ME 450- DESIGN AND MANUFACTURING III

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HYBRID INFANT WARMER-TEAM 17

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Executive Summary

A baby's inability to maintain its own body temperature is a leading cause of premature infant death. As a remedy, premature infants are put into incubators within hospitals. However, in low-income countries, sufficient incubators may be too costly to maintain. Therefore, The World Health Organization recommends the use of Kangaroo Mother Care (KMC) which facilitates skin to skin contact between the mother and child and constant breast feeding. However, most current products in the market only function as standalone incubators which discourages KMC. Our main goal, as described Leith Greenslade who is our sponsor, is to find a middle ground by creating a hybrid infant warmer that will allow the parent to practice KMC, but also can be detached from the mother to function as a standalone incubator.

The user requirements we've proposed to satisfy for our device are the ability to maintain the infant's body temperature, facilitate KMC and breast feeding, have an aesthetic appeal, allow for the parent to have high mobility, have an ease of use and maintainability, be safe and durable, and ideally able to be produced in a low resource setting. When the infant is utilizing the incubator feature, the infant's body should stay within the range of 36.5 - 37.5 degrees Celsius. Furthermore, when the infant and parent are utilizing the KMC feature, approximately 70% of the baby's front body should contact the parent's chest. The device should look like a typical sling to encourage mothers in low resource settings to use it. The parent should be able to perform daily activities for 5-6 hours while using the device and should have a maximum of 3 steps to put on the device. ASTM 2907 standards must be met when addressing the safety and durability of the device. Ideally, the device would be produced in the low resource setting for a cheaper cost.

To create design concepts, we used functional decomposition to break down our ideas into two categories: carrier types and incubator types. We used various design heuristics in the concept generation process to develop 3 carrier types and 9 incubator types. Combining one carrier type with one incubator type gives us a possible concept, so we generated a total of 27 concepts.

A Pugh chart was used to compare these four final options. Various weights were assigned to each combination design for each user requirement based on what we believed our sponsor, Ms. Greenslade, would choose.

Based on the Pugh chart, the integrated shirt with a Mylar insulation pack was chosen as the final design concept. This shirt is composed of two pockets: one on the inside front chest area of the shirt and one on the lower back outside. The inside front chest area pocket is for the infant to be placed in when the parent wants to utilize the skin-to-skin contact feature. If the parent needs to remove the infant from KMC, the collapsible Mylar insulation pack will be handily stored in the lower back outside pocket. The parent can simply take out the blanket when the infant needs to be away, wrap the infant in the Mylar, and the material will insulate and maintain the temperature of the infant. The final prototype passed all of our validation tests and met all of our user requirements.

Problem Description and Background

The leading cause of death in children younger than five years old is due to complications stemming from premature birth. More than fifteen million babies are born prematurely every year, with slightly more than one million of which pass away [1]. Many of these deaths could be prevented with proper thermal care [2, 3].Maintaining the proper body temperature for premature infants is critical in these early stages, as they struggle to regulate their own body temperature[3]. In order to care for premature infants, hospitals usually place them into neonatal intensive care with incubators. Due to the costs of maintaining incubators and a large enough facility to house them in, many hospitals in low income areas do not have the capacity to support this care. It is estimated that only 65% of infants that need care can be cared for at the hospital level [4]. As a result, many neonatal intensive care units are understaffed and can sometimes be forced to put two or as many as three babies in one incubator. This is not only ineffective from the standpoint of the incubator's operation, but also dangerous as it may leave children unattended for as the nursing staff is overwhelmed [5].

In an attempt to address the issue, the World Health Organization recommends Kangaroo Mother Care practice [6]. This not only involves maintaining prolonged skin-to-skin contact between the infant and mother but also allowing the infant to breast feed as frequently as possible [6]. This method has been shown to be as effective as incubator care, as determined by mortality rate [6]. In addition, the exercise requires next to no capital investment, as all that is required is a healthy mother, time to care for the infant, and a sling to secure the baby closely to the mother's body. This makes Kangaroo Mother Care an excellent solution for low resource settings, whose clinics struggle to meet the demands of neonatal intensive care units.

However, there has been little uptake of KMC to this point. Clinics thus far have not adopted the practice, and there's a conflict between public health policy makers and those pushing current products into the market. Many products either attempt to promote the Kangaroo Care Method or function as a standalone incubator. In order to bridge the gap between public policy makers and clinical care, we've been charged with creating a device that meets both worlds in the middle [7].

We intend to create a device that mothers can wear that promotes the Kangaroo Mother Care method, but can also be removed from the mother and function as a standalone incubator. Not only would this be a huge benefit in the neonatal intensive care units, but also in the comfort of the family's home. There is market demand for a device that promotes KMC, functions as an incubator in situations where Kangaroo Mother Care can't be administered, and appeals to mothers in low resource setting to use.

