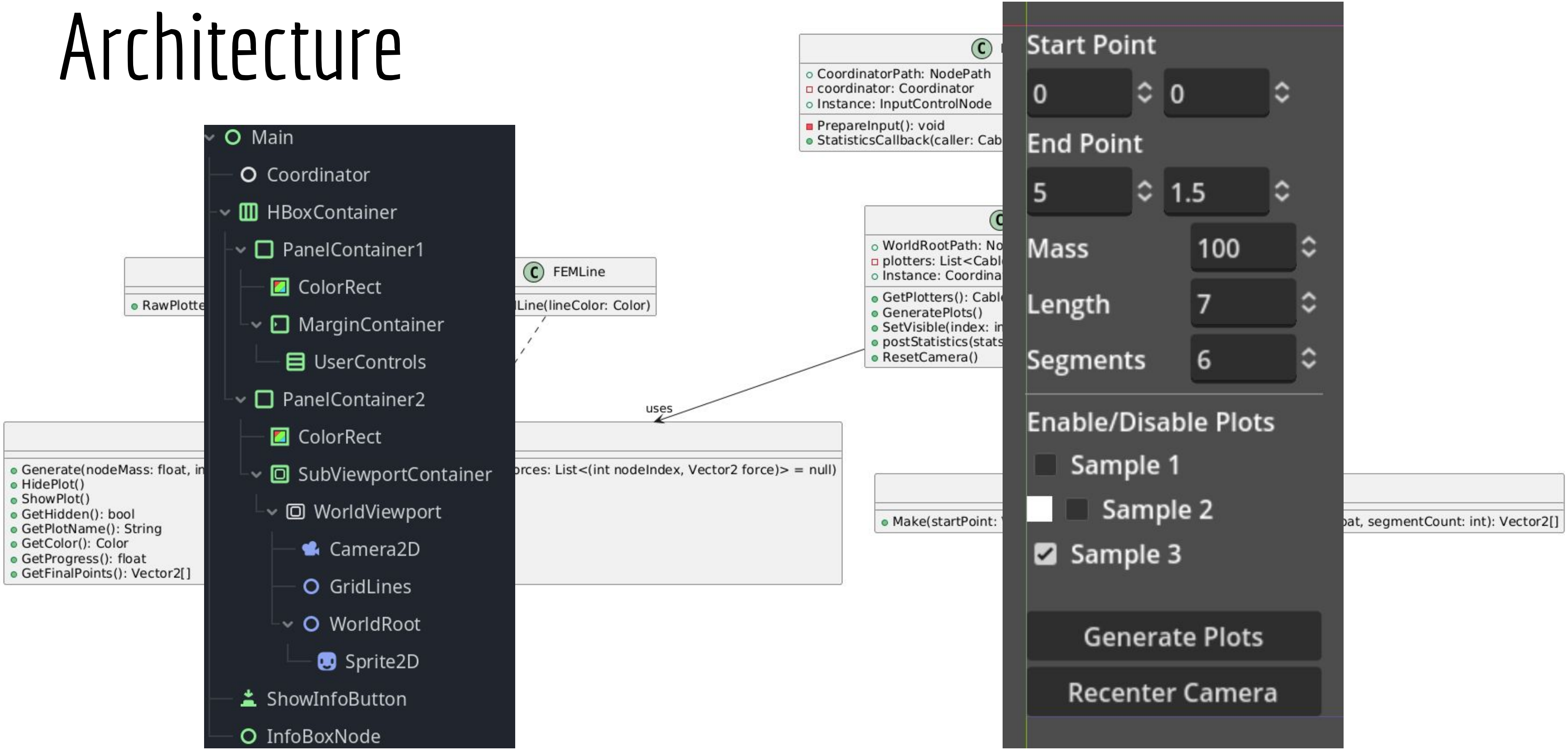
Finite Element Method / Mass-Spring Deformation to Final Shape

3

Output

Visible, interpretable, and useful statistics about the process and final position.

