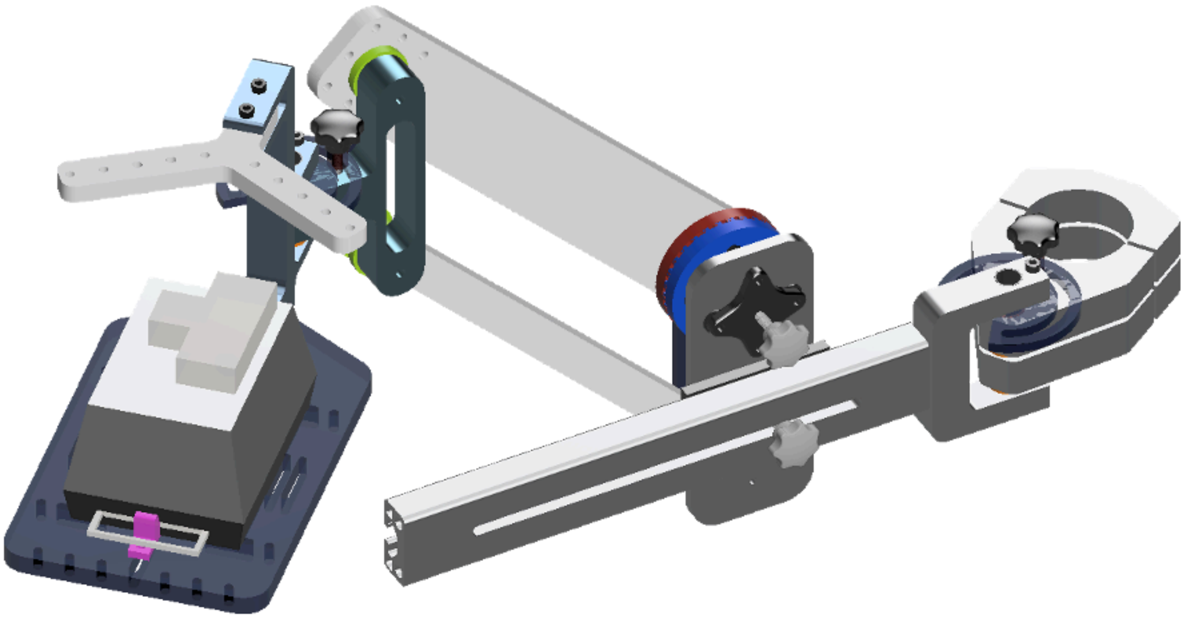
KangaMove™

Project Final Report



Reuven Reyman, Mayah Carlton, Jeffrey Keppler, Parissa Teli, Guorui Zhang

Sponsored by UC San Diego Health – Dr. Henry Lee

MAE 156B - Fundamental Principles of Mechanical Design II

University of California - San Diego

Professor David Gillett

20 January 2025

Abstract

Skin-to-skin contact between parents and their newborns, including pre-term infants, is essential for fostering bonding, stabilizing the baby's heart rate and breathing, and regulating body temperature. For pre-term infants, it supports neurodevelopment and improves weight gain, feeding behaviors, and immune function. Parents also benefit, experiencing reduced stress and increased confidence in caregiving. This practice, often called **"kangaroo care,"** is recommended by the World Health Organization for its numerous physiological and emotional benefits[1].

Our Solution

The KangaMove is designed to support parents during skin-to-skin contact by providing stability while holding their child. The device consists of an accessory plate to secure the jet ventilator box during skin-to-skin care which is connected to the ventilator through an appendage with locking joints. Its posable arm integrates seamlessly with vital neonatal intensive care unit (NICU) equipment, including Jet Ventilator auxiliary components, ventilator tubes, and IV lines. By securing these essential connections, the KangaMove alleviates concerns about tube displacement, allowing parents to focus on bonding with their infant. Through multiple design iterations, we incorporated direct nurse feedback at each stage, refining the solution to better support their workflow and address specific needs effectively.

What We Did

The student team collaborated closely with NICU nurses, respiratory therapists and staff to identify key challenges in their current Kangaroo Care procedures for infants on the jet venitlator. The first design iteration was modeled and analyzed using CAD software based on . Through focus groups with nurses and respiratory therapists, the team developed the kangamove*,* a posable arm to enhance the processtreatment time incorporated direct nurse feedback at each stage, refining the solution to better support their workflow and address specific needs effectively.

[1] Who Advises Immediate Skin to Skin Care for Survival of Small and Preterm Babies." World Health Organization, World Health Organization, 15 Nov. 2022,

Table of Contents

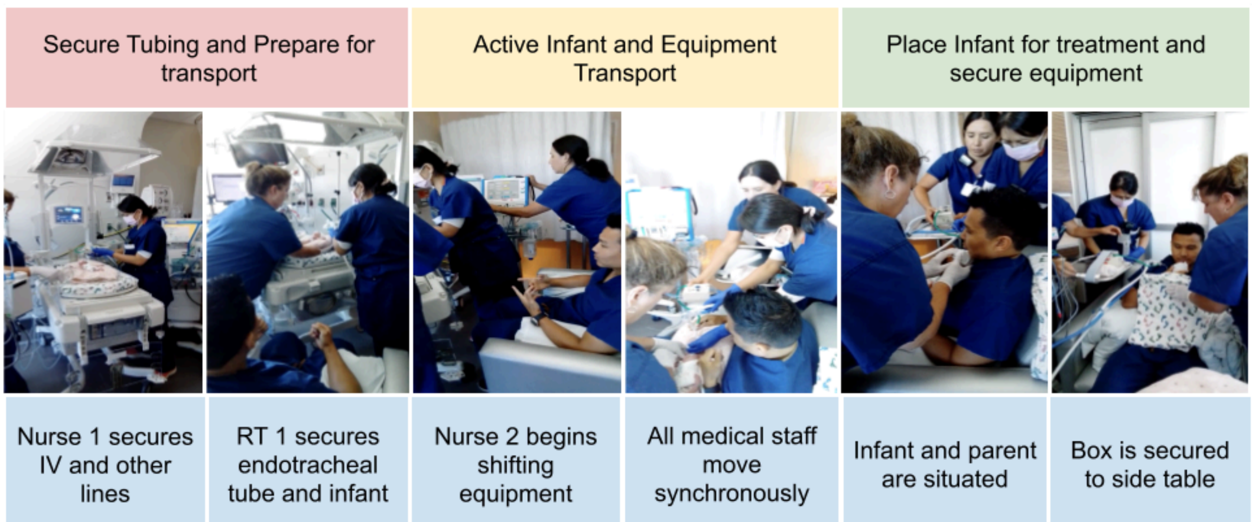
List of Figures

List of Tables

Chapter 1: Project Description

Background

Premature births affect about 10% of pregnancies and are a major concern in neonatal care. Skin-to-skin contact, or "kangaroo care," is a proven method to support preterm infants' development, offering physical and psychological benefits[2]. Unfortunately, many preterm infants require respiratory support via jet ventilators. These devices contain multiple tubes and accessories connected to the infant which increase the risk associated with moving them out of the incubator. For infants on the jet ventilator, a team of nurses and respiratory therapists (RT) are required to assist in transferring the infant from the incubator safely to the parents arms for treatment. The process includes securing loose tubing and gathering and relocating all vital equipment all while the infant is being transferred. Thus, the procedure is arduous and labor-intensive, as pictured in Figure 1 below.



Dr. Henry Lee, a neonatologist and medical director at UC San Diego Health's Jacobs Medical Center, advocates for fostering family connections in the NICU promoting their clinical and psychological benefits. He has sponsored the Kanga*Move* project to improve the accessibility of skin-to-skin care for ventilated preterm infants.

With guidance from Dr. Lee, the Kanga*Move* team came up with a solution which incorporated a mechanical posable arm with locking joints. The device will help secure and organize ventilator tubes, simplify infant transfers for skin-to-skin contact, and maintain a safe distance between the infant and the ventilator box, reducing risk and improving ergonomics for caregivers.

[2] Lazarus, Molly F., et al. "Inpatient Skin-to-Skin Care Predicts 12-Month Neurodevelopmental Outcomes in Very Preterm Infants." The Journal of Pediatrics

Impact on Society

This project has the potential to profoundly improve the health and psychological well-being of preterm infants and their families. By addressing the challenges associated with skin-to-skin contact in the neonatal intensive care unit (NICU), it helps mitigate the anxiety parents often feel when holding their preterm newborns. Sharing this technology widely can reduce parental nervousness, fostering a stronger emotional bond and sense of connection within families during a critical period in their child's development.