There are a few low resource-setting devices available that have attempted to address the problem stated above. Embrace is a standalone infant incubator that functions as a sleeping bag for the baby. It has a phase change material that can be inserted to maintain a constant temperature for the baby. However, it does not promote KMC. ANYA is similar to Embrace but can also strap the baby to his/her mother while maintaining a healthy body temperature. The Neonurture Car Parts Incubator functions as a low cost incubator that can be easily rolled around. Though these three incubators function well, they do not promote KMC. Other devices such as the Moby Sling and traditional style wraps facilitate KMC, but do not insulate the baby well.

User Requirements and Engineering Specs

The most important user requirement is for the device to provide insulation and warmth whether or not the infant is exposed to skin to skin contact [7]. If the infant is away from the mother, the infant's body temperature should stay within the range of 36.5 - 37.5 degrees Celsius within 1 hour of being separated from the parent's body [1]. To test this, a material with temperature maintaining properties similar to the human body (i.e. wax) will be used to mimic a baby within the device. The temperature of the wax can be measured while it is in the device and in direct contact with a human then measured once again after 1 hour of not being in direct contact. A safety concern for the team is if the baby's temperature drops to 36 degrees Celsius, which is deemed a mild form of hypothermia [1].

A second user requirement is that the device should "facilitate breast feeding… the baby has to be positioned in a way to have continual access to breast" as well as have "as much skin as possible touching [between the baby and the parent]... the more skin touching the better" [7]. When the baby and parent practice Kangaroo Mother Care, skin to skin contact is maintained which is approximately 70% of the baby's front body contacting the parent's chest. To test this, the distance between a woman's breast and location of typical swaddled babies will be measured and used to determine the ideal placement of the baby in the new device.

From an aesthetics standpoint, the user should "have an emotional attachment to the product… [the product should be] more blanket-like, have an attractive fabric" since the feel of the fabric is important. While it is not the most important requirement, it should still be taken into account. Since third world country healthcare sites lack resources that first world countries have, some people in third world countries are unfamiliar with medical looking devices. If the device looks too technical, the end user may be discouraged from using it. The shape of the device should look like a normal baby sling that parents in third world countries are accustom to use [7]. A consumer survey of different hybrid infant warmer designs will be utilized in order to meet this requirement.

A fourth user requirement is that the device should allow high mobility for the parent when being used. The parent should be able to "walk, work, or do anything as much as possible… the more mobile the better" with the device on. While it is not as important as the first user requirement stated, we want the user to have as much mobility as possible. Initially, the device will be used in a hospital setting, but eventually it should be able to be used at home as well. The parent should be able to "easily take [the device] on and off by themselves" [7]. This translates to 5-6 hours of the parent going about their daily business while wearing the device and baby while facing minimal difficulties. This requirement takes into account the comfort of the parent. By keeping the baby in the same position, it alleviates any additional motion the parent would have to perform while carrying the baby in the device. Customer reviews on commercially available baby slings can be read to determine the most effective method of slinging that results in the most comfort for both parties. Various designs can be rated on a scale to decide on the ideal device structure.

The device will be used for the majority of the day so it must have an ease of use as well as an ease of maintainability [7]. There should be less than 3 steps involved in putting on the device with a maximum throughput time of 30 seconds. This requirement was decided on by noting the steps and timing how long it takes a parent to attach a commercially available baby sling to themselves. Since a baby may urinate or defecate unplanned, the device should be easy to clean and bring back to standards. To keep the holding device free from harmful bacteria, a non-absorbent material will be used. Materials can be tested to determine a balance between absorptivity and comfort to both parties.

A regulation standard implemented user requirement for the device is that it must be safe for the user and baby. This requirement is of utmost importance. Going along with the idea of strong device, a team implemented user requirement is that it must be durable. There are severe consequences to the baby, parent, designer of the device, and so on if the device cannot hold a baby. According to the ASTM 2907 standards, while the device is static it must support a 15-kilogram mass on an area with a 150-millimeter diameter for 120 seconds. While the device is dynamic it must support a 10-kilogram mass dropped from 25 millimeters above the 150 millimeter diameter supporting area for ten trials. The device should be durable enough to last the entirety of the premature baby's transition from premature to healthy and 1-2 years afterwards.

A last user specification is that the device would ideally be produced at a low resource setting, perhaps locally for a cheaper cost and availability of knowledgeable people to maintain it. The device should have low energy consumption; meaning the water and chemicals to maintain the device should be cost effective. Further research will need to be conducted to determine what materials are readily available in various third world countries and can be used to construct the device. We approximate the cost to be $25 - $50, which is significantly cheaper than other low resource setting incubators described in the benchmarking section.

