SKADI
Preliminary Design Review

10/12/2021, AERO 120
ASEN 4018-012 Team 9

Sponsor: USA Nordic Team
Faculty Advisor: Dr. Melvin Rafi

Presenters: Hunter Daboll, Landon Nurge, Max Page, Joaquin Ramirez, Michael Schlittenhart, Julia Sheeran, Mary Sobernheim

Additional Team Members: Maya Greenstein, Max Page
Outline

● Project Description

● Evidence of Baseline Feasibility
  ○ Critical Elements
  ○ Feasibility Analyses
    ■ Visual
    ■ Mechanical
    ■ Force Data Collection

● Status Summary & Future Work

SKADI = Ski jump Athletic Development Interface
Project Description

Section Outline

- What is Nordic Ski Jumping?
- Project Motivation
- Mission Statement
- Functional Requirements
- ConOps (Static)
- Baseline Design
- ConOps (Animated)
- Functional Block Diagram

Presenters: Mary Sobernheim, Joaquin Ramirez, Hunter Daboll
What is Nordic Ski Jumping?
Project Motivation

- **USA Nordic Ski** needs a better way to train their ski-jump athletes off the slopes.

- Current training methods lack **visual aids**, cause the athlete to experience unrealistic **external forces**, and do not provide a way to collect **foot force distribution**.

USA Nordic’s Current Training Methods:

Videos courtesy of USA Nordic
Mission Statement

SKi jump Athletic Development Interface (SKADI) will provide the USA Nordic team with a modern training device that will visually and physically model the effects of a ski jump while measuring the force applied by the athlete.
## Functional Requirements

<table>
<thead>
<tr>
<th>ID</th>
<th>Functional Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR1</td>
<td>SKADI shall provide visual cues correlating to the phase in jump.</td>
</tr>
<tr>
<td>FR2</td>
<td>SKADI shall provide force and motion cues correlating to the phase in jump.</td>
</tr>
<tr>
<td>FR3</td>
<td>SKADI shall be able to support the forces generated when used by the full range of USA Nordic athletes.</td>
</tr>
<tr>
<td>FR4</td>
<td>SKADI shall be able to be disassembled, transported, and reassembled with standard tools and equipment.</td>
</tr>
<tr>
<td>FR5</td>
<td>SKADI shall capture the data of the athlete’s force profile.</td>
</tr>
<tr>
<td>FR6</td>
<td>SKADI shall safely bring the user to rest following the jump.</td>
</tr>
<tr>
<td>FR7</td>
<td>Each use of the SKADI simulation shall require less than 5 minutes.</td>
</tr>
<tr>
<td>FR8</td>
<td>SKADI shall be operable within a gymnasium while other athletes are adjacently training.</td>
</tr>
</tbody>
</table>
**Setup**

1. Simulation configured, athlete mounts the machine

2. Visual cue correlating to phase in jump begins

3. Physical cue relating to acceleration is applied to athlete

4. Force profile data is collected

5. Movement to flight position

6. Athlete brought to rest and de-mounts

**Take-off**

**Feasibility Analyses**

**Status Summary & Future Work**
Baseline Design: Visual

VR Headset:
Oculus Quest 2

User
Baseline Design: Force Data Collection

User

Force Data Sensors

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Critical Elements</th>
<th>Feasibility Analyses</th>
<th>Status Summary &amp; Future Work</th>
</tr>
</thead>
</table>
Baseline Design: Mechanical

Critical Elements

Feasibility Analyses

Status Summary & Future Work

1. Belay Mechanism, Operated by 3rd Party, Attached to Ceiling
2. User Harness
3. Coach
4. Lifting Platform
5. Connection Rod
6. Support Poles (x4)
7. Linear Actuator
8. Stairs
Full Baseline Design

VR Headset: Oculus Quest 2

User Harness

Lifting Platform

Stairs

Linear Actuator

Support Poles (x4)

Connection Rod

Force Data Sensors

User

Belay Mechanism, Operated by 3rd Party, Attached to Ceiling

Coach

Project Description

Critical Elements

Feasibility Analyses

Status Summary & Future Work
Event Number: 0
Event:
User, Coach, and Belayer enter defined area for SKADI training
Event Number: 1

Event:
Don safety harness, Belayer prepares their harness and belay (ropes) system
Event Number: 2
Event: Don Training Boots (User’s personal boots, Force Data Insoles inserted)
Event Number: 3
Event: Acquire Standalone VR Headset
(Protected by training helmet)

Project Description

Critical Elements
Feasibility Analyses
Status Summary & Future Work
<table>
<thead>
<tr>
<th>Project Description</th>
<th>Critical Elements</th>
<th>Feasibility Analyses</th>
<th>Status Summary &amp; Future Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifting Platform</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standing VR Headset</td>
<td>User (Nordic Ski Team Athlete)</td>
<td>User Harness</td>
<td>Training Ski Boots with Force Data Insoles inserted</td>
</tr>
</tbody>
</table>