This project demonstrates the power of technology in enhancing human experiences. By introducing a modular arm to secure equipment for the transfer and duration of the skin-to-skin care time the whole process can become safer and more consistent. At the same time, it leaves room for human creativity and adaptability by allowing medical professionals to tailor interactions to each patient's unique needs. With the flexibility of the device, professionals can assess each individual case and cater the positioning of all essential equipment with ease.

Additionally, the device aligns with the sponsor's goal of improving the NICU experience for families. By enhancing the standard workflow, the project encourages hospitals to explore improved methods of transferring infants for skin-to-skin contact. This broader adoption could lead to a shift in neonatal care, prioritizing both the physical health of the infant and emotional security of their families.

Review of Existing Solutions

During the research phase, the team conducted an on-site evaluation at Sharp Mary Birch Hospital, where Nurses and Respiratory Therapists demonstrated their interim method for supporting jet ventilator boxes during skin-to-skin contact with preterm infants. The setup used a Draeger mounting arm connected to the respirator with an aluminum plate and Velcro straps to secure the box near the infant. While functional, the arm's stiff joints limited its mobility, making it impractical for assisting in transferring the infant and tubes to the parent.

Our proposed design addresses this limitation by incorporating more flexible joints and a locking mechanism. This allows the arm to move freely for positioning and securely lock when not in use, enabling safer and more efficient transfers.

Existing patents Through multiple design iterations, we incorporated direct nurse feedback at each stage, refining the solution to better support their workflow and address specific needs effectively.

A similar patented device found on the market is the VHM-P series mounting solution by GCX Healthcare Solutions[3] seen in Figure 2. The device uses a patented handle and hydraulic technology to control the flexibility of the arm and allow users to move it freely before locking it

3 "VHM-PL." *GCX Medical Mounting Solutions*, GCX, https://www.gcx.com/products/series/vhm-series/vhm-pl/. Accessed 17 Jan. 2025.

in place. The system incorporates pivots, a rail mounting system, and a modular attachment piece to enhance adaptability.

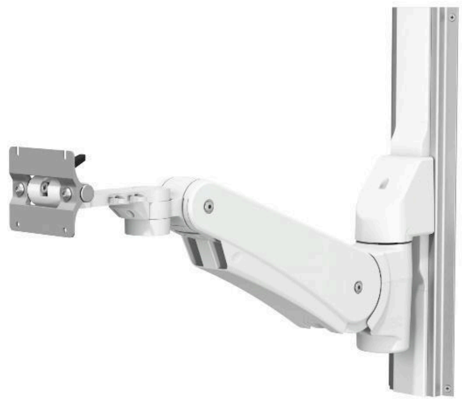


Figure 2. VHM-P Variable Height arm used in Medical Environments

While this device is not specifically designed for NICU environments, this system demonstrates key principles of adjustable medical arm supports. Existing solutions typically rely on hydraulic or mechanical locking mechanisms to provide stability and ease of movement.

Statement of Requirements and Deliverables

Fundamental Requirements Essential functions, features, and performance criteria	**Constraints** Limitations, restrictions, boundaries of operation
The device shall incorporate secure, adjustable support mechanisms that can bear the weight of the device components and accessories with a factor of safety ≥4*.	Maximum distance from Infant to ventilator box is 12 inches for entire transfer process and thereafter.
Device needs to be able to easily be secured out of the way when not in use.	Lack of space around vertical stand site, high chance of colliding with pre-existing accessories.
Linear slider and pivot points much provide enough DOF to allow for easy manipulation during procedures.	The linear slider may not protrude beyond 12” from the base of the ventilator, high chance of getting caught when not in use
The device mount shall be compatible with standard NICU equipment.	Materials used are required to comply with applicable medical safety standards.
The device must integrate with existing tubes and accessories of the ventilator and other equipment.	Extended force input from user under 10N (2.2 lbf) threshold for accessibility.

Deliverables

- **Device Components**
  - Posable Arm System
    - Locking Joints
      - Support Linkages
      - Alignment Linkages
      - User Controls
  - Ventilator Box / Accessory Mount

  Provides support to the ventilator box and tubes ensuring they remain close and connected to the infant during transfer and procedure.
  - Rail / Arm Base Mount

  Connects the base of the arm to the ventilator .
- **User Manual**

Guide users on the proper use of the device including initial setup, safeguards and ways to be incorporated into standard procedures.
- **Final Report**

Outlines research and information collected depicting the timeline leading to the final product.
- **Design Manual**

A beginning-to-end guide on manufacturing and packaging of the device for shipping to hospitals. Intended to ensure a proper lifecycle of the device past the end of the MAE 156B course when the student team will no longer be on the project.
- **Project Website**

A portfolio that contains all documentation relating to the project from start to finish.

Chapter 2: Description of Final Design Solution

High-Level Design Overview

- **Description of design, how it works**
- **Full annotated CAD assembly**
- **Block diagram**
- **General instructions for use**

Secure Tubing and Prepare for transport			Active Infant and Equipment Transport	Place Infant for treatment and secure equipment		
Transport Arm Joints are unlocked	Nurse 1 secures IV and endotracheal tube to transport arm	Nurse 1 secures box onto custom mount	Utilize handles to move arm with baby, tubes, and equipment	Secure arm to parents shoulder	Transfer baby to parent	Transport Arm Joints are locked

Applicable Standards and Regulations

Standard	Title	Conditions to SatisfyCompliance Steps
ISO 14971	Risk Management for Medical Devices	Produce documentation for Risk management plan, Hazard Identification, Risk Evaluation, Risk – Benefit Analysis, and Post Market Surveillance. Maintain these documents and conduct internal and external audits.
ISO 13485	Quality Management System for Medical Devices	• **Produce documentation for Quality management system, Supplier Management, Document control, Production and Process control, Corrective and Preventive Actions, Complaint Handling and** reporting. • **Maintain a quality manual and standard operating** procedure. Apply for ISO 13465 certification for market access.
IEC 62366	Usability Engineering to Ensure Safe Design	• **Produce Documentation for all usability activities, Formative testing, User and environment** analysis. Produce evidence of usability validation and design validation.

Table 2. List of applicable standards and regulations for the Kangamove system and its operation.

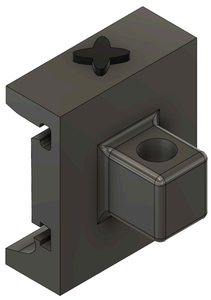
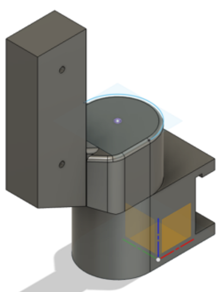
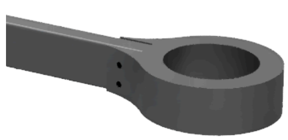
Chapter 3: Design of Key Components

Major Components:

1. **Vent Clamp Mount**

Functional Requirements: This component is required to be able to support the weight of the system and keep it stuck in one location.

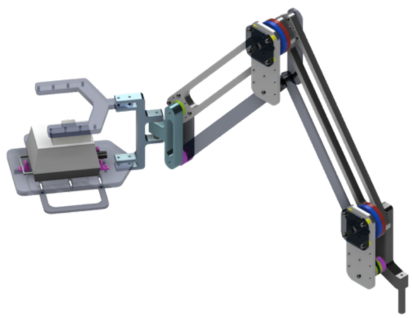
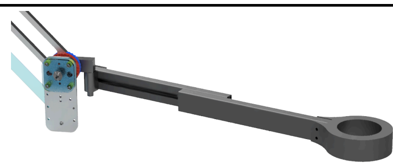
** Simulation results from Fusion 360 can be found in the Appendix under 3.1*

Design Iteration	Image	Fabrication	Notes
1		● Initial Prototype was 3D Printed for testing	● Rail cannot be used because it sits too low on Brunnel machine ● This mount is applicable to the incorrect machine
2		● Second Prototype was also 3D printed	● Unable to mount onto Draeger Ventilator stand ● Difficult to manufacture ● Fusion 360 FEA analysis showed a FOA less than 1
3		● Manufactured using Water Jet from MAE EBU 2 Machine Shop ● Holes were drilled using manual machines incorporating end mills, center drills, various width drills	● Simple ● Clamps down correctly on Draeger Ventilator stand

2. **Linkage Arm**

Functional Requirements: Be able to extend the lower plate to the desired length allowing for the jet ventilator box to rest as close as possible to the pre-term infant and parent, while being still out of the way.