User Requirements	**Engineering Specifications**
Insulation	Maintain body temperature between 36.5 ℃ and 37.5 ℃
Support skin-to-skin contact and Breastfeeding	> 70% of baby's front surface contacted with mother (except arms and legs)
Aesthetic	Parents accustom to shape and feel
High Mobility	Wear the device for 5 hours and do not feel tired; lightweight <4 kg
Easy to use and maintenance	Change Style: ≤ 3 steps & < 30 s set up time; non-absorbent material
Strength, Durability, Safety	Static: Support 15 kg mass on the area of 150 mm diameter for 2 minutes; Dynamic: Support 10 kg mass dropped from 25 mm above the same area 10 times ≥ 2 years

	Do not present a strangulation or suffocation hazard. No straps or soft cushion material near the child.
Low Resource Setting	Low cost: < $ 50; Low Energy Consumption: Spend water or chemical substances < $0.5/Hr

CONCEPT GENERATION

Based on our benchmarking of various infant slings and incubator designs, we generated 27 concepts for the hybrid infant warmer. The three major categories of concepts are based on the method and styles of carrying the infant: sling, backpack, and an integrated shirt “pocket”. To generate these concepts, we utilized the design heuristics cards that were distributed during lecture.

Carrier Styles

The heuristic of combining two items was utilized with our sling category. We took the idea of an arm sling used for supporting an injured arm and combined it with the idea of a large blanket used for maintaining warmth to get an large sling that wraps around the parent’s shoulder to support the infant. As with an arm sling, the infant would be held tightly in place to minimize movement. The blanket would insulate the infant so its body temperature is maintained. The sling would also facilitate skin to skin contact and breast feeding since the baby would be held against the parent’s body.

The heuristic of applying an existing mechanism in a new way, or repurposing, was utilized with our category of backpack style carrier. Backpacks are typically used for easily carrying items in a pack on one’s back while taking advantage of the strength of humans’ backs and shoulders. Rather than carrying multiple items in a pack, it was proposed that an infant be carried in the pack. The backpack also would be repurposed as a front pack so instead of the infant being carried on the back of the parent it could be carried on the front to facilitate constant breast feeding. The front pack concept would facilitate skin to skin contact, similar to how a backpack normally is pressed firmly on the user’s back.

Our final category of an integrated shirt “pocket” for infants was generated using the heuristic of adding onto an item. When shirts are worn, they are constantly in contact with the user’s skin and keep the wearer warm. Pockets in clothing also keep the items pressed against the skin. Using these ideas, we generated the concept of having a pocket within the shirt in the chest area so the baby could be easily placed inside. The insulation portion of the concept could be stored in a pocket on the front outside of the shirt. This carrier concept would facilitate skin to skin contact, breast feeding as well as insulate the baby.

Combination of Carrier and Incubator

In addition to the carrier type, 9 different methods to incubate the infant were generated. These methods are shown in the functional decomposition chart below. Combining the three carrier types and the nine incubation methods, we get 27 different ideas for a final product. Our top four choices are a pocket shirt with Mylar insulation, a pocket shirt with a phase change material insulation, a sling with Mylar insulation, and a sling with a phase change material insulation.

The pocket shirt with a Mylar insulation pack would be composed of a shirt with two pockets - one pocket on the outside of the bottom of the shirt to hold the Mylar insulation blanket and one pocket on the inside of the shirt to hold the infant. When the parent wants to use the KMC function they can place the baby on the inside of their shirt and it will be held firmly against the parent's chest by the stretchiness of the fabric. When the parent wants to use the incubator function they can take the Mylar blanket from the outside bottom shirt pocket and wrap the infant inside it to maintain its temperature.

The pocket shirt with the phase change material insulation would have two pockets similar to the shirt with Mylar insulation. Instead of the outside shirt pocket being located at the bottom of the shirt, the pocket would be located on the front center outside closest to where the infant would be resting. Inside this outside pocket would be the phase change material, such as the paraffin wax that Embrace promotes. This wax phase change material would be melting by pouring boiling water over the pack and inserting the melted wax packet into the outside shirt pocket. This would keep the infant warm independent of the parent.

