DESIGN AND DEVELOPMENT OF A PEDIATRIC WHEELCHAIR WITH TILT-IN-SPACE SEATING

by

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The Pediatric Adjustable Lightweight Modular (PALM) wheelchair project consisted of three design iterations, full-scale working prototypes, durability testing and user evaluation, and technology transfer activities. User input was crucial to developing design requirements. A handful of concepts developed for this design are novel in the wheelchair market and potentially beneficial to pediatric wheelchair users and their caregivers. Some of the concepts could be applied to other wheelchair designs in the future, including adult tilt-in-space wheelchairs and seating for both adults and children.

The PALM's primary construction consists of modular plastic injection molded components and straight tubes. This feature allows it to be easily customized on site by a therapist who can swap components and make adjustments. The modular design also allows it to be packed more compactly thereby decreasing manufacturing and shipping costs. Second, the tilt-in-space mechanism utilizes a unique four-bar linkage design that decreases the need for small moving parts such as rollers and spring loaded mechanisms used in other tilt-in-space center-of-gravity chairs. Third, the PALM's modular design allows for greater flexibility in the configuration of the wheelchair and adaptation to different-sized bodies. Fourth, the PALM is highly adjustable and selectable: The seat depth, seat width, back rest height, back rest angle, leg rest angle, footrest angle, seat-to-floor height, and axle position are all adjustable. Finally, the PALM converts from an attendant-style wheelchair to a self-propelled wheelchair. These features create a variety of characteristics that clearly distinguish the PALM from other currently available pediatric wheelchairs.

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PREFACE

The PALM (Pediatric Adjustable Lightweight Manual) wheelchair project was conceptualized as part of a larger project, the "India Wheelchair Project," intended to improve the quality of wheelchairs available in India. [1,2] That project consisted of three parts; the design and technology transfer of an adult manual wheelchair, a power wheelchair, and a manual pediatric wheelchair. The India wheelchair work was funded collaboratively by the United States government via NIDRR (National Institute on Disability and Rehabilitation Research), the National Science Foundation (NSF) and the Indian government. The work was a collaborative effort between the Human Engineering Research Laboratories (HERL is a joint wheelchair research lab between the University of Pittsburgh and the Veterans Affairs Healthcare System) and ALIMCO (the Artificial Limbs Manufacturing Corporation of India, a government funded manufacturer of assistive devices). The first phase of the India project, the adult manual wheelchair, was developed and transferred to ALIMCO with some degree of success. However, through the process of developing the pediatric wheelchair, the project took a slightly different turn.

While designing the pediatric wheelchair for India, the design team came up with a handful of unique ideas that could potentially benefit users in India as well as in a developed country such as the U.S. One year into the pediatric wheelchair development, funding and commitment in both countries waned and it became necessary to seek additional funds. At this point the team sought SBIR (Small Business Innovation Research) funding from NIDRR to develop the pediatric wheelchair design into a product for the U.S. market. While the original concept of a wheelchair for developing countries was not abandoned, that focus of the project was temporarily put on hold.

The work described in this thesis first covers the need for pediatric wheelchairs worldwide and the complex needs of pediatric wheelchair users and their caregivers. The thesis chronologically follows the development of three wheelchair prototypes, from design work done

specifically for the Indian context through final revisions done for a U.S. company, Three Rivers Holdings, LLC. This paper ends at the final development stage before the design reached the pre-production stage.

I would like to acknowledge the help I received over the course of this project from all staff, students and faculty at the Human Engineering Research Laboratories, especially, Dr. Rory Cooper, Mark McCartney, Jeremy Puhlman and Jonathan Pearlman. Other key participants to this project's success were David Boninger and Chris Willems at Three Rivers Holdings, with whom two SBIR grants were written to fund this endeavor. I would also like to thank the UPMC Center for Assistive Technology who allowed us to use the clinic space for focus groups. I gratefully acknowledge the participation of the subjects; children, parents, and clinicians who shared their creativity and enthusiasm with the project team. Lastly, this project would not have been possible without funding from NIDRR, NSF and the Department of Veterans Affairs.

1.0 BACKGROUND

The main drivers for the design were; feedback from the end-users, analysis of existing products and literature on pediatric wheelchair users.

A key consideration in the design of any product is the end-user. In the realm of consumer products, end-users often determine the success or failure of products by their willingness to purchase. Therefore, many products attempt to appeal to the sensibilities of the end-users. However, in the case of assistive technology for people with disabilities, often an insurance company rather than the end-user purchases the product. Consequently, design is often performed with the bottom line of the insurance payer paramount, healthcare provider recommendations secondary, and user needs relegated to the bottom of the priority list. This can have negative consequences for the end-users of assistive technology. In best case scenarios, an assistive device can become an extension of the body. [3,4] It can become something that users rely heavily on to perform even the most basic activities of daily living as well as a tool with which to achieve life goals. In the worse case scenarios, a device can become not only a source of frustration but can also lead to injury and secondary disabilities if improperly fitted or inappropriately prescribed.

Looking at user needs expands designers' technical understanding of the design problem and potentially heightens their empathy for the user. [5,6,7] In assistive technology design, understanding user needs is paramount. Device designs which do not consider the users' needs are likely to be misused or abandoned. [8,9,10] A goal of this project was to get feedback on the design from pediatric wheelchair users, their parents, caregivers, and clinicians during the early phases of product development through focus groups. In doing this, it is hoped that the end product will be easier to use, more therapeutic, more appealing and provide a product development model for assistive technology.

The end users of this design are pediatric wheelchair users, their parents, and caregivers. The term “pediatric wheelchair users” covers a broad spectrum of children with disabilities. The PALM design aims to meet the needs of those children who, due to cognitive state and/or physical disability are unable to independently shift their weight and transfer, may be unable to maintain an upright posture and may be unable to communicate or ambulate and are therefore highly dependent. Due to these disabilities, they may be at a high risk for secondary disabilities, such as decubitus ulcers and postural deformities. Conditions such as severe cerebral palsy, muscular dystrophy, mental retardation, and high-level spina bifida can lead to development of this level of disability. Although the child is the primary end-user of this equipment, their parents and caregivers are likely to perform tasks such as seat adjustments and transportation. Therefore, their needs are crucial to consider as well.

1.1 WORLDWIDE NEED FOR PEDIATRIC WHEELCHAIRS

In the United States, there are over four million children under the age of 18 with disabilities, and more than 10% of this pediatric population, or over 400,000, have physical disabilities such as paralysis, Cerebral Palsy, or orthopedic impairments that may require the use of a wheelchair.[11] Internationally the need for pediatric wheelchairs is significantly higher, particularly in developing countries where the population, poverty, and disability occurrences are higher. [12] In most of the world, poverty and disability go hand-in-hand. [13] There are 1.5 billion children worldwide living in low-income conditions and roughly 3.5 million of these children live in India. According to surveys conducted by the World Bank in the last ten years, 15 countries (including India) reported that at least 80% of the population earns below $2 USD a day. [14] Average yearly income is thus below $730 USD, rendering many families incapable of affording a wheelchair for a disabled child. Many of these countries do not have enough public medical funding programs (such as Medicaid in the U.S.). The Wheelchairs for the World charity that distributes wheelchairs worldwide reports that there are more than 21 million people in developing countries in need of wheelchairs but many adults in these countries earn less than $300/yr. [12] Charities, governmental, and non-governmental organizations comprise the majority

of wheelchair purchasers internationally. However, to the detriment of wheelchair users, most organizations purchase low quality depot-style wheelchairs because they are inexpensive.