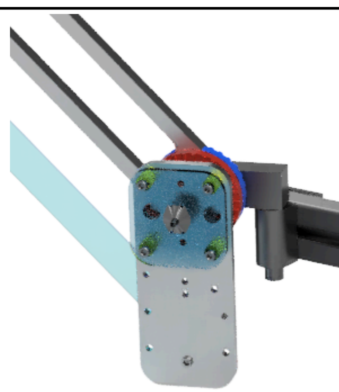
** Simulation results from Fusion 360 can be found in the Appendix under 3.2*

Design Iteration	Image	Fabrication	Notes
1		• Water Jet was used to cut out linkage arms • Drill press used to create holes to screws and secure linkages to locking joints	• Effective & easy to manufacture • Using aluminum increases weight • Two linkages is not needed, one is sufficient
2		• WIP	• FOA is 12.61

3. **Locking Joints**

Functional Requirements: Allow the linkage arms to stop at the correct location and stay in position throughout the entire procedure and duration of time that the parent is maintain skin-to-skin contact with pre-term infant.

** Simulation results from Fusion 360 can be found in the Appendix under 3.3*

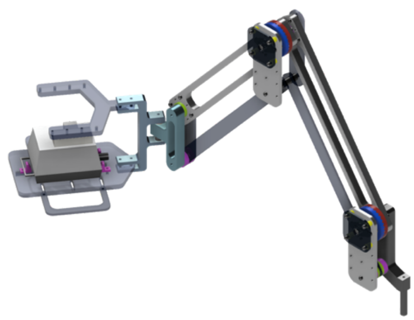
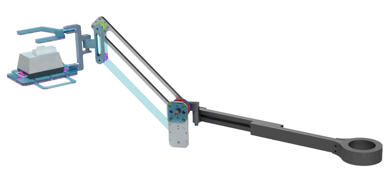
Design Iteration	Image	Fabrication	Notes
1		• Aluminum Plate used Water Jet to cut out from EBU 2 Machine Shop • Gears were printed at DIB using 3D printers	• Able to lock the joints together and make adjustmentssuc cessfully • To enable/ disable Locking Mechanism requires adjustments from metal cable

2		•	•

- **Final Assembly:**

Functional Requirements: The entire system must abide by regulations/ standards placed by the FDA, while also being safe to handle and succeed in its mission to hold the jet ventilator box close to the parent and pre-term infant.

** Simulation results from Fusion 360 can be found in the Appendix under 3.4*

Design Iteration	Image	Fabrication	Notes
1		• Used water jet, 3d printer, Laser Cutter to create parts	• Large moment arm created • Aluminum parts increase weight • Top fork shaped holder is removed since pre-term infant no longer transferred on mechanical arm, only jet ventilator box • Box holder received positive feedback, need to include slots to add Velcro
2		• Used water jet, 3d printer, Laser Cutter to create parts	• Allows space for Velcro and Handle for lower plate • Parts combined is lighter • Reduces locking joints for pivoting from two to one • Easier to mount to Jet Ventilator stand using the pole

- **Each major component should have a sub-section that includes the following:**
  - **Include analysis used to justify design decisions, but details of analysis can be included in Appendices.**
  - **Describe fabrication methods where relevant. (Do not describe routine techniques)**
- **Show exploded assembly diagrams (like lego instructions)**

Risk Management and Mitigation

Failure Mode	Severity	Failure Cause	Mitigation / Control

Chapter 4: Prototype Performance

Performance Results

Figure 3. Prototype 1 constructed for the first round of demonstrations to nurses

Feb. 3, 2025

Summary: Mock Trials were held on Feb. 3, 2025 at the UCSD Jacob Medical Center under Doctor Henry Lee with a group of Nurses and Respiratory Therapists (RT). After explaining the initial concept, trials were held to understand the uses for the Kangamove system and feedback was provided during this time. The results from this showed that the group agreed the pre-term infant should not be placed on the Kangamove arm, but rather only support the jet ventilator box. In addition, the arm was a success, but the group preferred the idea of an extendable arm such as a telescoping system. This feedback led to the Mark 2 Version of the Kangamove system.

Theoretical Predictions:

- Improved design and simpler
- Unsure about Telescoping arm
- Clamp will be easier to mount and secure device

Test Parameters:

- Quantified device specifications (max load, weight, etc.)

Final Results:

Feedback	Design Decisions
Nurses prefer more hands-on transfer process	Reduce the accessory plate features
	Reduce the robustness of the arms
The range of motion of the device is beyond what's necessary	Reduce the length of the arms
	Reduce the range of motion
Nurses feel uneasy with the current box securing features	Add feature for added security for the box

Figure 4: Summary of feedback and proposed design changes from NICU Mock Trial 1

Figure 5. Second prototype iteration being tested with a NICU nurse

Feb. 20, 2025

Summary: On Feb. 20, 2025 Mock Trials were once again hosted under Doctor Henry Lee, but under a new group of Nurses and Respiratory Therapists comprising of members from the NICU Holding Task Force. Our predictions and results of this meeting can be seen here:

Theoretical Predictions:

- Improved design and simplerreceived.
- Unsure about Telescoping armlocation.
- Clamp will be easier to mount and secure device

Test Parameters:

- Quantified device specifications (max load, weight, etc.)requirements.
-

Final Results:

<table>
<tr><th>Feedback</th><th>Design Decisions</th></tr>
<tr><td>The current device reach is still excessive for application</td><td>Reduce length of linear slider</td></tr>
<tr><td>Different nurses would prefer the tube support in different locations</td><td>Make the tube support modular</td></tr>
<tr><td rowspan="3">Nurses would like to be able to fix every joint independently</td><td>Add friction locking joints at pivots at the accessory mount and ventilator clamp</td></tr>
<tr><td>Add locking joint for the linear slider</td></tr>
<tr><td>Move locking joint knob to the locking joint hub</td></tr>
<tr><td rowspan="2">The device is intimidating for parents to be near</td><td>Paint the aluminum</td></tr>
<tr><td>Hide all visible fasteners with end caps</td></tr>
</table>

Figure 6: Summary of feedback and proposed design decisions from NICU Mock Trails 2

Chapter 5: Design Recommendations and Conclusions

- **Design recommendations for the future**

Based on nurse feedback, we should consider replacing the current adjustable arm with a telescoping arm system. This change could provide better operability.

According to prototype test results, several areas need optimization:

- Reduce overall weight by replacing some aluminum parts with lighter materials
- Simplify the locking mechanism design to improve reliability

- **If the product is to be mass produced, discuss how the final version will differ from the prototype made in MAE156B. Include cost estimate for product when mass produced.**

If mass-produced, the product will differ from the prototype made in MAE156B. For manufacturing processes, we will purchase standardized parts to reduce costs. Through mass production, the cost per device will decrease significantly. This cost reduction will come from optimized design using less material, material substitutions, and bulk purchase discounts on components.

- **Safety Considerations**

Include both considerations for use of the prototype as well as for the product if it is to be mass-produced

- **Prototype Safety Considerations**

  The device's support mechanism must maintain a safety factor of 4 or higher. The user input force must be limited to 10N for easy operation. Other safety concerns include risk points from the Risk Management table and safety issues found during testing discussions.

- **Mass Production Safety Considerations**

  For mass production, we need to:

  Implement safety standards throughout manufacturing

  Establish quality control and testing procedures

  Develop comprehensive safety guidelines for users

- **Applicable Standards**

ISO 14971: Risk Management for Medical Devices
ISO 13485: Quality Management System for Medical Devices
IEC 62366: Usability Engineering to Ensure Safe Design

- **Impact on Society. List all impacts including economic profit.**

- Healthcare Impact

Improves quality and efficiency of preterm infant care
Enhances skin-to-skin contact experience between parents and infants

- Economic Benefits

Reduces nursing staff requirements
Decreases care procedure time
Shows potential for market growth

- Social Benefits

Promotes medical technology innovation
Raises healthcare service standards
Improves family healthcare experience

- **Lessons learned.**

Through developing the KangaMove project, we learned valuable lessons in many areas. In early February 2025, feedback from the NICU nursing team guided us to change our design direction. They helped us realize the robotic arm should focus on supporting ventilation equipment rather than directly holding premature babies.

When it came to materials, we found that aluminum parts were sturdy but made everything too heavy. This taught us to better balance material performance with weight. During manufacturing, we discovered that different techniques like water jet cutting, 3D printing, and laser cutting each had their own strengths. We learned to pick the best method based on what each part needed to do.

The risk management process showed us how important it is to think ahead about what could go wrong. It also reminded us why we need to keep proper safety margins. In the end, working with a team of different specialists proved something important - clear roles and good communication are key to making a project successful.

- **Conclusions**

The KangaMove project has successfully developed a working solution that helps simplify kangaroo care in the NICU. We worked closely with doctors and nurses to refine the device, and after several design changes, it's looking really promising in practice. Though we can still make it better, we're happy that it's working as planned and is actually helping make life easier for those caring for premature babies.

Acknowledgements

References

- Lazarus, Molly F., et al. "Inpatient Skin-to-Skin Care Predicts 12-Month Neurodevelopmental Outcomes in Very Preterm Infants." The Journal of Pediatrics vol. 274, no. , 2024 pp. [Publisher or DOI if applicable].