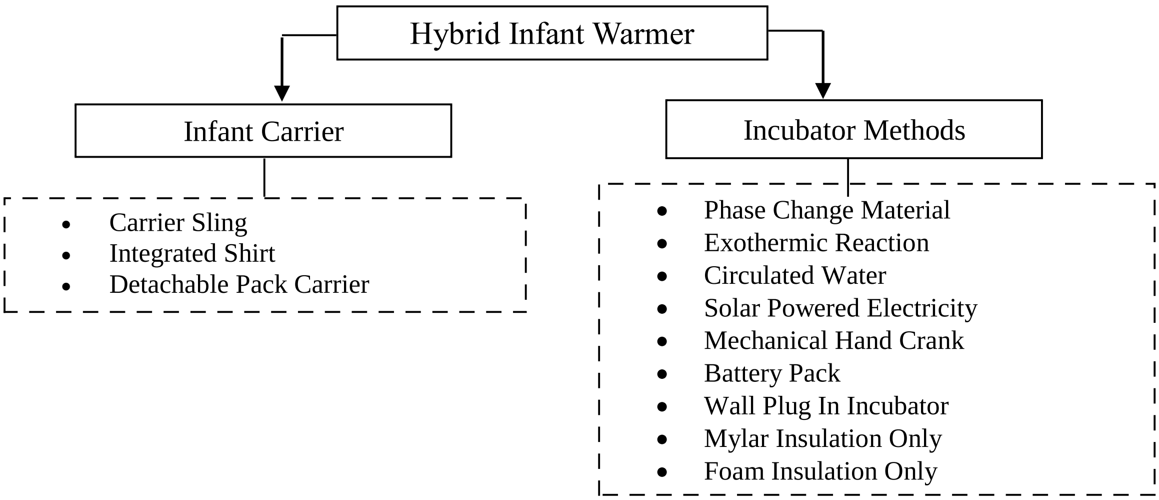
The sling with Mylar insulation would be composed of a blanket of some sort that could be wrapped tightly around the parent to hold the infant inside. The Mylar insulation would be used as the incubator type and would also wrap around the infant either while the infant is inside the sling or if the infant is outside of the sling.

The sling with the phase change material insulation would have a pocket in the outside of the sling in the same position as where the infant would be placed. The phase change material would be stored similar to the Embrace's design in the back of the product to minimize direct contact with the hot melted wax.

More descriptions of the various concepts generated can be found in the Appendix.

Functional Decomposition Model

Below is our breakdown of our concept generation process into the 3 infant carrier styles and 9 incubator methods.



CONCEPT SELECTION

Our user requirements and engineering specifications that were determined from the first design report are restated below to better understand our end goal.

User Requirements	Engineering Specifications
Help the infant maintain their body temperature while in use as an incubator	Maintain body temperature between 36.5 ℃ and 37.5 ℃
Satisfy guidelines for the safety of infant products provided in "Baby Product Safety Tips"[1]	Does not present a strangulation or suffocation hazard. No straps or soft cushion material near child.
Support skin-to-skin contact between the wearer and infant	Cover > 70% of baby's front surface contacted with parent (except arms and legs)
Allow for breastfeeding when in use by the mother	Position the baby in the correct position on the chest to support breast feeding
Allow users to reasonably perform chores while wearing	Wear the device for 5 hours and do not feel tired; lightweight < 4kg for entire system
Easy to use and maintain	Switch from KMC to insulation and vice versa: ≤ 3 steps with a < 30 second set up time; 100% non-absorbent material
Meet the ASME requirements provided for infant carriers [2]	Static: Support 15 kg mass on the area of 150 mm diameter for 2 minutes; Dynamic: Support 10 kg mass dropped from 25 mm above the same area 10 times
Durable and long lasting	≥ 2 years
Target consumers in low resource settings	Low cost: < $10 Power: Require no grid power Aesthetics: Appeal to user

A Pugh chart was used to create our logical, objective scoring system to assess the ability of the four main concepts that we chose to meet the user requirements that were developed in the first design report. The Pugh chart can be found below.

User requirement	Weight	Shirt with Mylar Insulation Pack	Shirt with Phase Change Material	Sling with Mylar Insulation Pack	Sling with Phase Change Material
Maintain body temp, incubator	5	4	5	3	4
Follow safety guidelines	3	3	3	2	2
Support skin-to-skin contact	5	5	5	5	5
Facilitate breastfeeding	5	5	5	5	5
High Mobility	4	4	3	3	2
Easy to use and maintain	3	3	2	2	2
Meet ASME reqs	3	3	3	2	2
Durable, long lasting	3	2	1	2	1
Low resource setting	5	5	1	3	1
Total	**36**	**34**	**28**	**27**	**24**

The pocket shirt with a Mylar insulation pack was chosen as our final concept. In terms of ease of use, the pocket shirt option was the most ideal. Using the sling or backpack carrier type would involve the parent needing to take off their shirt to provide the skin to skin contact. With the pocket shirt, the parent can simply place the infant into the shirt they are already wearing. This option would also be the most cost efficient which is a key point to address when designing a product to be used in low resource settings. This type of carrier would also fulfill the requirement of integrating into the low resource setting culture and society without looking "too technological", as defined by our sponsor. The Mylar insulation pack was the best option for our final concept because it can be easily collapsible and stored away into the back pocket of the shirt. It would not be bulky like a phase change material or exothermic reaction incubator material nor would it involve using energy to bring the material up to a specific temperature. In addition, if the Mylar insulation pack is torn or damaged it is simple to piece back together and clean. With the phase change material or exothermic reaction packet, if these items are damaged then there will be dangerous chemicals strewn around. These two materials are also composed of chemicals that are not readily available in these low resource settings and would be costly to replace. With these considerations in mind, we believe this concept is the most feasible to fabricate in terms of price, material availability, and ease of use for the parent.