**ConOps**

**Event Number:** 4  
**Event:** Tie into belay mechanism
Event Number: 5
Event: Mount Lifting Platform (Currently Lowered)

User with harness and sensors donned, and headset acquired
Event Number: 6
Event: Lifting Platform rises slowly
Event Number: 7
Event:

Raised Lifting Platform

Corresponding Jump Location
Event Number: 8
Event:
Lifting Platform drops quickly, allowing User to reach downward velocity of 0.64 [m/s]

VR Simulation mimics motion on ski jump ramp

Force data is continuously collected

Corresponding Jump Location
Event Number: 8.1
Event: Lifting Platform, moving downward, begins upward acceleration (causing upward normal force on user, creating sensation of compression)

VR Simulation mimics motion on ski jump ramp

Force data is continuously collected
Event Number: 8.2
Event: Lifting Platform, having become motionless, now has upward velocity - continuing upward acceleration (User continues to experience compressive force)

VR Simulation approaches end of ski jump ramp

Force data is continuously collected

Corresponding Jump Location
Event Number:  9  

Event:  
VR Simulation indicates end of ski jump ramp  

User jumps from lifting platform  

Force data is continuously collected
Event Number: 10
Event: VR simulation turns off

Data collection ceases

User is caught by belayer with belay system
Event Number: 11
Event: User removes VR Headset
User is lowered to platform by belay system
Event Number: 12
Event: User detaches from belay device

User demounts lifting platform, optionally doffs headset and boots
Event Number: 13
Event: Coach and user analyze force data, discuss improvements. Training simulation may be repeated.
(Evidence of Baseline Feasibility)

Critical Elements

Presenters: Mary Soberheim, Joaquin Ramirez

Section Outline

- Identification of CPEs
- Key Feasibility Elements
# Identification of Critical Project Elements (CPEs)

<table>
<thead>
<tr>
<th>Func. Req.</th>
<th>CPE</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR1</td>
<td>E1</td>
<td>The synchronization of the visual and mechanical subsystems</td>
</tr>
<tr>
<td>FR2</td>
<td>E2</td>
<td>The production of similar forces to those experienced by an athlete during ski jump takeoff while supporting at least 200 kg</td>
</tr>
<tr>
<td>FR3</td>
<td>E3</td>
<td>The ability of SKADI’s users to participate in multiple simulations</td>
</tr>
<tr>
<td>FR5</td>
<td>E4</td>
<td>The capturing of user’s foot force profile throughout the takeoff phase</td>
</tr>
</tbody>
</table>
# Key Feasibility Elements

<table>
<thead>
<tr>
<th>Label</th>
<th>Functional Requirement</th>
<th>CPE</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIS</td>
<td>FR1</td>
<td>E1</td>
<td>Headset that is able to display visual cues and be synced with physical cues</td>
</tr>
</tbody>
</table>
| MECH  | FR2                    | E2,E3 | Linear actuators that provide analogous physical cues to that of an Olympic ski jump  
Supports weight of athlete with FOS of (#) |
| FOOT  | FR2, FR5               | E4  | Pressure mapping system that successfully records necessary data throughout the simulation  
Supports weight of athlete with a FOS of 1.1 |
| COST  | Budget                 | Budget | The total monetary cost of SKADI must be <$5k. |
(Evidence of Baseline Feasibility)

Feasibility Analyses

Presenters: Michael Schlittenhart, Landon Nurge, Julia Sheeran

Section Outline

- Visual Feasibility (VIS)
- Mechanical Feasibility (MECH)
- Force Data Collection Feasibility (FOOT)
- Financial Feasibility (COST)
Visual Feasibility (VIS)
Visual Feasibility Analysis Justification

1) Display visual cues - use Oculus Quest 2
2) Synchronize visual cues with physical stimuli - synchronize VR presentation with physical platform motion
Visual Feasibility Analysis - Display Format

**Display Format Options:**

1) Animated Video Game

2) 180° or 360° Video

[1] Ski Jump VR Game Trailer, 2017

## Visual Feasibility Analysis - Display Format

<table>
<thead>
<tr>
<th>Display Format</th>
<th>Animated Video Game</th>
<th>180° or 360° Video</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fulfills Requirement?</strong></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Functional with Oculus Quest 2?</strong></td>
<td>Yes (via Unity [3])</td>
<td>Yes (via apps from Oculus App Store [4])</td>
</tr>
<tr>
<td><strong>Feasible?</strong></td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Visual Feasibility Analysis - Timing

Timing with Physical Cues Options:

1) Manual Start
   ● Manually begin VR Simulation from Goggles
   ● Less precisely synchronized with physical system
   ● Less development work required

1) Software Integration
   ● Integrate VR start with start of physical system using software
   ● Unsure if VR can be started with external software
     ○ Awaiting reply from Oculus
   ● Better synchronized with physical system
## Visual Feasibility Analysis - Timing