(1) "VHM-PL." *GCX Medical Mounting Solutions*, GCX, https://www.gcx.com/products/series/vhm-series/vhm-pl/. Accessed 17 Jan. 2025.

Appendix

Project Management

Task Distribution

Reuven Reyman	• Design and Technical Lead • Risk Management • Components: Linkages, Ventilator Clamp, Accessory Mounts and plates
Mayah Carlton	• Compliance and Safety Lead • Components: Locking joint, linear slider
Parissa Teli	• Project Manager • Sponsor and Client Laision • Research
Jeffrey Keppler	• Manufacturing Lead • Components FEA
Guorui Zhang	• Purchasing • CAD Drawings

- Reuven: Lead mechanical design of ventilator clamp mount, CAD modeling, prototype fabrication
- Mayah: Design and analysis of linear slider components, stress testing, documentation
- Parissa: Development of locking joint mechanism, gear system design, integration testing
- Jeffrey: Support linkage design, structural analysis, material optimization
- Mike: Contributed to overall mechanical design, created CAD drawings, and compiled documentation.

Risk Reduction Effort

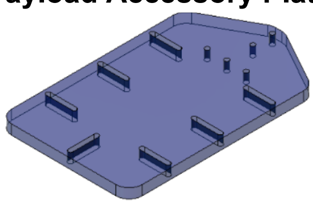
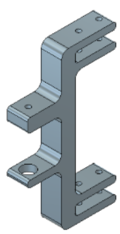
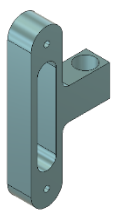
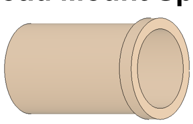
- Identified risk of excessive moment forces causing system instability or failure

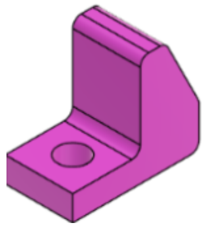
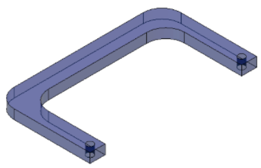
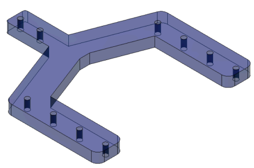
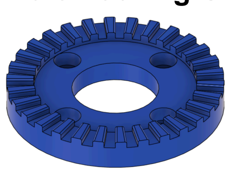
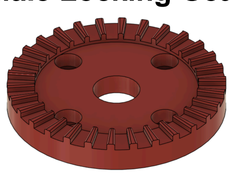
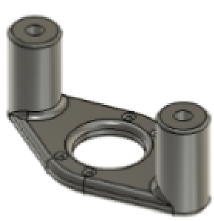
Reduced risk through iterative design process to minimize arm length and optimize weight distribution

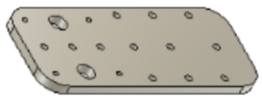
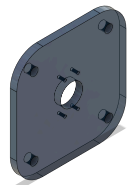
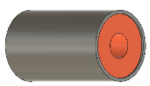
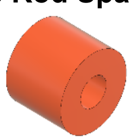
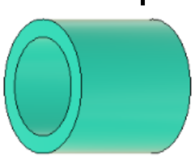
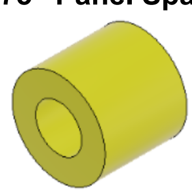
- Performed comprehensive FEA analysis to ensure safety factor > 4 throughout the system
- List high risk issues identified and how risk was reduced :
- Brittle failure in acrylic components: Mitigated by adding fillets to corners, optimizing stress distribution

- Joint stability under load: Addressed by incorporating redundant locking mechanisms and spring compression
- Compatibility with existing NICU equipment: Reduced through multiple on-site tests and nurse feedback sessions
- User operation complexity: Simplified through intuitive design iterations based on nurse feedback
- Infant safety concerns: Mitigated through design changes that focused on securing equipment rather than patients

1. List of Individual Components

Device Element *Image*	Description	Material (s) *Manufacturing / Source*	Qnty used in device
	Accessory Plate / Payload		
Payload Accessory Plate 	Holds the Jet Ventilator Auxiliary equipment, mounts to the handle, break toggle, and shoulder mount	0.375” Acrylic *2D Laser Cutting*	**1**
Payload Mount Female 	Connects to the male partner and supports the accessory plate and infant table.	0.75” Aluminum *2D Water Jet + Drilling / Bore* Connects to plate w/ 2 M4 screws and 2 M4 nuts.	**1**
Payload Mount Male 	Interconnects with the female partner to connect the Accessory Plate to the end of the linkage arm.	0.75” Aluminum *2D Water Jet + Drilling / Bore* Connects to female with Payload mount axle	**1**
Payload Mount Axle (2”) 	Swivel point between the male and female payload mounts. The top hole is a tapped M4 screw hole	Hallow Steel + 0.375 Acrylic end cap *Band Saw, Arbor Press*	**1**
Payload Mount Spacer 	Meshes into the male payload mount to ease wear on the aluminum components	Plastic *Resin Printed*	**1**
Payload Hub Mounting Plate 	Holds the other end of the mounting axles (secondary support to the payload male mount)	0.187” Acrylic *Laser Cutting*	**1**
Accessory Plate Foot Lock	Use 3-4 of these to secure the Ventilator Auxiliary Equipment box to the Accessory Plate	ABS Plastic *3D Printing* Connects to accessory plate with a single M4 screw and a M4 nut	**4**

			
Payload Accessory Plate Handle 	Grab-point for nurse to move the arm and accessory plate. Will hold the brake toggle so nurse can release brakes and position arm simultaneously.	0.187” Acrylic *2D laser Cut* Connects to accessory plate with two M4 screws and nuts	**2**
Accessory Management Mount 	Mounts to ventilator accessories to hold tubes and cables	0.375” Acrylic *2D Laser Cutting*	**1**
	Joint Hubs (Locking Joints)		
Female Locking Gear 	This is the stationary gear, mounted to the pull-back mount. Interfaces with the male partner to prevent rotation of the joint.		**2**
Male Locking Gear 	Attached to a support linkage, interfaces with female partner to prevent rotation.		**2**
Pull Back Mount 	When brake is applied, steel cable pulls on this component to separate the male and female locking gears.	Steel? *CNC Machining*	**2**
1.1x10x10 mm Springs 	The compression springs hold the male and female gears together when the brake is not toggled	Off-the-shelf component *McMaster*	**4**

Joint Hub Inside Plate 	The main support structure of the locking joints. The extra holes are for flexibility in mounting other components.	0.25” Aluminum *Laser / Water Jet Cutting*	**2**
Joint Hub Outside Plate 	The back plate of the locking joint, connects to the exterior tubing of the tension cable.	0.187” Acrylic *2D Laser Cut*	**2**
Joint Hub Aux Plate 	The partner support structure for the locking joints and payload hub.	0.187” Acrylic *Laser / Water Jet Cutting*	**2**
Center Hub Axle (2.56”) 	The 2 axles holding the Center Hub together.	Hallow Steel + 0.375 Acrylic end cap *Band Saw, Arbor Press*	**2**
Rail Mounting Hub Axle (1.71”) 	The two axles holding the Rail Mounting Hub together.	Hallow Steel + 0.375 Acrylic end cap *Band Saw, Arbor Press*	**2**
Payload Hub Axle (0.90”) 	The two axles holding the payload hub together	Hallow Steel + 0.375 Acrylic end cap *Band Saw, Arbor Press*	**2**
Axle Rod Spacers 	M4 clearance spacers slipped inside the hallow axles to align them with connecting rod	0.375” Acrylic *Laser Cut, Hand tapped*	**14**
Alignment Linkages 	Ensure the payload / accessory plate remain level regardless of arm rotation	0.125” Acrylic *2D Laser Cut*	**2**
Joint Hub Spacer 	Separates the female and male locking gears. 3D printed as it needs to be a specific length	Plastic *3D Printing*	**2**
0.375” Panel Spacer 	Separates the outer and inner mounting plates	0.375” Acrylic *2D Laser Cutting*	**8**

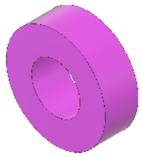
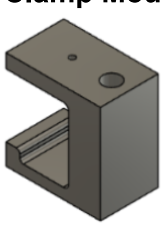
Linkage Spacer 0.375 	Separates the two linkage pairs and some other components	0.375” Acrylic *2D Laser Cutting*	**6**
Wall Spacer 0.187 	Ensures alignment of the linkages on the payload mount	0.187” Acrylic *2D Laser Cutting*	**6**
Support Linkages			
Linkage Single Side 	Each support linkage is made from two single sides connected via M4 screws and nuts	Aluminum *Water Jet Cut -> CNC Bore*	**4**
0.5 x 1-1/8 x 5/16” Ball Bearing	Sits between the two sides of each support linkage, absorbs force onto axle.	Off-the-shelf component *McMaster*	**4**
User Interface			
Cable Brake Knob Exterior			
Cable Brake Knob Interior			
Steel Tension Cable			
Tension Cable Exterior Tube			
Ventilator Mount			
C-Clamp Mount 	Used to mount the kangamove arm to the Jet Ventilator, clamps to most handle-like surfaces or rails.	Aluminum Stock *Water Jet / CNC Machined*	**1**
Rail Hub Pivot Mount	Connects the mounting hub to the C-Clamp. Has a 0.5” diameter axle that slips into the C-Clamp so it can pivot	0.75” Aluminum *Water Jet, drill holes, bore 0.5” slip fit*	**1**

Table 1. List of individual designed components for the Kangamove system and how they are sourced / manufactured. Includes images of each component.