The pocket shirt with the phase change material insulation was our second best concept in terms of fulfilling the user requirements. As stated above, the pocket shirt has many benefits compared to the sling or the backpack style detachable carrier. An issue we foresee with fabricating the pocket shirt is finding the best material for the shirt that is robust and durable enough so an infant can safely lie inside the pocket while also still comfortable for the parent to wear for extended periods of time. The phase change material is the best portable material to be used as an incubator in the sense that it supplies a constant heat for the longest period of time out of the other concepts. However, due to the reasons stated above it would not be ideal to use the material since it would be expensive to replace. It also adds the aspect of the parent having to find boiling water to melt the phase change material and start the heating cycle. If the parent is pressed for time or for some reason cannot find boiling water, then the infant will not be kept warm which will negate the entire purpose of this product.

The sling with Mylar insulation is our third best concept that somewhat fulfills our user requirements. Slings are typically used in low resource settings so it would not be difficult to gently integrate the usage of the Mylar insulation pack into society along with the current product. Compared to a backpack carrier type, the sling looks far less “technical” which would encourage parents to use the product. However, the sling can be worn in various ways depending on the user’s preference which can put the infant in a position where breast feeding is not constantly facilitated. In addition, if the parent wants to use the sling for the skin-to-skin contact function, the parent would need to take off their shirt first and then attach the sling to their body. This causes some unnecessary steps in taking off the shirt and fastening on the sling compared to the shirt pocket which the parent would already be wearing as a normal shirt.

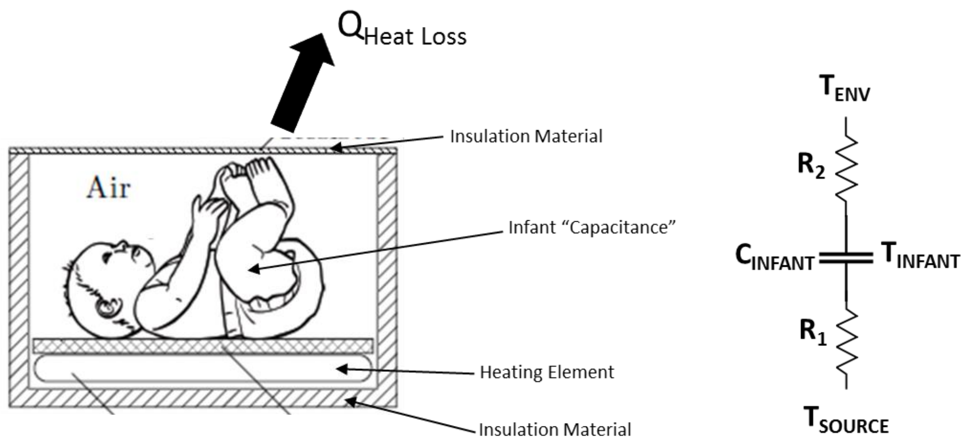
The sling with the phase change material insulation is our fourth best concept to somewhat fulfill our user requirements. This sling would facilitate skin to skin contact, but there are more cons that pros in this concept. A drawback with this design is that if the parent wants to set the child down then the sling material would be the only factor in keeping the infant’s front of the body warm since the phase change material would be located on the back of the sling. As stated previously, if the parent needed to place their child down but did not have time to find the boiling water to start the heat reaction in the phase change material, then the infant’s body temperature would decrease which is the opposite of our goal.

KEY DESIGN DRIVERS AND CHALLENGES

Simplest Competent Model

At the core of our project is the thermal management of an infant while this device is used in the incubator state. We have talked about this project as two challenges, as highlighted by the functional decomposition, and the heart of the engineering in this project lies in the thermal management.

We've modeled our project as a thermal circuit between the heat source - if there is one at all, the infant, and the surrounding environment. This is shown below:



This model has the corresponding differential equation:

$$\frac{T_{SOURCE} - T_{INFANT}}{R_1} + \frac{T_{ENV} - T_{INFANT}}{R_2} = mC_{INFANT}\frac{dT}{dt}$$

Our final design should fulfill our time and temperature management requirements, and the initial step in that process is validating our choices with the model above. This may not be complete, some possible sources of radiation heat transfer and free convection from the infant are ignored, and only one dimension is considered, but we believe the items modeled above represent the major components of the thermal circuit.

Key Challenges

The most challenging aspect of our design is finding the materials that will allow our best final concept idea see the light while fulfilling our main design drivers of supporting KMC, facilitating breastfeeding, low price, and able to be integrated in low resource settings. It is difficult to make a product look simplistic enough that people will not be wary of it. We also face challenges in our testing of our engineering specifications and finding materials that mimic human body behaviors since we cannot test on actual premature infants.