<table>
<thead>
<tr>
<th></th>
<th>Manual Start</th>
<th>Software Integration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fulfills Requirement?</strong></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Description of Functionality</strong></td>
<td>User would manually begin visual simulation on VR headset. SKADI would have timing worked out with instructions on how to align that with physical cues</td>
<td>SKADI would connect the software to start the physical and visual simulations simultaneously</td>
</tr>
<tr>
<td><strong>Feasible?</strong></td>
<td>Yes</td>
<td>TBD*</td>
</tr>
</tbody>
</table>

*TBD* will pursue if feasible.
### VIS Feasibility Analysis Results

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Design that Fulfills Requirement</th>
<th>Feasible?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display Visual Cues</td>
<td>Animated video game/recorded video</td>
<td>Yes</td>
</tr>
<tr>
<td>Synchronize visual cues with physical stimuli</td>
<td>Manual Timing</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Visual Feasibility:** Yes
Mechanical Feasibility (MECH)
Driving Requirements

“FR2: SKADI shall provide force and motion cues correlating to the phase in jump”

- SKADI will cue the beginning of the transition to flight phase by enacting analogous forces on the ski jumper.
  - The platform must exert a compressive force of at least +0.06 Gs on the athlete
  - The total displacement shall be minimized for the sake of volume constraints
- The mechanical system will minimize forces that are not felt during an actual jump to preserve immersion

“FR3: SKADI shall be able to support the forces generated when used by the full range of USA Nordic athletes”

- The velocity shall be minimized for the sake of user safety
Assumptions

- **Maximum 200 kg needs to be supported by the mechanical system**
  - According to the 2014 Sochi Olympics database, winter athlete weights vary from 53kg (lightest female) to 98kg (heaviest male skier).
  - Account for up to 220 kg under maximum Gs
  - Account for up to 50 kg lifting platform
  - Design for 540 kg to ensure FOS of 2
- **+0.02 Gs = minimum deviation in vertical acceleration that a human can detect** [10]
- **Kinematic calculations (assuming constant acceleration) can be used to break into the design loop**
  - End states calculated numerically using the acceleration profile closely resemble end states calculated kinematically using the average acceleration across the profile
  - Must still model numerically to ensure constraints are met
Physical Cue

- Transition from in-line to takeoff phase will be simulated mechanically
  - Compressive forces are high during takeoff phase
  - In-line phase does have significant compressive force
- A compressive force will be applied to cue the beginning of the takeoff phase
  - +.02 Gs is the minimum a human can detect
  - +.06 Gs is enough to be felt by the athlete (FOS = 3.0)
Model: Governing Equations

- Compression Profile
  - Using kinematics, assuming constant acceleration
  - Conditions
    - Simulation Time = 2.5s
    - Displacement = 1m
    - Minimize velocity
    - Maximize acceleration
  - Yield
    - Avg: 0.033 Gs
    - Max: 0.8 m/s

<table>
<thead>
<tr>
<th>Governing Equation</th>
<th>This Case</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>( d = \frac{v + v_0}{2} t )</td>
<td>(1m) = ( \frac{(0m/s) + v_0}{2} (2.5s) )</td>
<td>( v_0 = 0.8m/s )</td>
</tr>
<tr>
<td>( v = v_0 + at )</td>
<td>0 = (0.8m/s) + a(2.5s)</td>
<td>( a = 0.033Gs )</td>
</tr>
<tr>
<td>( \sigma^2 = \frac{1}{N} \sum (a - \mu)^2 )</td>
<td>( \mu = 0.033G ) ( N = 1000 )</td>
<td>Model</td>
</tr>
<tr>
<td>( a(t) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(t-\mu)^2}{2\sigma^2}} )</td>
<td>( \mu = 0.033G ) ( \sigma = STDEV )</td>
<td>Model</td>
</tr>
</tbody>
</table>
Enacting a Compressive Force

- Forces cannot be enacted immediately
  - Need a gradual application of acceleration
- This Gaussian curve describes how the compression will be enacted
- Driving Constraints:
  - (Time of simulation) Time = 2.5s
  - (Volume) Vertical displacement is to be < 1m
  - (Safety) Velocity is to be minimized
  - (Gs) User is to experience at least +0.06 Gs
Enacting a Compressive Force

- Start with free fall to generate velocity
- Accelerate upward to generate compression
- Bring athlete to rest
- User states
  - ode45 integration
    - Acceleration = 0 until necessary speed is reached
    - Acceleration follows Gaussian curve
Enacting a Compressive Force

User Experience State

Position and velocity state of user throughout simulation

T = 0s

T = 2s

VIS  MECH  FOOT  COST

Status Summary & Future Work

Project Description
Critical Elements
Feasibility Analyses
Enacting a Compressive Force