2. List of Suppliers / Purchased Part Information

Name	Contact information
ePlastics	ePlastics 5535 Ruffin Road San Diego, CA 92123 United States 858-560-1551 www.eplastics.com
Industry Metal Supply Co.	Industrial Metal Supply Co. San Diego 7550 Ronson Road San Diego, CA 92111 (858) 277-8200 www.industrialmetalsupply.com/
McMaster-Carr	562-692-5911 562-695-2323(fax) la.sales@mcmaster.com

3. Designs Considered

- **Table that you referenced in the above comparison section**

Information / calculations and anything else used in other designs

4. Equations and Formulas Used

The following equations were used throughout the design process for structural analysis and component sizing:

Static Load Analysis

- Force calculation: $F = m \times g$

Where F is force (N), m is mass (kg), and g is gravitational acceleration (9.81 m/s²)

- Moment calculation: $M = F \times d$

Where M is moment (N·m), F is force (N), and d is distance from pivot point (m)

- Safety Factor: $SF = \sigma_{yield} / \sigma_{actual}$

Where SF is safety factor, σ_{yield} is yield strength of material, and σ_{actual} is actual stress

Stress Analysis

- Bending stress: $\sigma = M \times y / I$

Where σ is stress (Pa), M is moment (N·m), y is distance from neutral axis (m), and I is area moment of inertia (m⁴)

- Axial stress: $\sigma = F / A$

Where σ is stress (Pa), F is force (N), and A is cross-sectional area (m²)

- Shear stress: $\tau = V / A$

Where τ is shear stress (Pa), V is shear force (N), and A is cross-sectional area (m²)

Component Sizing

- Deflection of beam: $\delta = F \times L^3 / (3 \times E \times I)$

Where δ is deflection (m), F is force (N), L is beam length (m), E is Young's modulus (Pa), and I is area moment of inertia (m⁴)

- Gear engagement force: $F_{gear} = T / (r \times \cos(\varphi))$

Where F_{gear} is force between gear teeth (N), T is torque (N·m), r is gear radius (m), and φ is pressure angle

Calculations

Weight Load Calculations

- Arm assembly mass (from CAD model): 2.729 kg
- Force due to gravity: $F = 2.729\ kg \times 9.81\ m/s^2 = 26.77\ N$

Moment Calculations

- Mass of ventilator box: ~1.5 kg
- Distance from pivot point: ~0.3 m
- Resulting moment: $M = 1.5\ kg \times 9.81\ m/s^2 \times 0.3\ m = 4.41\ N \cdot m$

Joint Analysis

- Required torque to maintain position: $T = F \times d = 26.77\ N \times 0.22\ m = 5.89\ N \cdot m$

- Required gear engagement force (assuming 30 mm radius gear and 20° pressure angle): $F_{gear} = 5.89\ N \cdot m / (0.03\ m \times \cos(20°)) = 208.7\ N$

Linear Slider Analysis

- Maximum expected deflection (from FEA): 0.12 mm
- Maximum von Mises stress (from FEA): 3.8 MPa
- Yield strength of aluminum 6061-T651: 276 MPa
- Resulting safety factor: SF = 276 MPa / 3.8 MPa = 72.6

Factor of Safety Calculations

- For acrylic components (σ_{yield} = 69 MPa): Minimum safety factor from FEA: 4.26
- For aluminum components (σ_{yield} = 276 MPa): Minimum safety factor from FEA: 12.61
- Required safety factor per specifications: ≥4
- All components meet or exceed the required safety factor

5. Budget

Bill of Materials

Description	*Supplier*	*Cost*	Unit	Quantity Used Per Device	Cost Per Device
Stock Materials					
0.125" x 24" x 48" (1152in^2) 2447 White Acrylic	*EPlastics*	$49.72	Sheet		
0.187" x 24" x 48" (1152in^2) 2447 White Acrylic	*EPlastics*	$61.89	Sheet		
0.375" x 24" x 48" (1152in^2) 2447 White Acrylic	*EPlastics*	$121.26	Sheet		
1/4" x 24" x 48" (1152in^2) 6061-T651 Aluminum Sheet	*Industrial Metal Supply*	$190.36	Sheet	128in^2	
3/4" x 12" x 12" (144in^2) 6061-T651 Aluminum Plate	*Industrial Metal Supply*	$92.99	Sheet	32in^2	
D1/2" x T18ga x L36" 304 Polished Stainless Round Tube	*Industrial Metal Supply*	$0.17	inch (length)	16.14"	
3D Printer Filament					
M4x0.7mm Thread Pitch Tapped Rod	*Amazon*	$10.00	50cm		
Fasteners and Off-The-Shelf Components					
1/2 x 1-1/8 x 5/16 Steel Ball Bearings	*Amazon*	$12.99	10 units	4	**$5.20**
M4 x 6mm SHCS	*McMaster*	$11.44	100 units		
M4 x 8mm SHCS	*McMaster*	$12.94	100 units		
M4 x 10mm SHCS	*McMaster*	$12.24	100 units		
M4 x 12mm SHCS	*McMaster*	$12.02	100 units		
M4 x 14mm SHCS	*McMaster*	$13.91	100 units		
M4 x 16mm SHCS	*McMaster*	$12.40	100 units		
M4 x 18mm SHCS	*McMaster*	$15.99	100 units		
M4 x 20mm SHCS	*McMaster*	$14.14	100 units		
M4 x 25mm SHCS	*McMaster*	$10.17	500 units		

M4 x 30mm SHCS	*McMaster*	$3.71	5 units		
M4 Hex Nuts	*McMaster*	$3.11	100 units		
M4 Washers	*McMaster*	$3.57	100 units	8	
M4 Allen Key	*McMaster*	$0.35	1 unit	1	**$0.35**
	Total Order Cost		**$2000**	Total Device Cost	**$400**

- SHCS – Socket Head Cap Screw
- P# – per # units
- Quantity Used Per Device does not include excess material left over from laser / water cutting materials
- We already minimize costs by using standard purchased components wherever possible. Since the design is still in iteration, we will further consider material selection and manufacturing processes to reduce mass production costs.

Individual Component Analyses

A. Locking Joints – Parissa

Brief Description and Function

Through the locking/unlocking of two gears, the locking joint allows the arm to move freely when necessary and then lock when the desired position is obtained. By joining two gears together, the locking joints in the arm system prevent the arm from moving and ensures that the box is held at an appropriate height. In addition, the joint will interface with both the linear slider and support linkage. The system will be unlocked/locked manually by the personnel using the device.