CONCEPT DESCRIPTION

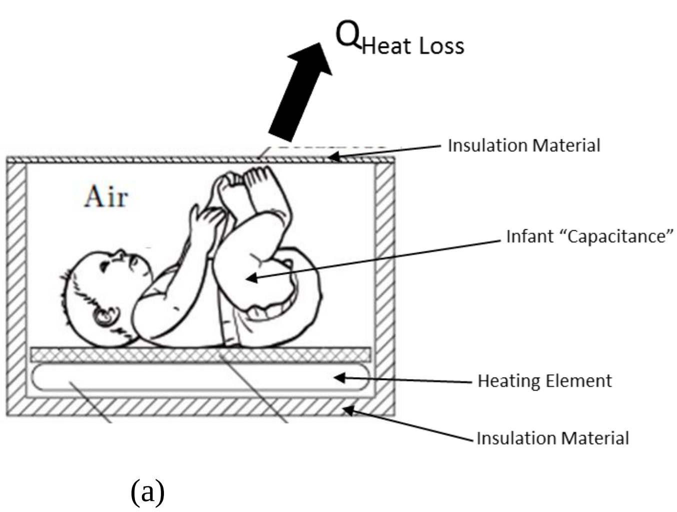
The integrated backpack carrier consists of all the components needed to serve not only Kangaroo Mother Care, but also incubator functions. It includes an adjustable breast plate made of cotton and foam that will be placed on the mother's chest. The baby is then put between this plate and the mother's chest. The plate is adjustable because there will be three Velcro straps across the front of the breast plate. The breast plate is complemented with side borders to provide a border for further support and insulation for the baby. There will be two adjustable drawstring straps on the sides of the breast plate, similar to a backpack, with one strap on each end of the breast plate connecting the top to the bottom. A fourth Velcro strap will connect these backpack straps in the lower back to provide more support for the mother's back. Finally, a pack contacting Mylar may be inserted on the lower back attached to the straps for incubator purposes.

ENGINEERING ANALYSIS

Simplest Competent Model

At the core of our project is the thermal management of an infant while this device is used in the incubator state. This project is two challenges, as highlighted by the functional decomposition, and the heart of the engineering in this project lies in the thermal management.

In Fig. 1 (a) and (b) the project is modeled as a thermal circuit between the heat source – if we choose to implement one at all – the infant, and the surrounding environment.



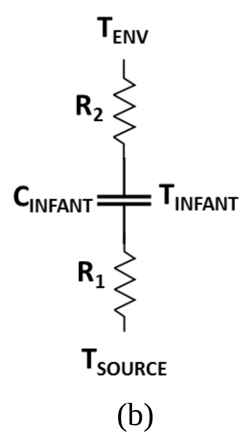


Fig. 1: (a) The infant utilizing the incubator function and (b) The thermal circuit of our project

This model has the corresponding differential equation, as defined by Eq. 1.

$$\frac{T_{SOURCE} - T_{INFANT}}{R_1} + \frac{T_{ENV} - T_{INFANT}}{R_2} = mC_{INFANT}\frac{dT}{dt} \qquad \text{(Eq. 1)}$$

Where T_{SOURCE} is temperature of the source, T_{INFANT} is the temperature of the infant, T_{ENV} is the temperature of the environment, R_1 is the resistance of the insulation/heat source, R_2 is the resistance of the insulation, m is the mass of the infant, C_{INFANT} is the specific heat of the infant, and $\frac{dT}{dt}$ is the change in temperature with respect to time.

The final design should fulfill our time and temperature management requirements, and the initial step in that process is validating our choices with the model above. Other possible sources of radiation heat transfer and free convection from the infant are ignored and only one dimension is considered, but the items modeled above represent the major components of the thermal circuit.

Empirical Testing

The simplest competent model is used to evaluate our thermal management options of insulation only, an exothermic reaction, and a phase change material. In order to do this, the test set up shown in Fig. 2 is used.

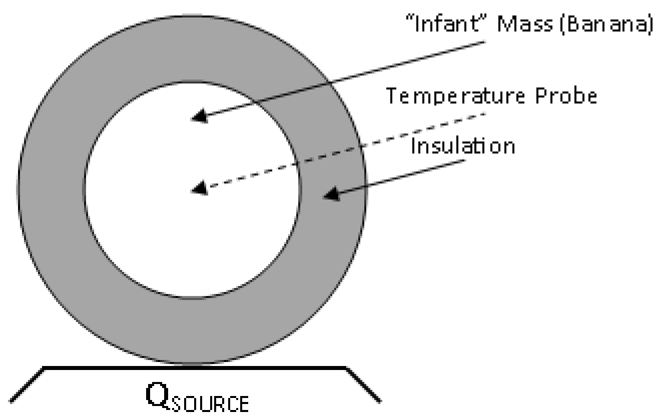


Fig. 2: Test set up to evaluate the degree of thermal management each material provides when the incubator function is utilized.