For this to work we need:
- Maximum force of 1075.41 N
- Maximum acceleration of 1.10 Gs
- Maximum displacement of 0.78 m
- Maximum Impulse of 928.77 N/s
Mechanical Feasibility Analysis

**Hardware:** Belt Driven Linear Actuator

**Cost:** ~$3300 per unit

**Models Options:** Misumi MSA-SBH Series, Macron Dynamics MSA-14S, Parker OSPE BHD Belt Actuator

**Important Specs:**

<table>
<thead>
<tr>
<th>Speed</th>
<th>Actuation Length</th>
<th>Maximum Load</th>
<th>Maximum Acceleration</th>
<th>Maximum Vertical Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-10 m/s</td>
<td>0.8-1.2m</td>
<td>50-567 kg each</td>
<td>~1-4 Gs</td>
<td>~180Nm</td>
</tr>
</tbody>
</table>

Misumi MSA-SBH Series
FOS Feasibility Analysis/Results

- **Analysis**
  - Max g-force = 1.1 g
  - Max user mass = 100 kg (1000 N)
  - Max platform mass = 50 kg (500 N)
  - Estimated max load = 270 kg (1600 N)
  - Linear actuator max vertical load = 567 kg
  - FOS = Up to 2.1 (depending on chosen actuator)

- **Result:** FOS of linear actuator = 2.1 > 2.0
# MECH Feasibility Analysis Results

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Fulfillment</th>
<th>Feasibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR2: SKADI shall provide force and motion cues correlating to the phase in jump</td>
<td>1 Misumi linear actuator can support the needed weight throughout maximum states of simulation</td>
<td>YES</td>
</tr>
<tr>
<td>FR2: SKADI shall provide force and motion cues correlating to the phase in jump</td>
<td>Expected +0.10 Gs at peak compression</td>
<td>YES</td>
</tr>
<tr>
<td>FR3: SKADI shall be able to support the forces generated when used by the full range of USA Nordic athletes</td>
<td>Expected maximum velocity of 0.64 m/s</td>
<td>YES</td>
</tr>
<tr>
<td>FR8: SKADI shall be operable within a gymnasium while other athletes are adjacently training</td>
<td>Expected maximum necessary displacement of 0.78 m</td>
<td>YES</td>
</tr>
</tbody>
</table>

**Mechanical Feasibility:** Yes
Force Data Collection Feasibility (FOOT)
FR5: SKADI shall capture the data of the athlete’s force profile.

1) **Data Collection** - Kitronyx Insole Sensor Kit, Snowboard 2, Snowforce Software

2) **Display Data** - Real time pressure distribution mapping

3) **Force Profile** - Calibration of CSV file to calculate the force values from the pressure distribution
Force Data Feasibility Analysis

**Hardware:** Foot Pressure Mapping System

**Cost:** $1,280

**Model:** Kitronyx Insole Sensor Kit

**Important Specs:**

<table>
<thead>
<tr>
<th>Number of Sensing Pixels</th>
<th>Pressure Range</th>
<th>Frame Rate</th>
<th>Number of Display Pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>118</td>
<td>180 kg</td>
<td>40 Hz</td>
<td>160</td>
</tr>
</tbody>
</table>

User Equipped with Insole Kit [8]
Force Data Feasibility Analysis

E4: The insoles will have a FOS of greater than 1.1 against structural failure

Maximum Force Supported by Sensors: 1765.8 N

Expected Maximum Mass ($m_{\text{max}}$): 100 kg

Expected Maximum Acceleration ($a_{\text{max}}$): 1.6 G = 15.696 m/s²

Expected Maximum Force Generated: $F_{\text{max}} = m_{\text{max}} \times a_{\text{max}} = (100 \text{ kg}) \times (15.696 \text{ m/s}^2) = 1569.6 \text{ N}$

FOS = 1.13 > 1.1
## FOOT Feasibility Analysis Results

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Fulfillment</th>
<th>Feasibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR5: SKADI shall capture the data of the athlete’s force profile.</td>
<td>Kitronyx Snowboard 2 and Insole Sensor Suite</td>
<td>YES</td>
</tr>
<tr>
<td>FR2: The insoles will have a FOS of greater than 1.1 against structural failure.</td>
<td>A 100 kg athlete can undergo 1.6 Gs without device breaking</td>
<td>YES</td>
</tr>
<tr>
<td>E3: The pressure distribution data shall be mapped visually.</td>
<td>Kitronyx Snowforce software provides real time mapping and data logging</td>
<td>YES</td>
</tr>
</tbody>
</table>

**Force Data Collection Feasibility:** Yes
Visual & Force Data Collection Costs

- Visual: ~$450
  - Oculus Quest 2: $300
  - Oculus accessories: $130

- Force Data Collection: ~$1300
  - Kitronyx Insole Sensor Kit: $1280
Mechanical Design Cost (1 Linear Actuator)