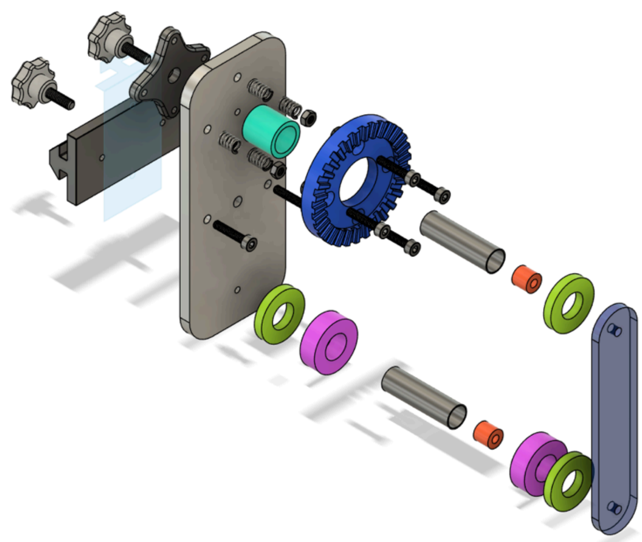
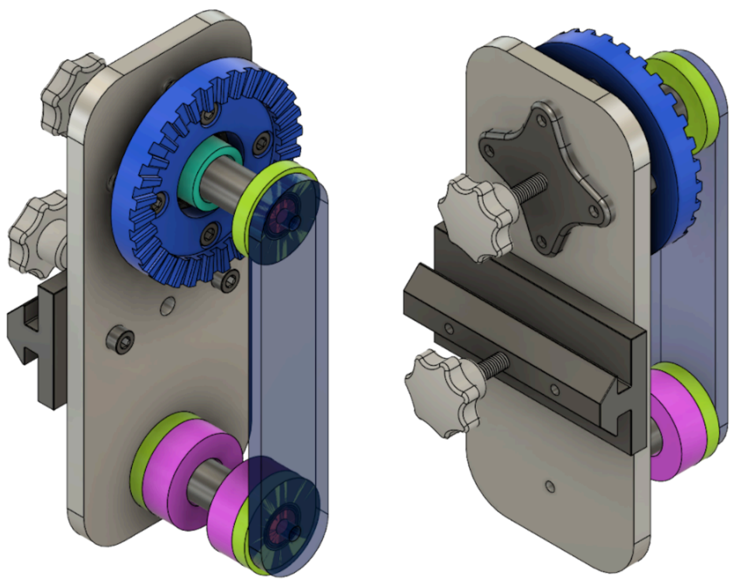


Figure 7. Image of component CAD rendering

Functional Requirements and Constraints

- Must fit into a 2.5 x 2.5 inches box
- Must have a thickness of less than .4 inches
- Must interface with linear slider and support linkages
- Must have a controlled release mechanism
- Must be able to withstand load of 25 N

With the functional requirements and constraints in mind, the following component was developed:



High Risk Factors and Mitigation

Risk / Failure Mode	Severity	Failure Cause	Mitigation
Components Fracturing	High	Overuse/High Impact	Create standard operating procedure guide with clear guidelines regarding component lifespan and replacement guidelines
Gear Failure - Binding /Jamming	Medium	Misalignment, debris	Regular maintenance, ensure proper alignment during assembly
Gear Failure - Slipping	High	Gears not interlocking, material wear	Regular maintenance and inspection, replacement guidelines

Fastener Failure	High	Vibrations	Torque fasteners properly before each use, use vibration mitigation techniques (safety wire, thread lockers, etc.)
Spring Failure	High	Loss of compression overtime, accidental disengagement	Regular maintenance and inspection, replacement guidelines
Environnmental Factors	Medium	Corrosion, debris in gears, temperature expansion / compression	Use heat and corrosion resistant materials, powder coat any unsealed surfaces, perform routine inspections

Calculations

Show calculations / FEA analysis performed to ensure component meets specifications

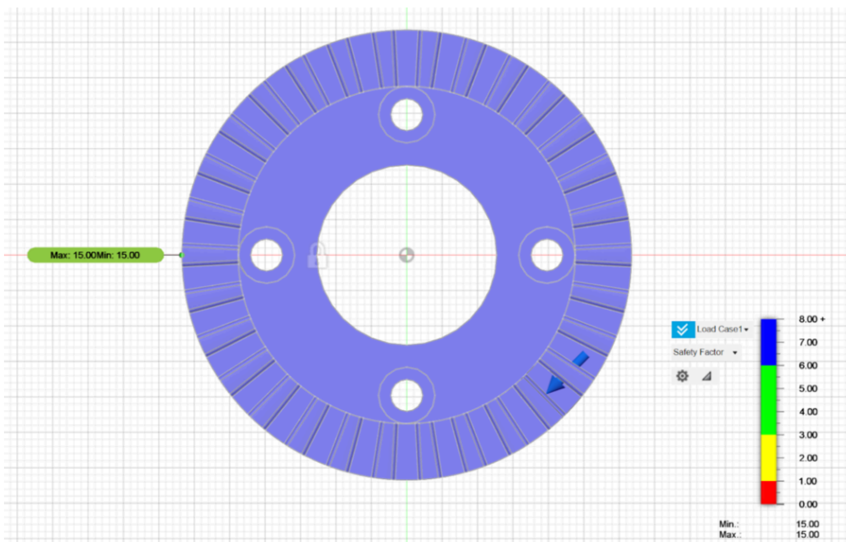
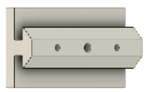
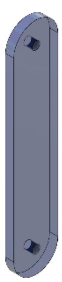


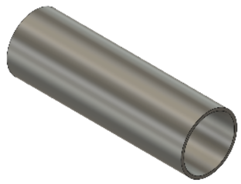
Figure X. Locking gear. Material aluminum 6061. Analysis assuming load is concentrated on a single tooth profile

Component Manufacturing

How will this component be manufactured, what materials used, etc.

Component	Stock Material	Manufacturing Process/ Source
Locking Gears	PVC	• Purchased stock material from ______ • CNC – Screw Holes & Gear Teeth

		
T Slotted Framing 	ABS Plastic	• Purchased from _____ •
15mm (0.8 mm pitch) M5 Knobs 	Steel	• Purchased from
Joint Hub Inside Plate 	Aluminum	• **Purchased stock material from** •
Payload Hub Aux Plate 	Acrylic	

Joint Hub Axle (x2) 	Steel	
Pullback Mount Spacer (x2)	Steel	
Joint Hub Spacer	Acrylic	
M4 Screws (20 mm x2) (30 mm x 2)	Steel	Purchased
Hex Nuts (x4)	Steel	Purchased

B. Ventilator Clamp - Reuven

The ventilator clamp supports the entire weight of the arm and its load and connects to the standard stand supporting the Jet Ventilator (a 2” diameter aluminum rod). The clamp features an adjustment knob which dampens or locks the pivot capabilities of the arm. The clamp is secured to the ventilator via 4 M5 Philips-head screws securing the two sides of the clamp together.

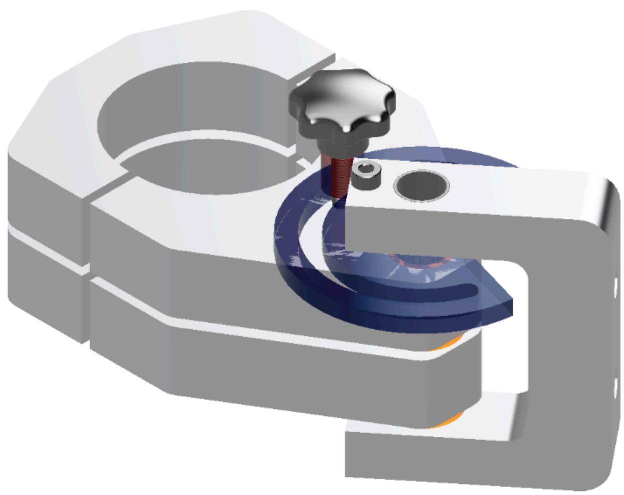


Figure 6. Image of component CAD rendering

Functional Requirements and Constraints

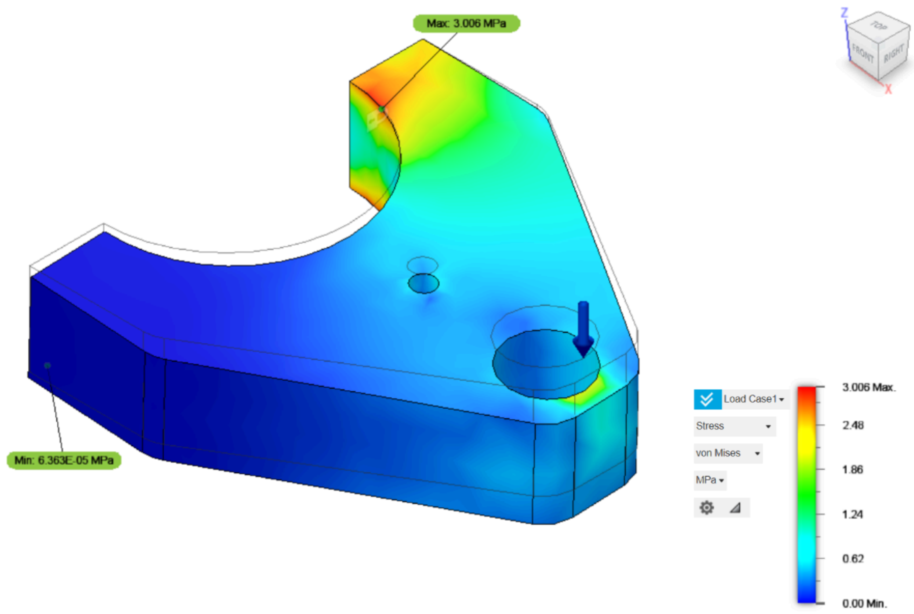
- Support entire weight of system ~ 3.22 kg
- Include pivot for adjustment of arm position
    - Add feature to dampen or lock the pivot capability
- Interlock with linear slider (2 M8 screws)
- Secure to 2” diameter ventilator pole with minimal damage
- Design clamp to be easily removed from ventilator with standard Philips screwdriver

High Risk Factors and Mitigation

Risk / Failure Mode	Severity	**Failure Cause**	**Mitigation**

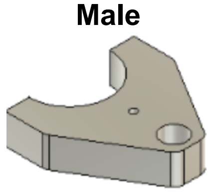
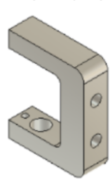
Calculations

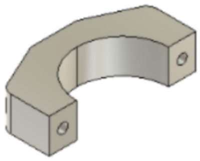
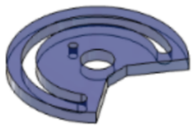
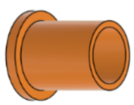
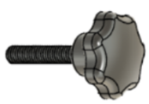
FEA was performed on the ventilator clamp male as this is the main component supporting the arm's weight. The applied force was a downwards 4kg force plus the moment created by the arm when it is fully extended.