The need for an appropriate wheelchair is even more severe for pediatric users. Many children who receive donated chairs end up with chairs that are much too big and have no room for growth adjustability. Some organizations provide adult-sized wheelchairs to children under the assumption that a child may only get one wheelchair in his lifetime. However, these donated wheelchairs often break or are abandoned because they are not usable. If used, these over-sized wheelchairs can lead to secondary disabilities because of poor fit.

Pediatric wheelchair users are distinct from their adult counterparts because they experience rapid physical growth and changing cognitive and functional skills. [15,16] Children also find themselves in a variety of environments, some of which may require dependant mobility systems in which they are pushed by others, while other environments may allow the child to self-propel their own wheelchair – an independence that is important to encourage in a growing child. [17-19] Finally, pediatric seating and positioning must address social and environmental demands unique to children while also minimizing the risk of secondary injuries such as pressure ulcers and postural deformities. [20]

It is not only in developing countries where the unique needs of pediatric wheelchair users have been underserved. Although adult manual wheelchairs have improved dramatically over the past two decades, innovations designed specifically for the pediatric population have been lacking. This is, at least in part, because research and development efforts have focused much more on independent adult wheelchair users than they have on children and their caregivers. [21] In addition, expert adult wheelchair users were the driving force behind the wheelchair design revolution. [22] When no existing products were sufficient to meet their needs, people began designing and building custom products, started wheelchair manufacturing companies, and the wheelchair design revolution was born. Naturally these products filled a gap for these active and educated wheelchair users through creating ultra-light manual wheelchairs, racing wheelchairs, and other sports chairs. Although some innovations from developments in this industry have been applicable in pediatric wheelchair design, a child's chair should rarely be just a miniature version of an adult chair. This, combined with the smaller market need in pediatric wheelchairs, means that the design of children's chairs has lagged somewhat. This is especially true for those children who have severe mobility disabilities, are highly dependent and

need highly supportive wheelchairs. The purpose of this project was to address this gap through the research and development of a manual pediatric wheelchair specifically designed to meet the complex needs of a growing child and his caregivers.

1.2 EXISTING PEDIATRIC WHEELCHAIRS

Key terms used in reference to seating and mobility:

Tilt-in-space: Tilting seat in which the hip and knee angles remain fixed, while the seat tilts posteriorly or anteriorly. This type of seating preserves postural alignment while changing the orientation of the body to gravity. [23]

Center-of-gravity tilt: A tilting system in which the user's center of gravity remains relatively stable while tilting. This allows for a shorter wheelbase and more stable chair. F**igure 1** illustrates the problem that arises when the seat is tilted posteriorly without a simultaneous shift forward. This leads to the center of gravity moving up and back.

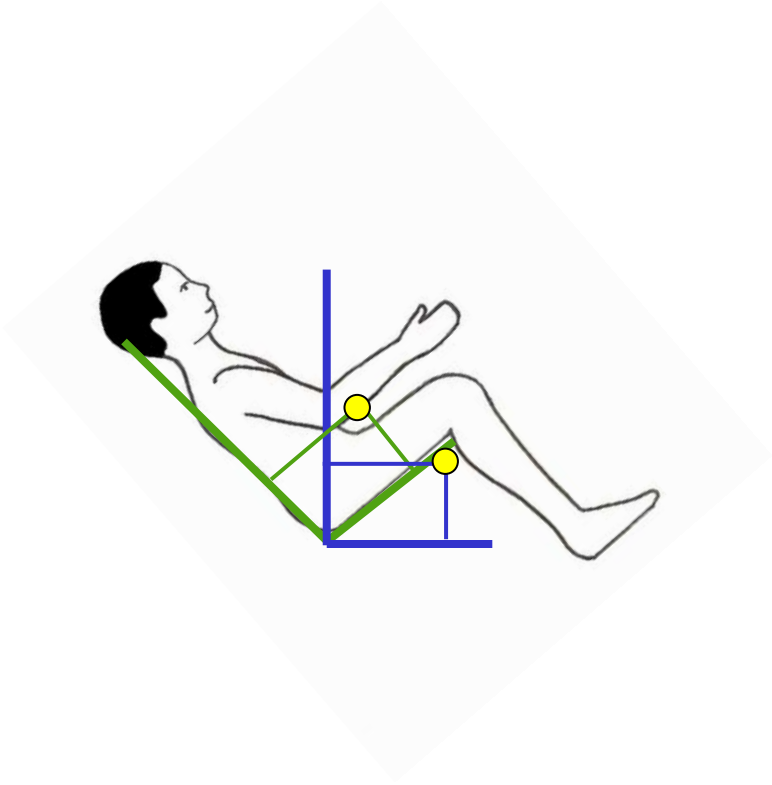


Figure 1: Tilting seat posteriorly without shifting seat forward results in the center of gravity moving up and back.

Pediatric wheelchairs fall into the following categories: power, power-assist, manual, attendant propelled, hybrid, tilt-in-space, and strollers. This research and development effort focuses on hybrid, manual, attendant-propelled, tilt-in-space, and strollers. Hybrid wheelchairs combine multiple functions into one wheelchair. They may be able to adapt to different environments, with a removable seat that can be used on a feeder chair base, jogging stroller, or tilt-in-space frame. One example of this kind of wheelchair is the Thomashilfen EasyS rehabilitation stroller (http://www.thomashilfen.de/easys/index_english.htm). Designs such as this are interesting in that they reflect the reality that children perform many different types of activities in different environments and may require different chairs in order to adapt to the different environments.

Many manual, tilt-in-space pediatric wheelchairs are currently on the market. However, as noted, all of these chairs have limitations. **Table 1** describes some popular products on the market in the U.S. and points out their unique features and limitations.