- Cost: ~$4000
- Meets minimum load requirements for the lowest cost
- Concerns:
  - High torques will be applied to actuator, could exceed limit
  - Max applied moment during simulation ~1000 Nm
Initial Financial Feasibility Analysis

- Initial cost estimate
- One linear actuator
  - Capable of supporting max load
  - High max torque

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td>$4000</td>
</tr>
<tr>
<td>Visual Cues</td>
<td>$450</td>
</tr>
<tr>
<td>Force Data Collection</td>
<td>$1300</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$5750</strong></td>
</tr>
</tbody>
</table>

Financial Feasibility: No
Final Financial Feasibility Analysis

- Additional $5k from USA Nordic to address safety, time cost, and simplicity
  - Added an additional linear actuator
  - Reduces moments applied to each linear actuator

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td>$7300</td>
</tr>
<tr>
<td>Visual Cues</td>
<td>$450</td>
</tr>
<tr>
<td>Force Data Collection</td>
<td>$1300</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$9050</strong></td>
</tr>
</tbody>
</table>

Financial Feasibility: Yes
Mechanical Design Cost (2 Linear Actuators)

- **Cost:** ~$7300
- **Improvements**
  - Much less torque related concerns
  - User cannot swing into structural poles
  - Lower height
    - Improved user safety
    - Eliminates need for stairs
- **Concerns**
  - Will cost close to twice as much as single actuator
Status Summary & Future Work

Presenter: Michael Schlittenhart

Section Outline

- Baseline Design Summary
- Feasibility Conclusion
- Future Work
- Plan of Action
Baseline Design Summary

- Oculus Quest 2
- Kitronyx piezoelectric sensors
- Moving platform
- Catching mechanism
# Feasibility Conclusion

<table>
<thead>
<tr>
<th>Label</th>
<th>Func. Req.</th>
<th>CPE</th>
<th>Description</th>
<th>Feasible?</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIS</td>
<td>FR1</td>
<td>E1</td>
<td>Headset will be able to display visual cues and be synchronized with physical cues.</td>
<td>Yes</td>
</tr>
<tr>
<td>MECH</td>
<td>FR2</td>
<td>E2</td>
<td>Provide analog force and motion cues to that of a standard ski jump to simulate proper jump timing. Sufficient load-bearing capabilities.</td>
<td>Yes</td>
</tr>
<tr>
<td>FOOT</td>
<td>FR5</td>
<td>E4</td>
<td>The pressure distribution data will be collected and mapped visually.</td>
<td>Yes</td>
</tr>
<tr>
<td>COST</td>
<td>Budget</td>
<td>Budget</td>
<td>The total monetary cost of SKADI is &lt;$10k*</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Adjusted from initial $5k*

## Overall Feasibility of Baseline Design

Yes
Future Work

● Visual
  ○ Select visual cue presentation format
  ○ Check if VR software can be integrated with mechanical software

● Mechanical
  ○ Further define mechanical design
  ○ Select linear actuator
  ○ Load analysis on connection between platform and linear actuator
  ○ FBD comparison of platform and real ski jump

● Force Data Collection
  ○ Bluetooth communication and range
  ○ Force data processing and Calibration of the force output
  ○ Battery supply
Plan of Action