The simulation resulted in a **factor of safety greater than 15** and thus it was determined that the component was satisfactory.

Component Manufacturing

Component	Stock Material Qnty	Manufacturing
Ventilator Clamp Male 	0.75" Aluminum Sheet x2	• Water jet 2D shape of clamp • Drill two M5 tapped holes in either side • Tap M5 holes and hole for locking pin
Ventilator Clamp Female 	0.75" Aluminum Sheet x1	• Water jet 2D shape of clamp • Drill M8 clearance holes • Drill 0.50" axle slot • Drill M4 tapped hole for clamp stopper
Ventilator Clamp Bracket	0.75" Aluminum Sheet x2	• Water jet 2D shape of clamp • **CNC** machine bore holes for M5 screws

		
Clamp Stopper 	0.187” Acrylic x1	• Laser Cut 2D profile • Tapped M4 hole
Ventilator Clamp Axle 2.7” 	Steel Hallow Rod x1	• Cut to size (2.7”)
Ventilator Clamp Axle Sleeve 	3D Printed PLA x2	3D Printed
25mm M5 knob 	McMaster Stock x1	-
Screws	• 1x **M4x16mm** socket head screw • 4x **M5x25mm** Philips head screws • 2x **M8x30mm** socket head screws	

C. Linear Slider - Mayah

The linear slider assembly allows the operator to adjust the reach of the kanga move arm horizontally. It is secured to the ventilator clamp on one end and allows the locking joint hub to move linearly along the guide rail. The knob allows the hub to be locked in place with the arm is in use.

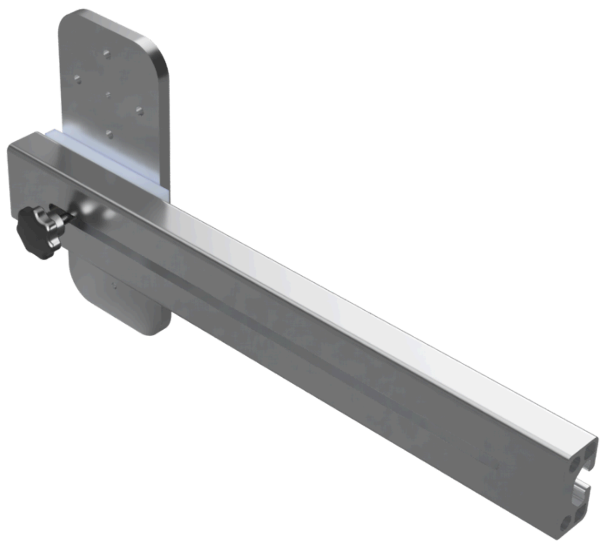


Figure 7. Image of linear slider assembly CAD rendering

Functional Requirements and Constraints

- **The device shall be able to support 325 kg at minimum**
- **The device shall be able to support moment of 13.57 Nm at minimum**

High Risk Factors and Mitigation

Risk / Failure Mode	Severity	**Failure Cause**	**Mitigation**
Guide rail deformation under load	High	The actual load surpasses the expected load	- Design to accommodate larger load than expected - Emphasis the hazards of improper device usage in documentation
Slider becomes unlocked	High	The knob disengages while the arm is in use	- Select material with high friction coefficient to

			act as the brake

Calculations

Calculating maximum expected load:

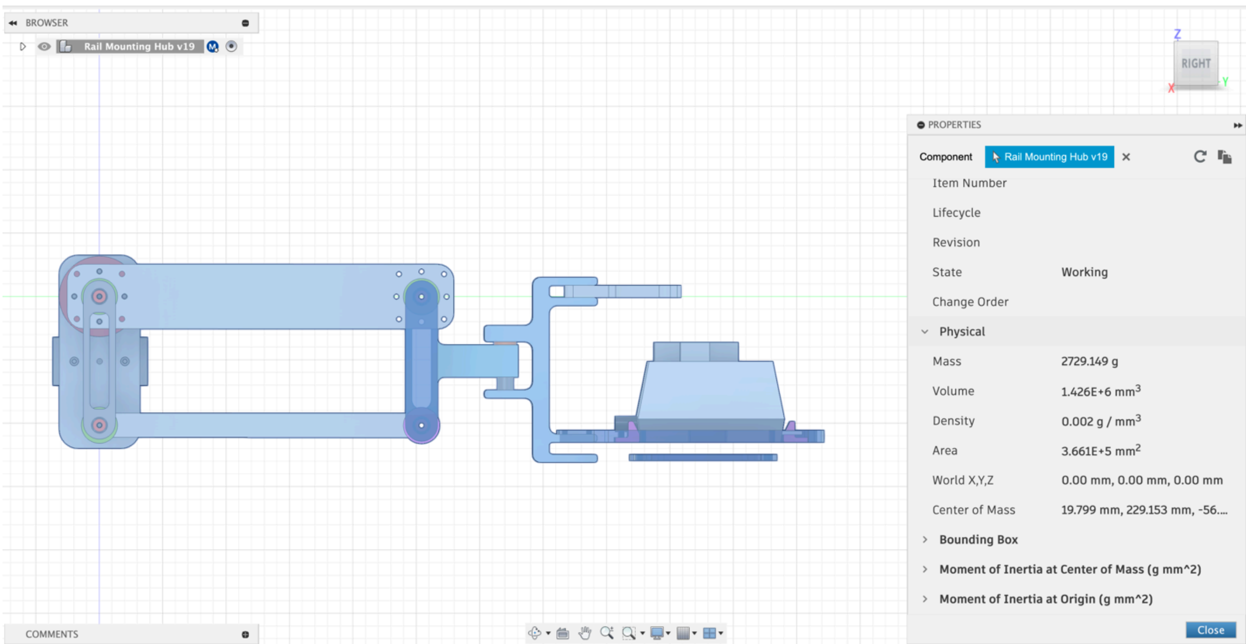


Figure 8: Fusion Properties menu used to determine maximum expected load applied to linear slider.

The fusion properties menu was used to determine the mass and location of the center of mass of the arm assembly that will be supported by the linear slider. These values were used to calculate the maximum expected load experienced by the linear slider.

Mass: 2.729 kg

Center of mass location:

x: 19.799 mm

y: 229.153 mm

z: -56.459 mm

$$F = m * g$$

$$F = 2.729\, kg * 9.81 \frac{m}{s^2} = 26.77\, N$$

Static stress studies were conducted to each load bearing component using remote loading conditions to mimic the moment arm produced by the arm assembly.