It consists of a heat source, if there is any, the insulation jacket, the approximation of the infant, the insulation jacket again, and then the surrounding atmosphere. A one dimensional thermal circuit analysis is used to evaluate the results of the test which will consist of a temperature profile of the center of our "infant's" mass over time. Fig. 3 displays the shapes of our anticipated results on a graph. We believe this is a sufficient experiment to test our thermal circuit.

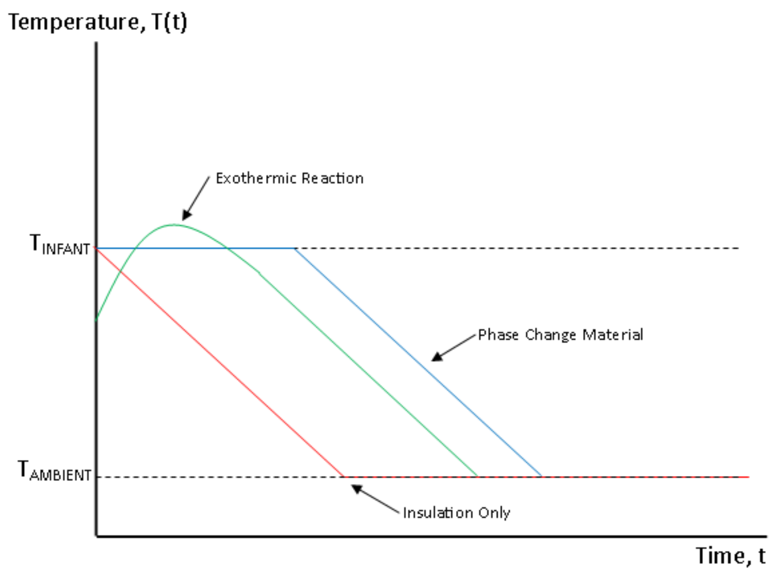


Fig. 3: Anticipated results of the three different thermal management evaluations

The thermal management options can be compared and contrasted against other design drivers such as ergonomics, mass, and set up time to determine the best design to move forward with.

Integrated Shirt Design

Table 1: The risk analysis of the integrated shirt is summarized.

Item	Function	Potential Failure Mode	Potential Effects of failure	Sev
Front Pocket	1. Support weight 2. Support skin-to-skin contact	1. Pocket is broken 2. Pocket is partially broken	1. Lost supporting force 2. Infant position changed	9 8
Back Pocket	Store insulation pack	Pocket is broken	Insulation pack falls off	9

Item	Potential Causes	Occ	Current Design Controls	Det	R.P.N.
Front Pocket	1. Baby falls off 2. Skin-to-skin contact was disabled	1 2	1. Durability Test 2. Durability Test	1 1	9 16
Back Pocket	Incubator mode is disabled	1	Durability Test	1	9

There are two main parts in our integrated shirt design: the front and back pockets. According to the Failure Modes and Effect Analysis, all of our Risk Priority Number are much smaller than 30 which agrees with the requirements set. Both of the pockets are sewn onto the shirt so durability test will be run. Other materials aside from the currently used cotton will be analyzed for their durability to determine the ideal material to use for the final product.

Discussion

We believe the fundamental core of our design hit the mark. At the most basic level, we needed to create a device that promoted Kangaroo Mother care and allowed incubator functionality if the parent and child needed to be separated. Our device fulfills both of these functions. However, as we dive deeper into how we achieved this functionality, this is where you can unearth some room for improvement. Most notably, the black support strap chassis that is in place to support the child. This is something that we think could be greatly refined by someone much more experienced in clothes manufacturing. Something like an integrated Teflon strap inside of the shirt could suffice while taking up much less room. At this point it would also be appropriate to try and distribute samples to low resource settings to get some feedback on the project, now that there is a viable prototype for comparison. I think pursuing these two items would get you very close to a complete and final product that fulfills all of your needs.