Currently the average cost of a pediatric, tilt-in-space wheelchair is $1700-$3000. Pediatric wheelchairs with additional features to accommodate comfort, ease of transportation, and growth adjustability have an increased price range of $2200-3000. The weight ranges of tilt-in-space wheelchairs usually fall between 40-50 pounds with standard components (See **Table 1** for comparisons). An example of a pediatric chair that has both positive features and limitations is the Solara by Invacare. This widely prescribed chair minimizes change in the center of gravity through its 45° range of tilt allowing for a smaller wheelbase while maintaining stability. However, the Solara costs upwards of $2100 and is heavy at 43 lbs. The Solara Jr., a lighter weight model, costs upwards of $2700. Lighter tilt-in-space strollers are available but typically cannot be adapted for self-propulsion and often do not have enough adjustability to accommodate complex seating needs. Strollers are a frequent choice for parents of young children with disabilities. This is due to several reasons; 1) they are “normal” in appearance, 2) they are lightweight and easily folded, 3) they are inexpensive. [24] However, the most portable strollers typically have sling seating and are not usually supportive enough for children with mobility disabilities and are inappropriate for long periods of sitting. [24] “Adaptive” strollers have the more appealing stroller aesthetic but have supportive seating for children with disabilities and are a better option than a standard baby stroller. However, these strollers may not be appropriate

for a school environment and may not have tilt-in-space seating and other features important in a truly accommodating mobility system. [25,26]

Table 1: Examples of currently available pediatric wheelchairs

Product	Unique features	Short comings	Weight (lb.)	Cost (USD)
Invacare Orbit	Detachable seat frame	Bulky frame, heavy, center of gravity change, institutional aesthetics	45	1916
Kid Kart	Folds, reversible seat direction	No self-propulsion capability, center of gravity change	34	1605
Invacare Solara Jr.	Stable center of gravity, light weight	institutional aesthetics	29 (Without seating or footrests)	2754
Otto Bock Kimba Pediatric (stroller)	Spring shocks/ Articulating leg rests	Stroller is not appropriate for older children, center of gravity change, institutional aesthetics, not collapsible	36	2800
Sunrise Zippie Pediatric TS	Adjustable Depth/ Angle footrests	Bulky frame, heavy, center of gravity change, institutional aesthetics	49	1689
Invacare Spree XT	Compact for easy moving and adjustability	Center of gravity change, institutional aesthetics	29 (Without seating or footrests)	2895

1.3 UNIQUE NEEDS OF PEDIATRIC WHEELCHAIR USERS

1.3.1 Physical growth and change

Children grow rapidly and are in need of wheelchairs with growth adjustability. [16] Most young children, regardless of disability, will experience dramatic changes in size, cognitive, functional and social skills over time. Changing function for children with disabilities may stem from

rapidly progressing diseases, an improving condition due to rehabilitation, medical intervention or normative developmental changes.

Most pediatric wheelchairs fulfill the adjustability requirements for seating as the child grows, yet fall short when changes must be made to accommodate changing function. In order to accommodate rapid changes in growth and function experienced by pediatric wheelchair users, the wheelchair needs to be either frequently replaced or the wheelchair needs to be able to adjust and grow with the child in both size and function. Using an improperly fitted chair which has been outgrown can further impede physical and cognitive development and will likely increase the risk for secondary injuries such as pressure ulcers. [17,18,19,20] The economic cost of frequently replacing a wheelchair is out of reach for most middle- and low-income families. In most states Medicaid will only reimburse wheelchair users for the cost of a new wheelchair about every three years. [26] Importantly, to address these changes, frequent wheelchair replacement is cost prohibitive and brings with it the challenges associated with repeated adjustment to a new wheelchair.[4] Thus, frequent replacement of the wheelchair is far from an optimal solution. Without replacing the wheelchair, this can only be achieved through highly adjustable components and/or modular multi-sized components. The adjustments are often cumbersome, difficult to adjust, and add excess weight to the chair. This problem represents one of the main challenges in pediatric wheelchair design.

1.3.2 Mobility

For children with mobility disabilities, effective mobility can be provided by power, power assist, manual self-propelled, or manual attendant propelled wheelchairs. This research investigates the option of manual and manual attendant-propelled wheelchairs which are typically used for younger children or those who are incapable of operating a power chair. However, in cases where children clearly cannot self-propel a manual wheelchair but have the ability to control a power chair and a medical reimbursement can be obtained, then the child will typically receive a power wheelchair. In cases where a power wheelchair is not an option (because of cost or ability limitations), a manual attendant-propelled chair is a reasonable alternative.

Whether or not a child is able to self-propel a manual wheelchair may vary over time and the environment of use. Because the child's ability and environment are always changing these changes will affect the extent to which manual self-propulsion is an option. To maximize opportunities for self-propulsion and to accommodate changing abilities and changing environments, a manual pediatric wheelchair with the capability of easily converting from an attendant-style wheelchair to manual self-propelled chair, could fill this gap. [17-19] For a child who is capable, having the option to propel or adjust his/her location and orientation independently is critical.

1.3.3 Self-sufficiency of child

Research conducted in the psychology discipline has uncovered substantial evidence of the need to feel in control of one's environment. [27] This need for a sense of control could be especially acute in children with disabilities. If self-sufficiency and independence are not encouraged whenever possible, then existing disabilities may feed into additional developmental deficits in learning and communication. [28] On the other hand, when independence and self-sufficiency are encouraged, it may help to facilitate exploration and stimulate intellectual growth. [17-19] Thus, a pediatric wheelchair should be designed to maximize the degree to which the user feels in control of his/her situation; whether this means propelling the chair, adjusting the seat, or manipulating some aspect of his wheelchair environment. This demands that the features of the wheelchair are easy to use and that the methods for adjustment or manipulation of the wheelchair are transparent. The ability of a child to perform tasks and make choices must be encouraged in order to avoid the consequence of "learned helplessness." [29] Some dependent mobility chairs are now being offered with a power tilt function. This power tilt can be operated with a simple push button and allows the user to have control over their sitting position even if they are unable to operate power mobility. Power seating can also be used as a precursor to power mobility. As with all add-on features though, the caregiver must make a trade-off decision, because a power actuator adds weight to the wheelchair. Wheelchairs that can be positioned to allow for independent or assisted transfers, as opposed to fully dependent transfers, give a degree of independence to the rider. In many cases, cognitive disabilities are the main barrier to self-

sufficiency. In the event that a child is able, the wheelchair should provide a means to independent activities.

1.3.4 Comfort and enjoyment

Comfort is a key feature to functionality for both adults and children. Comfort facilitates one's ability to focus, learn, and explore. Conversely, discomfort may lead to abandonment of the wheelchair, which adversely affects rehabilitation and may lead to further injury.[10] Not surprisingly, research indicates that highly adjustable wheelchairs are perceived as more comfortable than those that are less adjustable.[4] Comfort is also important for the caregiver who needs to take the chair apart, transport and push it.

Comfort is not only physical, but also psychological. The child and parent should be able to "feel good" about the wheelchair – that it be seen as a vehicle for exploration of the world. Without aesthetics and features that "speak" to a child's need for comfort and exploration, a child may feel trapped in the wheelchair. As one of the primary means by which a child with a disability may explore their world, the wheelchair must help promote development, learning, growth and health, rather than act as a barrier. Aesthetics can cause a parent to choose one wheelchair over another.[24,9,10] The ease with which a parent pushes, adjusts or transports a wheelchair will often determine what wheelchair is purchased. Good design not only facilitates ease of use but also addresses the need for an aesthetic which a parent and child can feel content with. Good design can minimize the stigma associated with disability in most societies and in the current trend of rapid technology acceptance; design can transform assistive technology into desirable technology. [24,7]

1.3.5 Seating

Children who, due to diagnosis or age, are unable to independently shift weight and relieve pressure are at risk for the development of decubitus ulcers.[20] The tilt-in-space manual wheelchairs currently available are often very bulky, scaled-down versions of adult chairs. To further prevent the development of secondary disabilities and deformities, a pediatric wheelchair must also accommodate different degrees of supportive seating. The seating should also be

dynamic, allowing for tilt and in some cases recline. Good seating postures can improve breathing, eating, digestion, circulation, and cardiovascular function. In an ideally designed pediatric chair, both caregiver and child (if appropriate) would be able to adjust the dynamic seating. Additional features, such as seating systems that can attach to both manual and power bases or manual chairs with detachable power modules, are also beneficial. Any added flexibility built into a design can potentially benefit a child who may be able to take advantage of the features.