<table>
<thead>
<tr>
<th>Task</th>
<th>Duration [weeks]</th>
<th>Planned Start Date</th>
<th>Actual Start Date</th>
<th>Planned End Date</th>
<th>Deadline Date</th>
<th>Actual End Date</th>
<th>Week of:</th>
<th>October</th>
<th>November</th>
<th>Project Description</th>
<th>Critical Elements</th>
<th>Feasibility Analyses</th>
<th>Status Summary &amp; Future Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Redesign of PDR Baseline</td>
<td>1</td>
<td>10/13</td>
<td></td>
<td>10/17</td>
<td>10/20</td>
<td></td>
<td></td>
<td>10/11</td>
<td>10/17</td>
<td>10/24</td>
<td>10/31</td>
<td>11/7</td>
<td>11/14</td>
</tr>
<tr>
<td>Selection of Linear Actuator</td>
<td>1</td>
<td>10/13</td>
<td></td>
<td>10/17</td>
<td>10/20</td>
<td></td>
<td></td>
<td>10/11</td>
<td>10/17</td>
<td>10/24</td>
<td>10/31</td>
<td>11/7</td>
<td>11/14</td>
</tr>
<tr>
<td>Manufacturing Plan</td>
<td>3</td>
<td>10/17</td>
<td></td>
<td>11/7</td>
<td>11/10</td>
<td></td>
<td></td>
<td>10/11</td>
<td>10/17</td>
<td>10/24</td>
<td>10/31</td>
<td>11/7</td>
<td>11/14</td>
</tr>
<tr>
<td>Manufacturing Diagrams</td>
<td>3</td>
<td>10/17</td>
<td></td>
<td>11/7</td>
<td>11/10</td>
<td></td>
<td></td>
<td>10/11</td>
<td>10/17</td>
<td>10/24</td>
<td>10/31</td>
<td>11/7</td>
<td>11/14</td>
</tr>
<tr>
<td>Design Component Selection (nuts &amp; bolts)</td>
<td>3</td>
<td>10/17</td>
<td></td>
<td>11/7</td>
<td>11/10</td>
<td></td>
<td></td>
<td>10/11</td>
<td>10/17</td>
<td>10/24</td>
<td>10/31</td>
<td>11/7</td>
<td>11/14</td>
</tr>
<tr>
<td>Visual</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual Cue Format Selection</td>
<td>1</td>
<td>10/13</td>
<td></td>
<td>10/17</td>
<td>10/20</td>
<td></td>
<td></td>
<td>10/11</td>
<td>10/17</td>
<td>10/24</td>
<td>10/31</td>
<td>11/7</td>
<td>11/14</td>
</tr>
<tr>
<td>Foot Force</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bluetooth Communication</td>
<td>1</td>
<td>10/13</td>
<td></td>
<td>10/20</td>
<td>10/25</td>
<td></td>
<td></td>
<td>10/11</td>
<td>10/17</td>
<td>10/24</td>
<td>10/31</td>
<td>11/7</td>
<td>11/14</td>
</tr>
<tr>
<td>Systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Updating Requirements</td>
<td>3</td>
<td>10/13</td>
<td></td>
<td>11/7</td>
<td>11/10</td>
<td></td>
<td></td>
<td>10/11</td>
<td>10/17</td>
<td>10/24</td>
<td>10/31</td>
<td>11/7</td>
<td>11/14</td>
</tr>
<tr>
<td>Verification &amp; Validation Plans</td>
<td>2</td>
<td>10/24</td>
<td></td>
<td>11/7</td>
<td>11/10</td>
<td></td>
<td></td>
<td>10/11</td>
<td>10/17</td>
<td>10/24</td>
<td>10/31</td>
<td>11/7</td>
<td>11/14</td>
</tr>
<tr>
<td>Risk Analysis</td>
<td>3</td>
<td>10/24</td>
<td></td>
<td>11/14</td>
<td>11/20</td>
<td></td>
<td></td>
<td>10/11</td>
<td>10/17</td>
<td>10/24</td>
<td>10/31</td>
<td>11/7</td>
<td>11/14</td>
</tr>
<tr>
<td>Deliverables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Acknowledgments

**USA Nordic Team:** Tim Tetreault, Jed Hinkley

**Faculty Advisor:** Dr. Melvin Rafi

**PDR Reviewers:** Blue Origin Team (SP4CE), Colin Claytor

**Additional Help:** Penina Axelrad
References

[5] Oculus Quest 2 Development Setup With Unity (Oculus Integration), Dilmer Valecillos, 2020
[7] How to View Your 360/VR Photos and Videos on Your Oculus Quest 2, Virtual Tours & Events, 2021
Questions?
Supporting Materials

Links to Sections
- Visual
- Mechanical
- Force Data Collection
- Logistics
- Budget
Visual Feasibility Analysis - Hardware

**Hardware:** Oculus Quest 2

**Cost:** $500 for goggles + accessories

**Important Specs:**

- **RAM:** 6GB
- **Storage:** 128GB
- **Maximum Render Resolution:** 5408 x 2736
# Standalone VR Headset Trade Study

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight (%)</th>
<th>Oculus Quest 2</th>
<th>HTC Vive Focus 3</th>
<th>Pico Neo 3 Pro</th>
<th>Pico G2 4K</th>
<th>DPVR P1</th>
<th>DPVR P1 Pro 4k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>40</td>
<td>3.5</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Memory</td>
<td>25</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Resolution per Eye</td>
<td>25</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Passthrough</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Battery Life</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td><strong>Weighted Score</strong></td>
<td><strong>3.30</strong></td>
<td><strong>3.25</strong></td>
<td><strong>2.50</strong></td>
<td><strong>3.15</strong></td>
<td><strong>2.80</strong></td>
<td><strong>2.00</strong></td>
<td></td>
</tr>
</tbody>
</table>
Mechanical

Links to Slides
Baseline Design
Mechanical Feasibility Analysis
Linear Motion Trade Study
Baseline Design

VR Headset: Oculus Quest 2

User

Force Data Sensors

Belay Mechanism, Operated by 3rd Party, Attached to scaffolding

Scaffold Structure to hold Belay System

Lifting Mechanism
Mechanical Feasibility Analysis

**Hardware:** Screw Driven Linear Actuator

**Cost:** $3000-$6000 per unit

**Models Options:** McMaster-Carr 4106N61, Sure Motion LAHP 33 Series, Oriental THK LM KR33 Linear Actuator

**Important Specs:**

<table>
<thead>
<tr>
<th>Speed</th>
<th>Actuation Length</th>
<th>Maximum Load</th>
<th>Maximum Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>400-1000mm/s</td>
<td>500-1000mm</td>
<td>~8-20kg each (depends on speed)</td>
<td>0.3-1g’s</td>
</tr>
</tbody>
</table>
Mechanical Feasibility Analysis