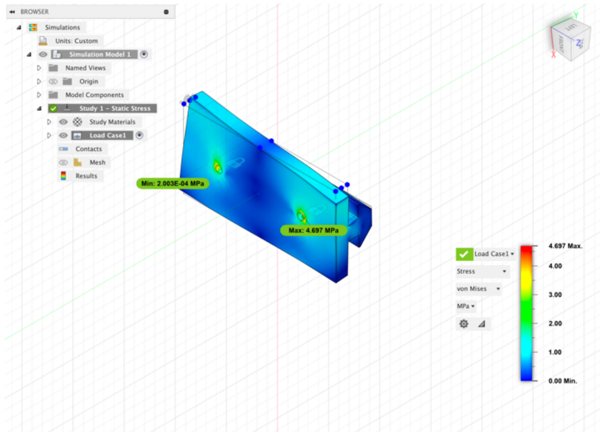


Figure 9: Stress analysis of T – Slotted Framing, Rail Slide under load as calculated above

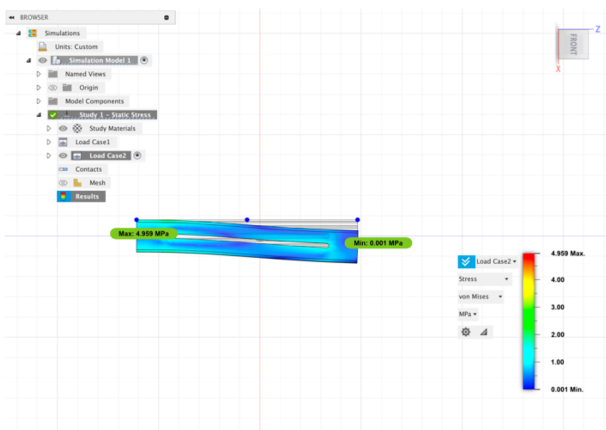


Figure 10: Stress analysis of T – Slotted Framing, Low Profile Single Rail under load as calculated above

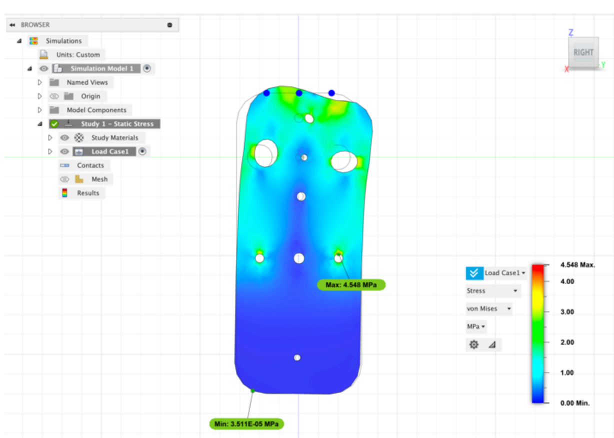


Figure 11: Stress analysis of Hub Outer Plate under load as calculated above

Component Manufacturing

How will this component be manufactured, what materials used, etc.

Component	Material	Manufacturing Process/ Source	Factor of safety
T – Slotted Framing, Rail Slide	Plastic	Purchased Holes tapped for m4 screws Manually drilled and tapped m5 hole	4.26
T – Slotted Framing, Low Profile Single Rail	Aluminum, Anodized	Purchased Slot manually cut	15
Hub Outer Plate	Aluminum	Water Jet cut Hand Tapped m4 holes	15

D. Support Linkage - Jeffrey

The Support Linkage is a structural component designed to provide stability and load distribution within the assembly. It is subjected to a 4-pound (17.3 N) static load, with stress distribution analyzed using Fusion 360's static stress simulation. The linkage is intended to maintain rigidity while minimizing material usage.

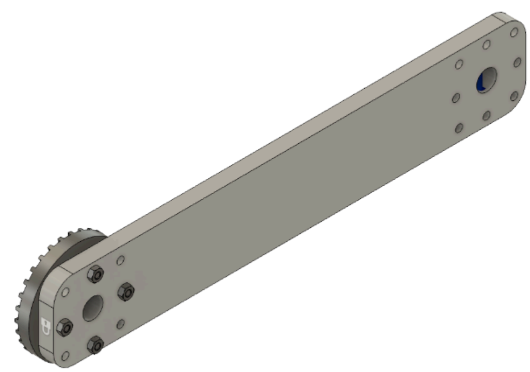


Figure 8. Support Linkage CAD Rendering

Functional Requirements and Constraints

- Must withstand a **static load of 4 pounds (17.3 N)** with an acceptable **Factor of Safety (FoS ≥ 3)**.
- Designed to minimize stress concentrations and prevent **cracking or brittle failure** in acrylic.
- Ensure **low deflection** to maintain alignment with surrounding components.
- Optimize material usage while retaining adequate strength.
- Compatible with **standard laser cutting or CNC machining** for manufacturing.

High Risk Factors and Mitigation

Risk / Failure Mode	Severity	**Failure Cause**	**Mitigation**
Brittle failure (cracking)	High	High localized stress	Increase fillet radii, avoid sharp corners
Excess material usage (overdesign)	Medium	High Factor of Safety due to oversized thickness	Reduce material in low-stress regions while keeping FoS > 3

Warping during machining	Low	Heat buildup from Laser cutting	Optimize cutting speed, use protective film
Stress risers at mounting holes	Medium	Bolt preload or improper fastening	Chamfer holes, verify bolt torque

Calculations

FEA analysis using Fusion360 to run Static Loading tests

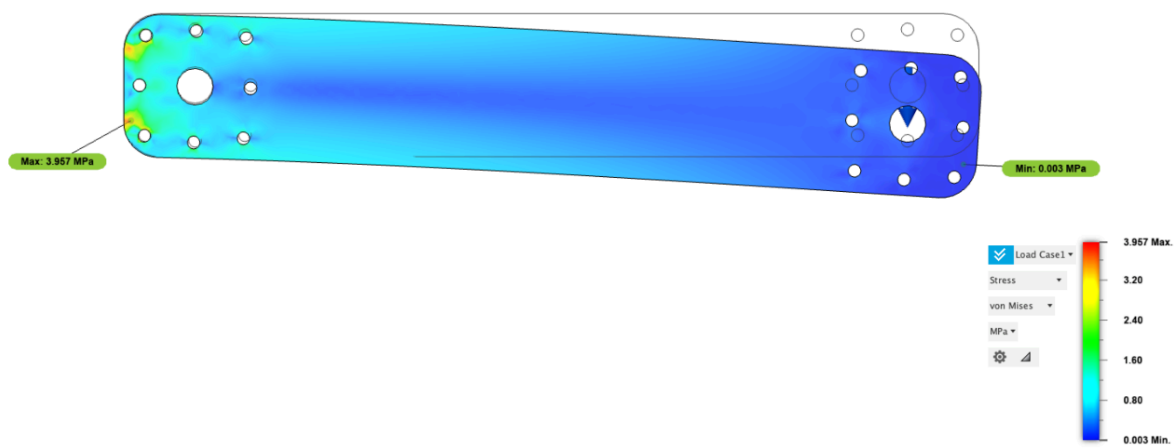


Figure 12: Vertical Loading (4 Pounds = 17.8N) on linkage Stress Simulation

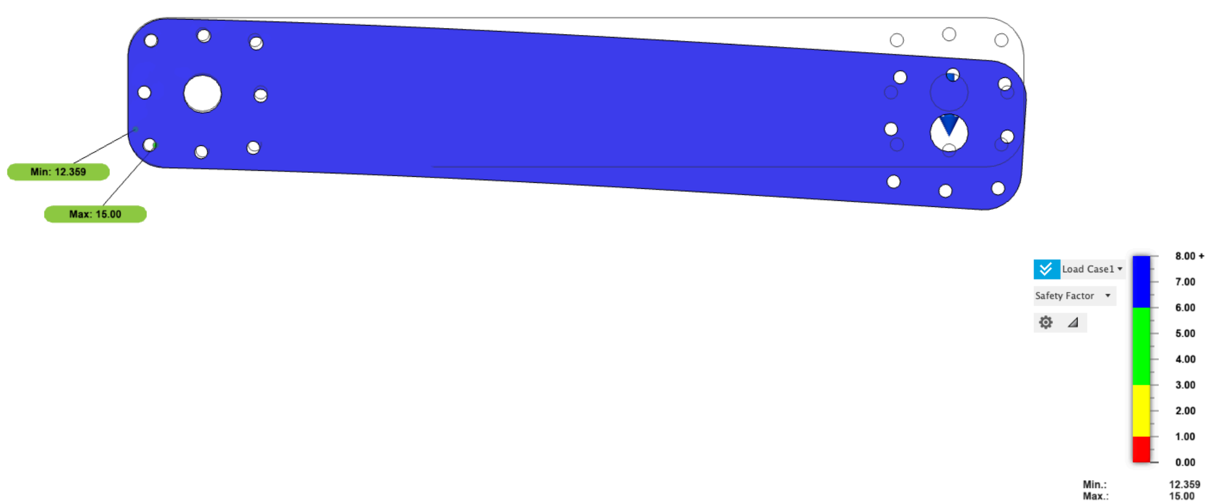


Figure 13: Vertical Loading (4 Pounds = 17.8N) on Linkage Safety Factor Simulation

Component Manufacturing

- **Material:** Acrylic due to its lightweight properties, rigidity, and ease of manufacturing.
- **Manufacturing Method:**
  - **Laser Cutting** – Preferred for its precision and clean edges.
  - **CNC Machining** – Alternative for finer tolerance control.
- **Post-processing:**
  - **Deburring edges** to prevent stress risers.
  - **Polishing/annealing (if needed)** to reduce internal stresses.
- **Assembly Considerations:**
  - Use of **chamfered holes** to prevent stress concentrations.
  - **Controlled bolt torques** to avoid localized stress buildup.