Tilt-in-space seating is also useful for transfers, easier toileting, feeding, breathing, and napping as well as stability during propulsion down hills and over rough terrain for children who can't stay upright.

Due to the complexity of postural deformities that can arise in children with mobility disabilities, a wide range of seating adjustments is needed. These postural deformities include; scoliosis, which can occur when the pelvis has an asymmetrical position over time, contractures which can be caused by long-term sitting in one position without change, or if the child is seated in a way that keeps the body tense and flexed for long periods.[30] A wide range of postural supports must be available for selection by a seating and mobility specialist. These supports are used on the wheelchair seat based on the specific needs of the user, disability type, postural condition, and medical treatment plan. A range of supports must be available for the clinician to choose from in order to build a truly accommodating seat. They include; lateral trunk supports, hip guides, head rest, lateral thigh supports, armrests, and abduction block. [24]

Straps and belts can be dangerous to the child if not used properly and therefore more adjustability and flexibility in seating supports is desirable. Restraints are sometimes used to maintain posture or to keep a child in the chair; however, these restraints can cause discomfort leading to restlessness, concentration problems, and often the restraints do not aid the underlying postural problems. [30] In some cases, straps and restraints can be dangerous. Butterfly harnesses have led to some cases of strangulation. [31,32] A wheelchair that can accommodate highly specialized off-the-shelf seating components is likely to be most prescribed for children with highly complex seating needs.

1.3.6 Transportation of wheelchair and child

A well-designed pediatric wheelchair must be easily and safely transportable. Just as able-bodied children must wear seatbelts for safety while traveling in cars, children who use wheelchairs must be secured either within their wheelchair which in turn is secured to the vehicle, or they must be secured in a passenger seat for safety. [33] Wheelchairs that comply with the wheelchair transportation safety standards are equipped with securement anchorage points and are crash tested according to the standards. [34] These standards are voluntary; therefore many wheelchairs do not comply with the standard. However, because a large number of pediatric wheelchair users ride buses while seated in their wheelchairs, transportation safety is likely to be a large factor in deciding which wheelchair to purchase. [35]

The ability for a wheelchair to be safely secured within a bus is just one feature of transportability. Unfortunately, the extra material needed on a wheelchair in order to make it crashworthy is also likely to add substantial weight to the chair making it harder for a caregiver to lift and transport in a passenger vehicle. The transportability of a wheelchair is also determined by the ease with which a caregiver can transfer the child from the wheelchair, collapse the wheelchair, and store it in a vehicle as cargo.

In some cases, the wheelchair seat may be removed and used as a car seat. This requires that the seat meet federal motor vehicle safety standards. In some regards, this is a good concept; however it has two main limitations. First, car seats are typically built on a plastic molded shell, often with 90-90-90 seating which is rarely appropriate for long periods of sitting. [30] Car seats with reclining seat backs are preferable.

1.3.7 Consequences of inadequate pediatric wheelchairs

A wheelchair that does not accommodate a child's seating and mobility needs may have serious consequences in a variety of areas including chronic discomfort, increased risk for secondary injuries, and poor cognitive and social development of the child. Research indicates that improperly fitted, non-adjustable, wheelchairs increase the risk of acquiring decubitus ulcers, growth deformities and secondary disabilities, which in extreme cases, may lead to death. [36] Pressure ulcers are a common secondary injury among pediatric wheelchair users. [20] In addition

to the physical risks posed by an inadequate wheelchair, there may also be dramatic effects on the cognitive and social development of the child. A wheelchair that is unable to grow with the child may feed into a downward cycle in which existing disabilities feed into additional developmental deficits in learning and communication. [17-19,28] Improper seating for a child can mean the difference between good cognitive and physiological development and poor development. A wheelchair that ends up restricting mobility (due to poor fit and function) rather than facilitating ease of movement will have a negative impact on the cognitive, scholastic, and neuropsychological development of the child. [17-19] During the course of childhood, it is difficult to overestimate the seriousness of these consequences. [37]

2.0 STATEMENT OF PROBLEM

Many currently available pediatric wheelchairs fail to meet many of the needs of the pediatric wheelchair population and their parents and caregivers. Chairs that aim to meet these needs are often either bulky, cumbersome to adjust, or expensive. The driving purpose of this project was to create a pediatric wheelchair that meets the complex needs of the pediatric wheelchair user population and their caregivers. These needs include a tilt-in-space pediatric wheelchair that maintains a fixed center of gravity and is adjustable, lightweight, modular, ergonomic, easy to use, comfortable, durable, and lower in cost. A design such as this would not only benefit end-users, but could also be useful as a practical and affordable option in rehabilitation hospitals where depot-style wheelchairs are most commonly used and could make in-patient treatment and transition to out-patient care more healthy and comfortable. In addition to enriching the U.S. pediatric wheelchair market, this product could also benefit the international wheelchair market, particularly in developing countries where there is a great need for high quality low-cost wheelchairs.

3.0 AIMS

The overall aim was to create a pediatric wheelchair that meets the complex needs of the pediatric wheelchair user population and their caregivers. In order to do this, focus groups and research needed to be carried out in order to understand these complex needs.

This project consisted of three phases. The first phase, the “India PALM” was a proof-of-concept phase consisting of design and prototyping. The India PALM model had many functional problems but served as a good basis on which to build the second phase, the “U.S. PALM.” The India PALM model was presented to clinicians and manufacturers in India for feedback. The U.S. PALM model was a more refined development model and was used for durability and fatigue testing and focus group evaluations in the U.S. The objective of the third phase, the “Final PALM,” was to further refine the design based on the earlier phases and to develop a more aesthetically resolved prototype that is closer to a pre-production model. A focus group was conducted to gain feedback on this third stage of the design.

Figure 2: Iterations of the design: Phase 1 (India PALM) Phase 2 (U.S. PALM) & Phase 3 (Final PALM)

4.0 WORK PLAN

All design and prototyping work was done in-house at HERL utilizing the machine shop. Testing was incorporated throughout the process. The following flow chart **(Figure 3)** illustrates the design process used. The description of this project flows chronologically, starting with the India PALM, followed by the U.S. PALM and ending with the final PALM. A subsection will go into more detail about the design and prototyping process.