Information Sources and Reference List

REFERENCES

1. "Preterm Birth." WHO. World Health Orginazation, n.d. Web. 24 Jan. 2015.
2. Cattaneo, Adriano, Riccardo Davanzo, Nils Bergman, and Nathalie Charpak. "Kangaroo Mother Care in Low-income Countries." Journal of Tropical Pediatrics 44 (n.d.): n. pag. Web.
3. Zahorsky, John. Baby Incubators, a Clinical Study Of The Premature Infant. N.p.: Courier of Medicine, 1905. Print.
4. Garg, Pankaj, Rajeev Krishak, and D. K. Shukla. "NICU in a Community Level Hospital." The Indian Journal of Pediatrics 72.1 (2005): 27-30. Web. 24 Jan. 2015.
5. Sienko, Kathleen. "Hybrid Infant Warmer meeting." G. G. Brown Building, Ann Arbor. January 15, 2015. Meeting.
6. "Neuroscience." Kangaroo Mother Care. Webmix, n.d. Web. 22 Jan. 2015.
7. Greenslade, Leith. "Hybrid Infant Warmer Sponsor meeting." James and Anne Duderstadt Center, Ann Arbor. January 19, 2015. Teleconference.
8. PATH, comp. "Newborn Thermal Care Devices: Establishing a Value Proposition for Low-Resource Settings." (2009): n. pag. Web. 24 Jan. 2015.
9. Chen, Jane, Linus Liang, Rahul Panicker, Razmig Hovaghimian, and Naganand Murty. System and Method to Regulate Temperature. Embrace, assignee. Patent US20120330388 A1. 4 Sept. 2012. Print.
10. Sienko, K. (2011, April 8). Kathleen Sienko: medical devices for resource-limited settings [Video file]. Retrieved from https://www.youtube.com/watch?v=xxB-vAVYd7o
11. Thairu, L., M. Wirth, and K. Lunze. "Innovative Newborn Health Technology for Resource-limited Environments." Tropical Medicine & International Health 18.1 (2013): 117-28. Web.
12. Walen, Stephanie A. "Nonelectric, Standalone Heating Element for an Infant Incubator." (n.d.): n. pag. Web. 24 Jan. 2015.
<http://dspace.mit.edu/bitstream/handle/1721.1/74672/815525828.pdf>.
13. "NeoNurture." Design That Matters. N.p., n.d. Web. 24 Jan. 2015.

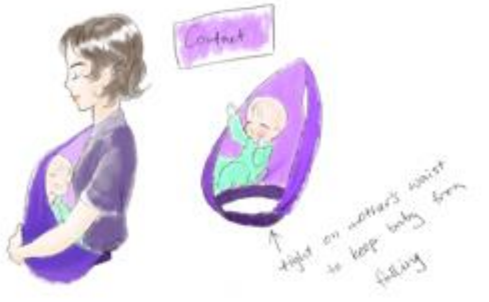
14. ASTM Standard F2236, 2003, " Standard Consumer Safety Specification for Soft Infant and Toddler Carriers," ASTM International, West Conshohocken, PA, 2003, DOI: 10.1520/C0033-03, www.astm.org
15. ASTM Standard F2907, 2003, " Standard Consumer Safety Specification for Sling Carriers " ASTM International, West Conshohocken, PA, 2003, DOI: 10.1520/C0033-03, www.astm.org
16. Oslo, Synnøve Stave, and Tore Mortvedt Oslo. Front Baby Carrier. Stokke AS, Skodje, assignee. Patent US D714,045 S. 21 July 2012. Print.
17. Muehlen, Vivian. US20140299639 A1. Vivian Muehlen, assignee. Patent US20140299639 A1. 21 Oct. 2013. Print.
18. Baby Product Safety Tips. N.p.: U.S. Consumer Product Safety Commission, 2009. Print.
19. "The MOBY Wrap." MOBY Baby Carriers. N.p., n.d. Web. 24 Jan. 2015.
20. "Wrapyourbaby.com." - Cultural Babywearing. N.p., n.d. Web. 24 Jan. 2015.
21. "KangaCarrier Shirt." KangaCarrier Shirt. N.p., n.d. Web. 27 Jan. 2015.

Appendices

Drawings

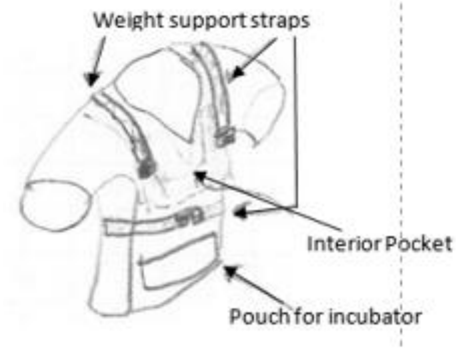
Carrier Styles

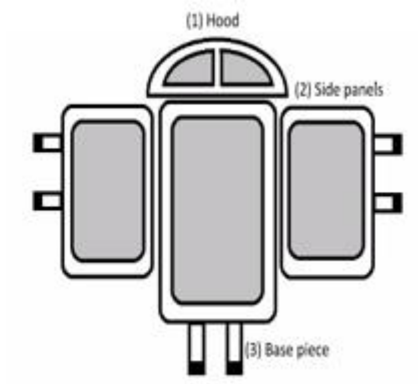
Sling



Detachable Carrier

Kanga Carrier Shirt





Manufacturing Plan

Integrated Shirt

Table 2: The manufacturing process for the integrated shirt along with the tools used.

Raw Material Stock: **T-shirt, cloth**

Step #	***Process Description***	***Tool(s)***
1	Measure and cut out a rectangle from the cloth that spans the chest of the t-shirt	Scissors
2	Sew the rectangle to the inside of the t-shirt, leaving space for the infant to lay in	Sewing machine
3	Measure and cut out a rectangle from the cloth for the back pocket	Scissors
4	Sew the rectangle to the bottom back outside of the t-shirt, leaving space for the insulation material to fit in	Sewing machine