**Hardware:** Roller Bearing

**Cost:** $26 per unit

**Models Options:** 010-2RS Bearing 50x80x16 Sealed Ball Bearings

**Diameter:** 50 mm
## Mechanical Feasibility Analysis Results

<table>
<thead>
<tr>
<th>Actuator</th>
<th>Belt Driven</th>
<th>Screw Driven</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fulfills Requirement?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Description of Functionality</td>
<td>Can produce desired forces and speed within a reasonable distance</td>
<td>Higher speeds but deform while under predicted loads</td>
</tr>
<tr>
<td>Feasible?</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

**Mechanical Feasibility:** Yes
## Mechanical Hardware Considerations: Linear Motion Trade Study

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight (%)</th>
<th>Screw Driven Actuator</th>
<th>Grade</th>
<th>Belt Driven Actuator</th>
<th>Grade</th>
<th>DIY Linear Actuator</th>
<th>Grade</th>
<th>Hydraulics</th>
<th>Grade</th>
<th>Pneumatics</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>20%</td>
<td>Difficult to find stroke length larger than 1000mm (screw bends)</td>
<td>2</td>
<td>Can be as long as 3 meters</td>
<td>5</td>
<td>Based off screw driven actuator, difficult to achieve more than 1000mm</td>
<td>2</td>
<td>Can be more than 1000mm long</td>
<td>5</td>
<td>Difficult to find over 2000mm</td>
<td>3</td>
</tr>
<tr>
<td>Speed</td>
<td>20%</td>
<td>Range from &lt;1m/s To 3m/s</td>
<td>4</td>
<td>Up to 10m/s</td>
<td>5</td>
<td>Range from &lt;1m/s to 3m/s</td>
<td>4</td>
<td>Very Slow, (in/min)</td>
<td>4</td>
<td>Speed is dependent on load, but can achieve &gt;1m/s</td>
<td>3</td>
</tr>
<tr>
<td>Force</td>
<td>20%</td>
<td>Can quickly switch directions, loses torque with longer ball screw</td>
<td>4</td>
<td>Belt can slip, cannot apply excessive force</td>
<td>3</td>
<td>Can quickly switch direction, loses torque with longer ball screw</td>
<td>4</td>
<td>Can supply lots of force, but has difficulty changing direction</td>
<td>3</td>
<td>Force applied is variable with position</td>
<td>2</td>
</tr>
<tr>
<td>Load Bearing</td>
<td>20%</td>
<td>Can support several hundred kg</td>
<td>5</td>
<td>Can hold ~100kg (ideally we have 4), belt can slip</td>
<td>3</td>
<td>Would need to conduct stress test, likely capable of supporting athlete</td>
<td>4</td>
<td>Can support any load</td>
<td>5</td>
<td>Can support several hundred pounds</td>
<td>5</td>
</tr>
<tr>
<td>Cost</td>
<td>10%</td>
<td>~$3000+ each</td>
<td>2</td>
<td>~$2000+ each</td>
<td>5</td>
<td>&lt;$1000 each</td>
<td>5</td>
<td>~$1000 each</td>
<td>4</td>
<td>~$1000 each</td>
<td>4</td>
</tr>
<tr>
<td>Integration Complexity</td>
<td>10%</td>
<td>Easy to program, and easy to integrate with platform</td>
<td>5</td>
<td>Easy to program, and easy to integrate with platform</td>
<td>5</td>
<td>Would needed to be designed, easy to integrate after</td>
<td>3</td>
<td>Very difficult to program, requires fluid</td>
<td>3</td>
<td>Difficult to program, force applied changes with mass</td>
<td>1</td>
</tr>
<tr>
<td>Average Score</td>
<td>100%</td>
<td>Screw Driven Actuator</td>
<td>3.666666667</td>
<td>Belt Driven Actuator</td>
<td>4</td>
<td>DIY Linear Actuator</td>
<td>3.666666667</td>
<td>Hydraulics</td>
<td>3.166666667</td>
<td>Pneumatics</td>
<td>3.166666667</td>
</tr>
<tr>
<td>Weighted Score</td>
<td></td>
<td></td>
<td>3.7</td>
<td></td>
<td>4</td>
<td></td>
<td>3.6</td>
<td></td>
<td>3.3</td>
<td></td>
<td>3.1</td>
</tr>
</tbody>
</table>
Force Data Collection

Links to Slides
- Next Steps
- Kitronyx Insoles Specifications
- Calibration
- Factor of Safety
- Force Trade Study
Next Steps