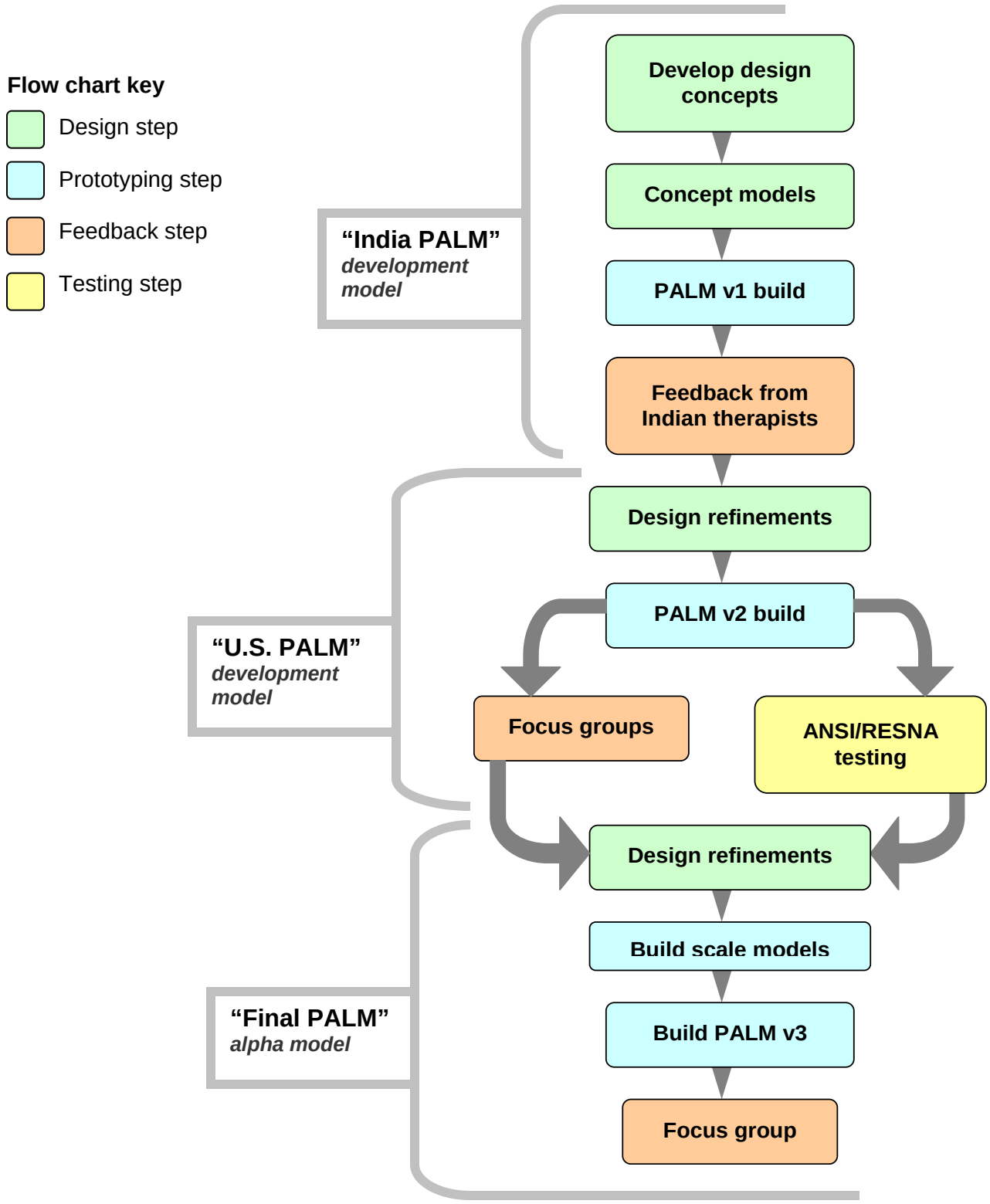


Figure 3: Flow chart describing work process

4.1 DESIGN PROCESS

The process of designing the PALM was an iterative one, with each model building and improving on the last. Each prototype was appropriate for its product development stage. This section covers the types of prototypes used at each stage and their purposes. Each type of prototype is defined first, followed by an example from the PALM process. All the models contributed to the problem-solving and design process. Although the PALM project has not been carried through the final stages, this outline will explain the logic of the design process. Depending on the complexity of the project and the experience of the design team, some steps may be skipped, but by following through with each level of modeling, the end product will have fewer glitches and the process from start to finish will likely be more efficient and less costly.

Concept models: These models are made using simple methods. The model typically focuses on only one aspect of the design or on the overall concept. The purpose is to communicate a concept rather than details. Concept models can be made throughout all stages of the design process.

Figure 4: CAD model

Figure 5: SLA concept model

The design was conceptualized on paper first using hand sketching (**Figure 6 & 13)**; these concepts were then further detailed using CAD (computer aided design) software. Solidworks™ was used to design and test the four bar linkage tilt mechanism for interferences. Concept models were made using Stereo Lithography (SLA) rapid prototyping.

Developmental prototypes: The purpose of these prototypes is to demonstrate a "proof-of-concept" and for internal testing. Rather than the kind of final testing procedures performed on a product before it goes to market, this testing serves as a problem-solving step and is used to

further develop and optimize the design. Emphasis is placed on the functions of the prototype rather than on the look and feel.

The US PALM and Final PALM prototypes fall in this category. Fairly detailed CAD models were made of these wheelchairs; however, during the prototyping process, tweaking and spontaneous design changes were made in the machine shop. These prototypes served as test platforms for two key design concepts; 1) a modular design using plastic nodes to join straight tubes and 2) the four-bar linkage tilt mechanism. These concepts provided plenty of design challenge in themselves; therefore the challenge of designing a seating system was left for the next design phase.

Figure 6: Hand sketches from early concept stage to final stage

Figure 8: India PALM

Figure 7: US PALM

The India phase prototype was constructed from mild steel 1" OD, .049 WT tubing. The seat pan and footplate were CNC milled from black ¼" ABS plastic. The foot rest brackets were machined on the wire EDM (electrical discharge machining) from 14 gauge cold rolled mild steel. Other footrest components were machined on the lathe and CNC milled from 6061 aluminum. All other components are OEM components. Parts were drawn in Solidworks™ and then either hand-machined or exported into Feature Cam™ software for CNC milling or wire EDM machining. Rather than using injection-molded polyethylene components in the prototype stage, the plastic components in the India and US phases were machined from Delrin plastic. This allowed greater flexibility when components needed to be redesigned and machined. SLA

was impractical because the resin available at the time of prototyping v1 was too brittle to use in full-scale functional parts.

Between the first and second prototypes, some of the materials used shifted from mild steel to 6061 aluminum tubing and bar stock and Chromium-Steel Alloy (SAE 4130) seamless tubing. This was primarily because the PALM design was meant to be versatile enough to be manufactured using lower-cost materials in developing countries and higher-end materials in developed countries, all the while using the same injection molded components. In terms of prototype construction, the India PALM is closer to the materials that would be used in the developing country version and the final PALM is closer to that which would be used domestically. The final PALM was constructed from 6061 aluminum 1" OD, 0.60" WT tubing.

Industrial design prototypes: The purpose of this type of model is to demonstrate the look and feel of a final product. Its main purpose is for gaining feedback from users and stakeholders. The leap in imagination from concept and development model to a final product can be difficult for people who aren't designers or engineers. The industrial design prototype may not look exactly as the final product will; however, it conveys the sense of a final product. A three dimensional full scale model is indispensable for gaining input from users even if the prototype is not fully functional.