Architecture



Integration Testing

Strategy:
Test end-to-end flow: user input → plot generation → FEM deformation

Test Cases:

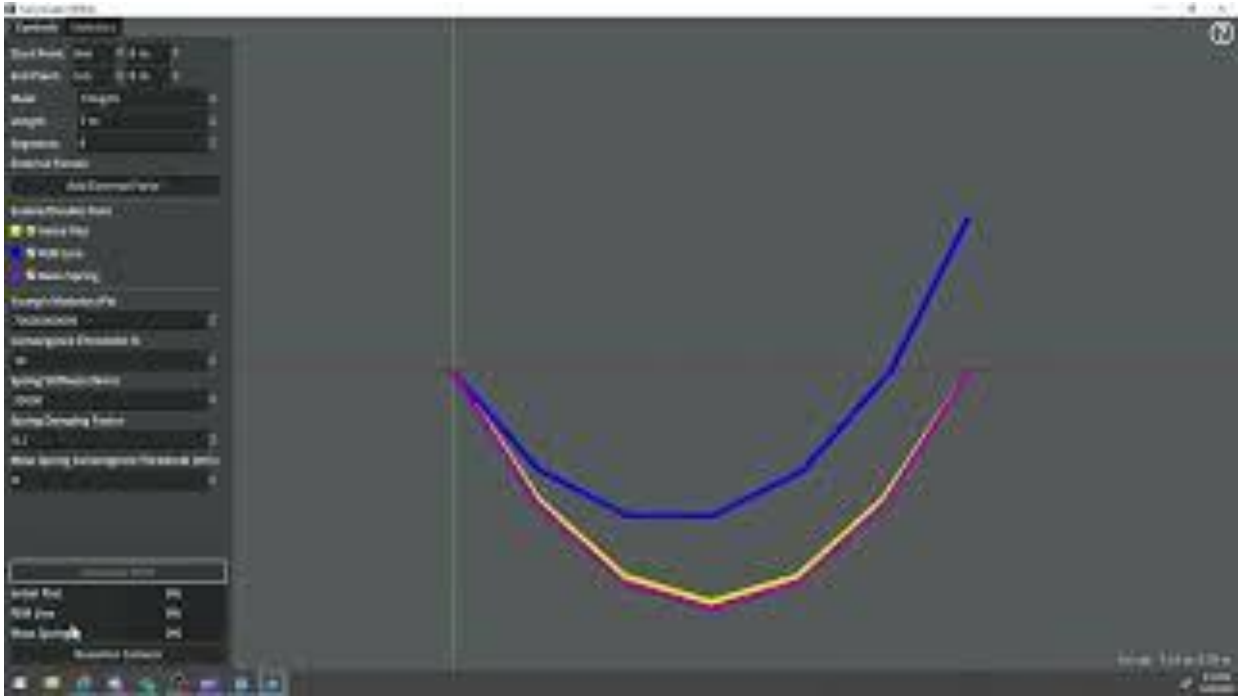
- Vary cable length and segment count.
- Move start and endpoints through quadrants. Vary length and mass to possible and impossible states.
- Check symmetry and behavior under known setups.
- Investigate stability of external force application.

Key Results:

- Visuals updated correctly for all inputs.
- FEM handled extreme cases without instability.
- Output matched expected physical trends.

DEMO

- In action
- simulation response to input
- Initial shape and final



04

Evaluation

Evaluation Design

- **Unit Testing**
  Tested core functions like coordinate mapping, vector math, and segment generation in isolation.
- **System Testing**
  Ran full simulations to confirm proper interaction between UI, solvers, and plotting system.
- **User Acceptance Testing (UAT)**
  Confirmed the app behaves as expected from a user’s perspective — inputs feel intuitive, output makes sense, visuals update reliably.

Quality Goals

Accurate Cable

Accuracy of structure, form, and final behavior.

Visual Feedback

Actions taken by the user should never go unacknowledged.

Helpful to Users

We want our users to actually find the tool helpful. This is the most important quality goal, and will be verified during user feedback

Zero UI Slowdowns

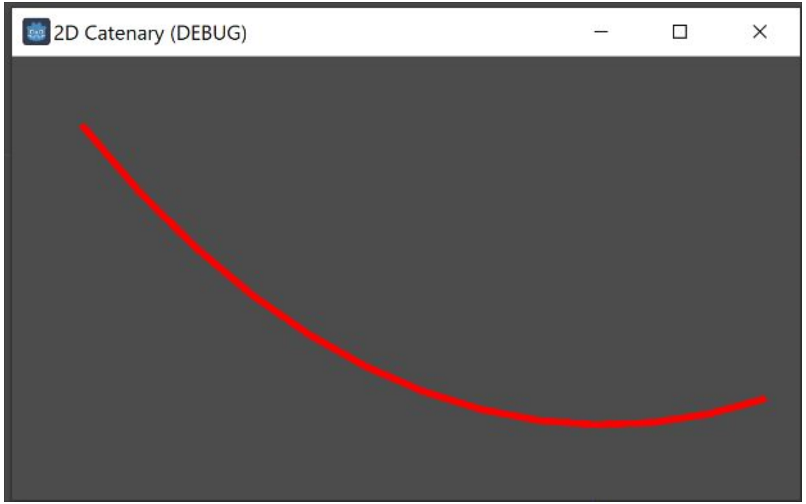
Slowdowns and freezing is frustrating to a user.