● Bluetooth communication with Snowforce software and computer

● Bluetooth communication distance
  ○ If customer is using Kitronyx kit on the real slope, we want to ensure that the Snowboard 2 can maintain communication with the computer

● Data processing
  ○ Create a program to display the force data from the CSV file
  ○ Test using simulated data
  ○ Simple interface so that coaches can use

● Test plans for calibration
  ○ Calibration feasibility
## Kitronyx Insoles Specifications

### Electronics

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions (mm)</td>
<td>109x71x29</td>
</tr>
<tr>
<td>Number of Sensing Pixels</td>
<td>160 (16x10)</td>
</tr>
<tr>
<td>Frame Rate (Hz)</td>
<td>40</td>
</tr>
<tr>
<td>Computer Interface</td>
<td>USB</td>
</tr>
<tr>
<td>Operating System</td>
<td>Windows 7-10</td>
</tr>
<tr>
<td>Power Supply</td>
<td>USB Powered</td>
</tr>
</tbody>
</table>

### Sensors

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Size (mm)</td>
<td>235, 270, 280</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Cable Length (mm)</td>
<td>150</td>
</tr>
<tr>
<td>Pressure Range (kg)</td>
<td>180</td>
</tr>
</tbody>
</table>
Calibration

Calibration is necessary to get physical pressure values from the pressure distribution

- Put an object of known mass on the sensor
- Record force and measure the ADC sum
- Using A and F you can get a linear relationship

Physical pressure not an accurate result

- Sensor ADC curve nonlinear
- Each pixel has a different response

Relationship between force and ADC output [10]
FOS: 1.1

FOS is 1.1 because the customer would like the ability of collect force data from a real ski jump.

An athlete (100 kg) pulls a maximum of 1.6 G will generate a maximum force of 1569.6.

From data sheet, sensor can accommodate up to 180 kg of mass or 1765.8 N.

\[
\frac{1765.8 \text{ N}}{1569.6 \text{ N}} = 1.125
\]

Therefore FOS > 1.1
Force Trade Study

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight (%)</th>
<th>Kitronyx</th>
<th>NURVV</th>
<th>PPS TactArray</th>
<th>Piezoelectric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>20</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>User Complexity</td>
<td>13</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Integrability</td>
<td>15</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Fidelity</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Accuracy</td>
<td>20</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Comfort</td>
<td>12</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Battery Life</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Data Acquisition</td>
<td>10</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Weighted Score</td>
<td></td>
<td>3.95</td>
<td>3.47</td>
<td>3.83</td>
<td>3.27</td>
</tr>
</tbody>
</table>

Trade study of the options investigated to collect the foot force data
Logistics

Links to Slides
Organization Chart
Organization Chart

Technical Leads

Mechanical Lead
Joaquin Ramirez

Visual Cues Lead
Maya Greenstein

Force Data Collection Lead
Julia Sheeran

Manufacturing Lead
Max Page

Human Factors Lead
Hunter Daboll

Software Lead
Landon Nurge

Team Members

Hunter Daboll, Landon Nurge, Mary Sobernheim, Max Page
Michael Schlittenhart, Max Page, Julia Sheeran, Landon Nurge
Mary Sobernheim, Max Page, Maya Greenstein
Joaquin Ramirez, Hunter Daboll, Julia Sheeran
Michael Schlittenhart
Maya Greenstein

Project Manager
Michael Schlittenhart

Systems Engineer
Mary Sobernheim

Sourcing Lead/CFO
Max Page

Accounting Lead
Maya Greenstein
Budget

Links to Slides
- Budget Breakdown - Visual
- Budget Breakdown - Mechanical
- Budget Breakdown - Force Data Collection
## Budget Breakdown - Visual

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oculus Quest 2 Base Headset (128 GB Storage)</td>
<td>$300</td>
</tr>
<tr>
<td>Elite Strap, Battery pack, Carrying Case</td>
<td>$130</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$430</td>
</tr>
</tbody>
</table>


# Budget Breakdown - Mechanical: Baseline

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear Actuator</td>
<td>$3300</td>
</tr>
<tr>
<td>Structural Elements</td>
<td>$600</td>
</tr>
<tr>
<td>Bearings</td>
<td>$100</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$4000</strong></td>
</tr>
</tbody>
</table>
# Budget Breakdown - Mechanical: New Budget

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear Actuator (x2)</td>
<td>$6600</td>
</tr>
<tr>
<td>Structural Elements</td>
<td>$600</td>
</tr>
<tr>
<td>Bearings</td>
<td>$100</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$7300</strong></td>
</tr>
</tbody>
</table>
## Budget Breakdown - Force Data Collection

<table>
<thead>
<tr>
<th>Kitronyx MP2513PLUS Insole Sensor Kit</th>
<th>$1300</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL</td>
<td>$1300</td>
</tr>
</tbody>
</table>