Alpha prototypes: This prototype has mostly full-features and can be used for internal testing. It may have some of the same materials and properties as the final product, but uses different manufacturing processes than would be used in full-scale production. For example, rather than using injection molding, rapid prototyping and soft-tooling would be used for plastic parts. Rather than stamping, CNC and EDM would be used for making sheet metal parts.

Figure 9: Final PALM

The final PALM prototype is somewhere between an industrial design and an alpha prototype. Because the previous development models did not focus on the seat design, the final PALM seating system is really in its first iteration, whereas the other areas of the wheelchair, the base and tilt system are more refined and closer to an alpha prototype.

The final PALM is constructed from aluminum tubing, machined parts and plastic components made using the Stereolithography (SLA) process and a resin with properties similar to ABS plastic. The parts weren't to be used for in-home-user trials or ANSI/RESNA durability testing, but were suitable for a focus group and give a sense of a final product.

Because the design was not fully resolved at this stage, SLA prototyping was appropriate. Selective laser sintering (SLS) is a rapid prototyping process yielding high resolution parts similar to those produced with SLA, however, higher strength materials are available. If the parts were to be made using SLS instead of SLA, the prototype could likely be durability tested and used for in-home trials, however, part geometries and design features should be fully resolved before this step is taken. Half scale SLA models were used to work out design details. **(Figure 10)**

Figure 10: Final PALM backrest and half scale experimental model made using SLA

Parts made for the final phase were intended to look like factory-made parts. Parts that would be made from stamped aluminum or steel in a full production stage were CNC machined from 0.0625" or 0.125" sheet aluminum and bent on the sheet metal brake. The resulting parts look similar to factory-made parts, even though each was individually crafted. **Figure 11** illustrates the process of CNC milling the aluminum sheet metal, the cut footplates, and the final powder coated part assembled on the wheelchair.

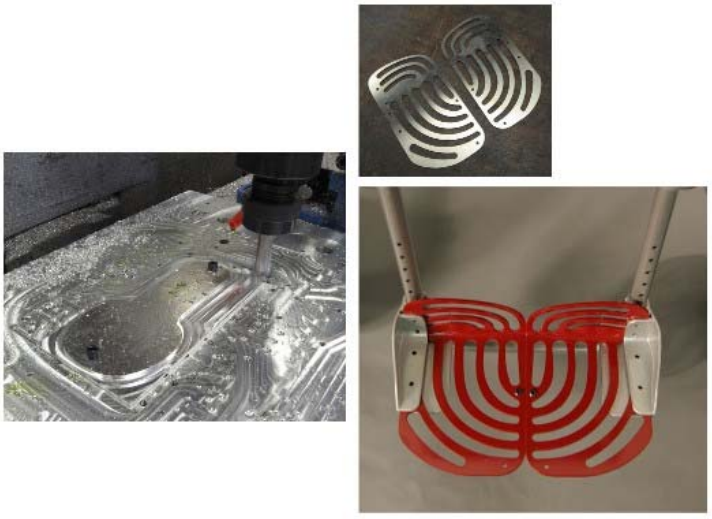


Figure 11: CNC manufacturing, cut part prior to bending and final product after finishing and powder coating

Figure 12: Images of SLA process. Vat in which parts are made, Unpainted SLA parts and SLA parts finished and assembled on final prototype

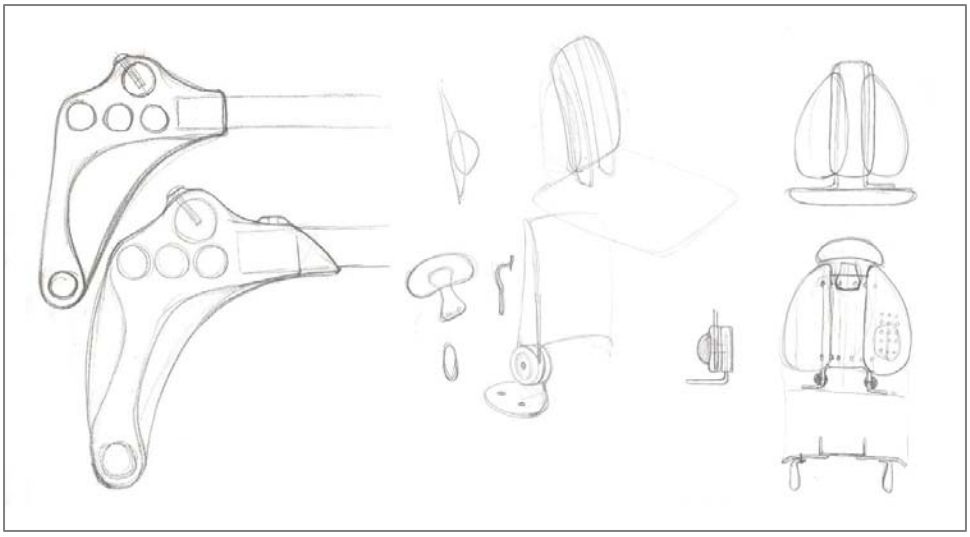


Figure 13: Hand concept sketches of rear plastic joints and backrest

Beta prototype: This prototype contains all the features of a final product. Comprehensive internal testing and external evaluation can be performed with a Beta prototype. It will likely use a combination of final production methods and rapid prototyping processes using material with equivalent properties to that which is necessary in a final product. For example, SLS could replace injection molding or even soft-tooling, if it is more cost effective. Testing in addition to finite element analysis (FEA) should be performed to ensure part equivalency between the different manufacturing methods. Beta prototypes, which should be durable and safe, can be used for take-home trials with users.

Pre-production prototype: This is the final step before a product goes to market. The prototype is manufactured using full production methods in small volumes. Whereas previous prototyping steps are intended to tune the design, this step is used to troubleshoot the manufacturing processes, assembly procedures, and identify any problems with production tooling. The short-run prototypes can be used for release to key customers.

5.0 INDIA PHASE

5.1 ANTHROPOMETRY

Anthropometric data for children with disabilities are unpublished; therefore dimensions of able-bodied children were used in this design. A large age range was chosen, 3-14.5, in order to accommodate most children and pre-teen wheelchair users. The PALM wheelchair is highly adjustable and selectable to accommodate this range of body sizes and accommodate a child weighing up to 50 kg. Although individuals are considered children until age 18 in the U.S., many teenagers are large enough to fit in adult wheelchairs. Wheelchairs with components capable of accommodating the full range of growth, through age 18, can add substantial weight to a wheelchair. In order to keep the wheelchair lightweight, it could be available in small and large sizes, each with a range of adjustability. **Table 2** indicates the anthropometric data used for the PALM wheelchair design. [38] **Figure 14** illustrates the ranges of adjustability built into the wheelchair based on the data.