Output Critical Data

All important output information shown. Hidden data is no good to anyone.

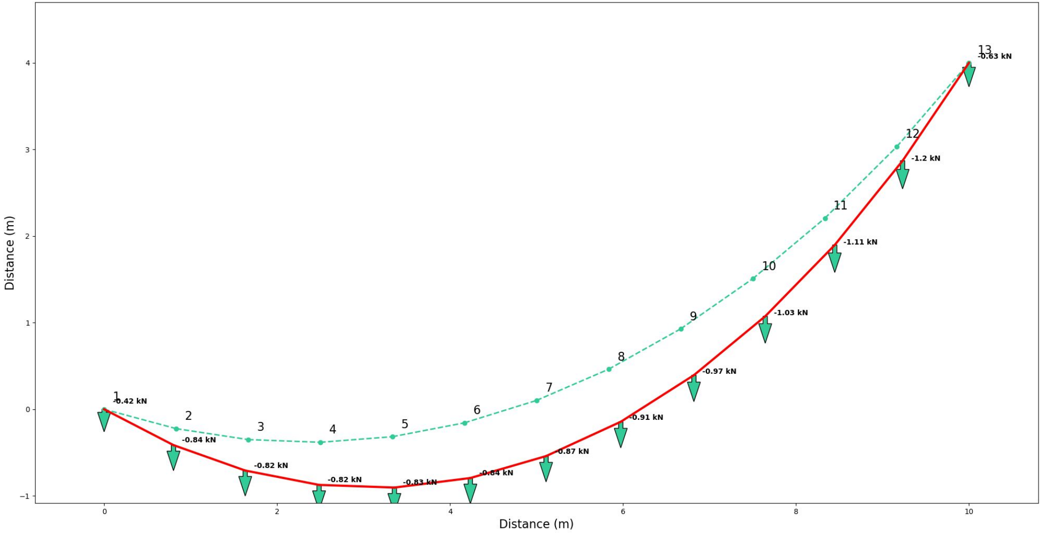
Unit Testing

- Initial Cable Catenary Curve Plotting/Generation Testing
- Cable Curve Plotting/Generation with Self-Weight after FEM
- Accurate cable curves that are the same results/outputs between the Python and C# implementation.



System Testing

- Initial Catenary Curve Plot and FEM plot give reasonable cable curves
- Accurate Cable Curves for the given input
- Stability given edge-case inputs



User Acceptance Testing

- Testable and User friendly interface for easy UAT for sponsors
- Recruitment of Users are from LANL
- Application for user to put in inputs and check the reliability of the output
- User friendly with easy to understand results

Reviews

Strategy:

- We reviewed the project iteratively — looking for clarity, correctness, and usability at each stage.

Types of Reviews:

- **Code Review**: Verified math logic, readability, and modularity
- **Visual Review**: Checked that plots look clean, scale properly, and update live
- **Peer Feedback**: Ensured the app was easy to use and delivered intuitive results