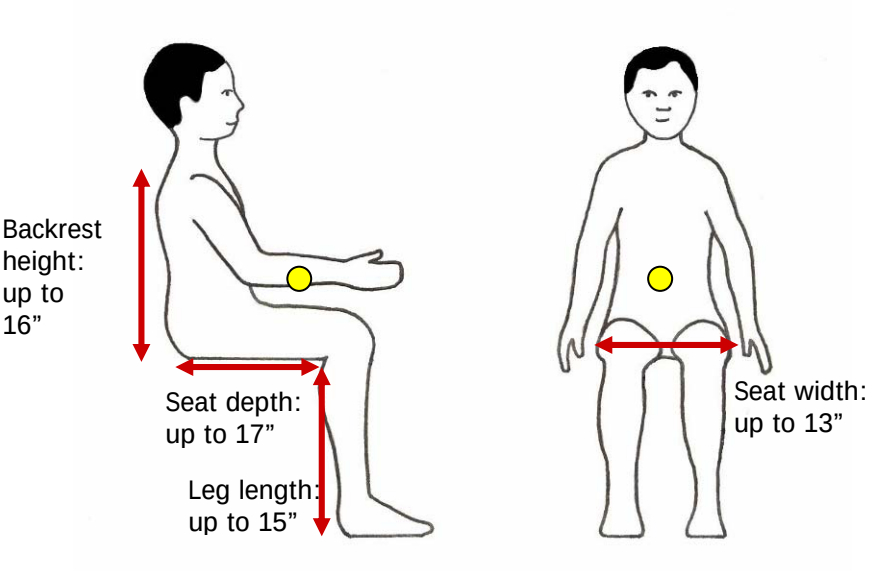


Figure 14: Illustration showing the range of growth adjustability built into the wheelchair based on anthropometric data

Table 2: Anthropometric data used to determine PALM range of adjustability. [38]

MEASUREMENT (male & female)	**RANGE OF MEANS**	
weight	14.1- 50.8 kg	31-112 lbs
max hip breadth (seated)	19.1- 31.1 cm	7.5-12”
max thigh breadth (seated)	19.2- 31.6 cm	7.5-12.5”
erect sitting height (seated)	54.4- 82.4 cm	21.5-32”
buttock-knee length	28.4- 54.3 cm	11-21”
knee height	27.0- 50.7 cm	10.5-20”
shoulder breadth	24.4- 38.6 cm	9.6-15”
foot length	14.7- 24.6 cm	6-10”
seated CoG (above seat)	20.1- 22.8 cm	8-8.5”
seated CoG (from back)	13.1- 22.8 cm	5-9”

5.2 INDIA PHASE DESIGN

5.2.1 Design criteria

Design criteria were determined based on research of existing products, informal discussion with seating and mobility clinicians, and literature review. Several design criteria were defined at the beginning of the India PALM project. These included:

1. **Tilt-in-space function with posterior/anterior tilt**

   Tilt-in-space seating is important to relieve pressure, improve posture, aid in feeding, toileting, napping and breathing. Anterior tilt aids children in performing standing pivot transfers and for performing activities when seated at a table.

2. **Seat adjustability; reclining seat-back, leg rest angle, foot plate height, seat depth**

   Seat adjustability is important for accommodating children's varying and growing body sizes as well as for achieving a comfortable body position throughout the day. Some adjustments must be performed frequently, while others may be infrequent.

3. **Exchangeable manual-propulsion and assistant-propulsion rear wheels**

   For children who are capable of self-propulsion, the option for a manual propulsion wheel is important, while other children who are unable to self-propel may benefit more from the durability and added cushion of a small diameter wheel with a thick tire.

4. **Adjustable manual-propulsion wheel axle position**

   For children who are capable of self-propulsion, adjustable axle position is needed to reduce risk of shoulder injury.

5. **Overall weight less than 40 pounds**

   Although this is quite heavy, the most realistic material for low cost production in India is low carbon steel, therefore, the wheelchair was expected to be heavy. This should be minimized as much as possible, and other materials such as plastic tubing could be evaluated for their feasibility in India.

6. **Collapsibility for transportability**

   In India, many people travel via train or bus, therefore the wheelchair should be collapsible to ease transport.

7. **Durability**

   The wheelchair should meet or exceed the durability standard set forth by the ANSI/RESNA wheelchair standards.

8. **Low cost**

   The Indian government provides $150 USD subsidy for people with disabilities who need wheelchairs and cannot afford one.

9. **Manufacturability in India**

   To keep cost low, the wheelchair should be made from local materials. In India, aluminum and alloy steels are quite expensive. By far the most common material is low carbon steel. Plastics and injection molding are available and because of their use in Indian prosthetics, they are a realistic choice for use in wheelchair manufacture.

5.2.2 Innovative concepts

The novel features of the PALM wheelchair can be broken down into two categories: 1) modular construction and 2) tilt-in-space linkage mechanism.

5.2.2.1 Modular construction

The wheelchair components consist of plastic injection molded modular components and tubing. All joints are connected without the use of welding. This greatly reduces the manufacturing costs and complexity compared to other tilt-in-space chairs on the market. The use of plastic modules allows the chair to break down into smaller units than comparable chairs on the market, thereby reducing shipping costs. This feature also allows the chair to be more easily customized on site because the therapist can select the size of parts.

Figure 15: India PALM prototype

In order to allow for growth and maintain a relatively lightweight frame, the modular design allows non-adjustable components to be removed and new properly sized components to be selected. If all components were adjustable, the wheelchair would have added weight and the adjustability would inhibit usability. The modular design allows for great flexibility in the configuration of the wheelchair and adaptation to different sized bodies.

A modular design provides the following benefits over an integrated design: 1) the wheelchair can be shipped as a kit-of-parts to be assembled on-site, thereby reducing shipping costs. 2) Should a component break, it can be swapped out and replaced, extending the life of the wheelchair. 3) The chair can be configured to meet the user's need, whether in terms of size changes or functional changes, allowing the chair to be lighter weight and more universal. Most pediatric chairs have a high degree of adjustability built in, which makes them quite heavy (many are 40 lbs and above). By replacing modular components rather than building all the growth adjustability into one integrated system, a modular design could accommodate the same breadth of human sizes but achieve an overall lighter weight. With a modular design this customization can be done on site rather than in a factory.

The plastic injection modules used in the PALM could reduce cost and increase flexibility by being used in multiple chair designs. The plastic injection molded components could be universal, whereas the metal tubes could be made of different metals. In a developing country, lower cost steel could be used whereas in the U.S. higher grade materials could be used. Use of the injection molded components further reduces cost and increases manufacturing precision by eliminating the need for weld jigs. The use of plastic nodes in this design minimizes

the use of tube bending and welding, thus reducing manufacturing complexity. In addition, the chair can change from manual-attendant propelled to push-rim self-propulsion.

5.2.2.2 Tilt-in-space mechanism

The tilt mechanism uses a four-bar linkage design **(Figures 16, 17).** The goal was to create a tilt mechanism that minimized the COG shift. This design decreases the need for small moving parts such as rollers and spring loaded mechanisms that are typically used in other tilt-in-space center-of-gravity chairs.

The tilt-in-space mechanism utilizes a four-bar type mechanism constructed from 0.75" aluminum tubing and plastic nodes. This mechanism allows the occupant to be tilted in the seat while minimizing a shift of the center of gravity. Although other chairs on the market use the concept of "center-of-gravity" tilt, none use a linkage such as this to achieve it. The linkage design decreases the need for small moving parts such as rollers and spring loaded mechanisms that are used in other tilt-in-space center-of-gravity chairs. In addition, the linkage mechanism is a lightweight, durable and low-cost design for a tilt-in-space system. The tilt locks via cable release and Mechlock,™ a common method used in commercial products.