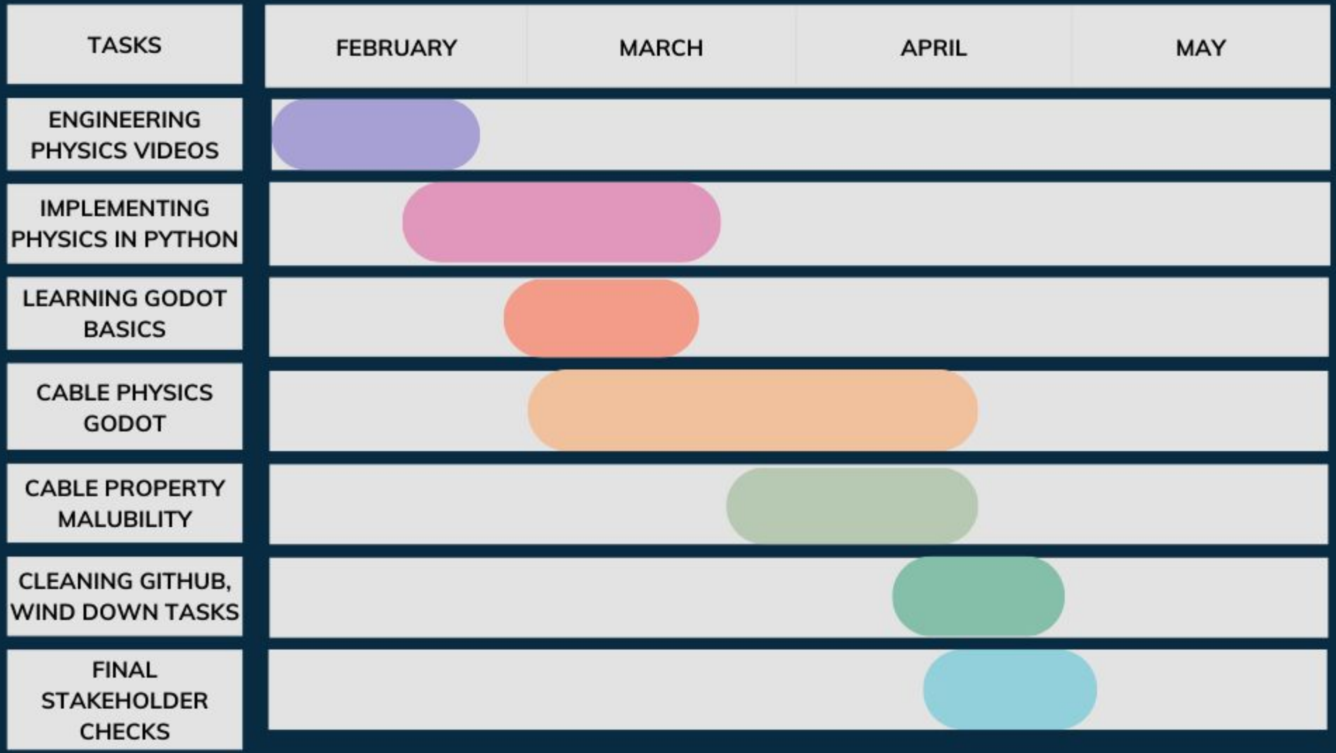
Professional/Ethical Concerns

1. Accuracy and Misrepresentation
If the simulation is used to inform real-world decisions, misleading visuals or incorrect assumptions could be dangerous.

2. Transparency of Assumptions
We must clearly communicate that the model uses simplifications (e.g., ideal materials, no damping) and is not a certified engineering tool.

3. Accessibility and Usability
Making the tool intuitive helps prevent user error — good design is an ethical responsibility when visualizing technical systems.

GANTT CHART
GODOT CABLE MODELS



Project Management – Team Dynamics

- Spiral Process Model
  - Adopted the **Spiral Model** to iteratively plan, build, evaluate, and refine.
  - Allowed for flexible adaptation to evolving requirements and risks.
  - Emphasized **risk assessment** and continuous stakeholder feedback at each cycle.

Spiral Model

- Discord communication and collaboration.
  - Used **Discord** for daily asynchronous communication and file sharing.
  - Created **dedicated channels** for tasks, bugs, documentation, and casual interaction.
  - Promoted **quick feedback loops**, real-time updates, and transparent collaboration.

Responsibilities

- Stakeholder Manager (John Mo)
  - Interacts with the stakeholder/sponsor.
- Schedule Coordinator (Jordan Daryanani)
  - Responsible for planning meeting times and long term goals.
- Risk Manager (Mustafa Tekin)
  - Responsible for tracking, considering, and mitigating risks.
- Quality Coordinator (Thomas Holt)
  - Responsible for ensuring quality of final product.
- Scope Manager (Johnathan Zhao)
  - Responsible for planning project scope.

05

Wrap-Up

Discussion

Advanced Understanding of Cable Simulation

- Quicker cable simulation processing
- 3D application

Potential Applications

- Any future cable related structures & projects.
- Provides a foundation for the future

Lessons Learned

- Cable simulation can be slow and may not function well with dynamic movement.

Future Work

- Important Features
  - 3D implementation.
  - Better UI controls.
  - Collision and friction consideration.
- External Solver
  - Building an FEM solver is a difficult task.
  - Floating point problems & extensibility are challenging.
  - Commercial and professional options do exist!
- Decision Making Processes
  - Detecting cable tangling.
  - Detecting bad tensions.
  - Integrating state detection into a tool.

Parting Thoughts

- Impact of our work: This will allow Los Alamos to not have to allocate so many people and resources into just dealing with the cables, so they can spend more time on other parts of the dry retrieval process

- Contribution to the existing body of knowledge: Our Cable Model will give Los Alamos the knowledge of what the best way to simulate the cables, and that will be useful for them down the line.

Thank you!

Questions?