Figure 16: Side view of India PALM in tilted position. Lines indicate position of four bars in linkage.

Figure 17: Side view of U.S. PALM. Improvements to linkage geometry were made between versions.

Figure 18 illustrates the process used to develop the tilt-in-space geometry. The sketch does not show the final linkage geometry, but illustrates the concept. The cross-hatched circle indicates the center-of-gravity (CoG). This point would not remain fixed due to the variation in body sizes among children; therefore, the goal is to keep the CoG relatively stable. The arc represents the tilt path if the seat is tilted around the CoG. Simple geometry methods were used to devise the optimal tilt geometry, the linkage arm lengths and the pivot points. The key constraint was that the linkage arms needed to be contained within the space beneath the wheelchair.

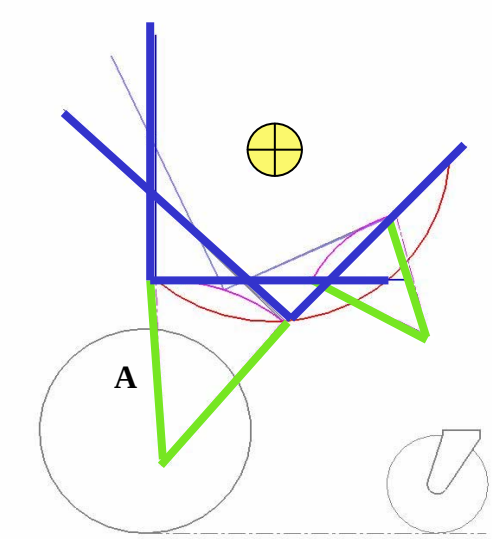


Figure 18: Process sketch of tilt mechanism

With varying body sizes and a dynamic child, it is impossible to predict exactly where the CoG will lie. Therefore the wheelchair was designed to accommodate a larger range of CoG positions. The effort required to tilt the seat was minimized by placing the arc of the rear linkage arm A **(Figure 18)** in an anteriorly tilted position. When the seat is tilted, the arm is in a position to allow an easy downward arcing tilt. The caregiver need only control the tilt as opposed to lift the CoG of the child.

5.2.3 Concept development

Initial concepts were developed using Solidworks software **(Figures 19)** and SLA prototyping. The India PALM prototype **(Figure 15)** was not tested to ANSI-RESNA standards or in a focus group. It was built as a development model for the purpose of design experimentation and as a point of discussion. Through the process of building and working with this model, features were identified for design improvements in the second version.

Figure 19: Initial concept drawings made prior to PALM P1 construction

5.3 INDIA PHASE CONCLUSION

To insure that the design was low cost and easy to manufacture, the India PALM prototype was presented to a wheelchair manufacturer in India, the Artificial Limbs Manufacturing Corporation (ALIMCO), and to the Indian Spinal Injury Center (ISIC), the leading rehabilitation hospital in India. The team visited ISIC and held a workshop with occupational and physical therapists in the clinic. During the workshop the team demonstrated the prototype and held an informal discussion using the prototype as a point of discussion. The clinicians offered many opinions on how the prototype could be improved. These opinions contributed to the design criteria for the next phase.

At this point commitment in India waned and funding changes required the team to seek funding and a partner in the U.S. in order to continue the work. Thus, the next phase of the project is “US PALM.”

6.0 U.S. PHASE

The US PALM was built as a second development model. It was an improvement over the India PALM which had many functional limitations. Based on the informal feedback from Indian clinicians and manufacturers as well as obvious design problems, the design was refined and the U.S. PALM was built. This version was evaluated formally in focus groups with clinicians in the U.S. and was tested to ANSI/RESNA standards.

Figure 20: US PALM prototype

6.1 U.S. PHASE DESIGN

There are several design criteria that differ between the U.S. and the Indian context. These differences in general terms are; materials, money, manufacturing, wheelchair prescription process, environment of use, and repairs. High-end lightweight materials such as aluminum, titanium, high carbon alloy steels and carbon fiber are impractical in most developing countries

and heavier low carbon steel is abundant. Using high-end materials in a U.S. product is almost a necessity for competitiveness and although they are expensive, medical reimbursements will typically cover the costs. These materials allow for a stronger and more lightweight product. The minimum expected level of quality in the U.S. is substantially higher than in India.

The environment of use in the U.S. and India are quite different. The U.S. environment is fairly accessible with flat pavement, school buses with lifts, cars with large trunks and mostly accessible public buildings. Although the Indian environment of use can be very hard on wheelchairs, an active wheelchair user or active caregiver in the U.S. will likely want a wheelchair that can be taken in the grass, over rough terrain in parks, cracks in the sidewalk and potholes. Therefore, the stresses imposed on the wheelchair are likely similar to those of a wheelchair in India. However, should the wheelchair break, it is much harder to replace in India, and in addition, the funding available to purchase a wheelchair in India is likely to be much less than what is available in the U.S.. In terms of prescription, in the U.S. a therapist will almost inevitably be involved in the wheelchair prescription process as well as in the continual maintenance of the wheelchair and ordering of any parts that may break or wear out.

The India PALM had certain design limitations which were addressed in the US PALM. **Table 3** shows a list of items in the left column which proved problematic in the first version and the right column explains how these problems were addressed in the U.S. Phase. One main limitation was the tilt mechanism. The linkage arm geometry shifted the CoG too far forward **(Figure 16 & 17)** placing too much weight over the front casters and the locking mechanism for the tilt was awkward. The tilt geometry was redesigned and a smoother OEM locking mechanism, Mechlok^{TM}, was used in the US PALM prototype. The Mechlok mechanism is used frequently for tilt-in-space and recline adjustments on wheelchairs and airline seating. It provides a strong locking mechanism with few moving parts and is durable. The US PALM **(Figure 20)** worked more smoothly, was sturdier and optimized for manufacture in the machine shop than the India PALM. The US PALM was highly adjustable and selectable to accommodate a range of body sizes. The seat depth, seat width, back rest height, back rest angle, leg rest angle, footrest angle, and axle position are all adjustable. It also converts from an attendant-style wheelchair to a self-propelled wheelchair.

Although adjustability was a large consideration in U.S. PALM, seating components were not given much design thought. A seating system is a fairly complex design problem; therefore its resolution was left for the Final PALM.

Table 3: Problems with India PALM and resolution in US PALM

Design Problem in India PALM	**US PALM solution**
Tilt-in-space shifted center of gravity too far forward over front casters	Refined four bar linkage design by changing lengths of arms and pivot points
Tilt-in-space locking mechanism was hard to use and not smooth	Changed from two locking gears to a one cylinder Mechlok™ (www.plporter.com/home/net/mechlok_001.html)
Holes drilled in tubing for adjustments were likely to weaken tubing	Use pinch clamps instead of bolting through tubes
Embedding caster housing in plastic created non-sturdy caster housing mount	Used an aluminum bracket to hold caster and bolt to plastic module.
Complicated machining of some plastic components	Decrease CNC milling setups from 2 to 1.
Non-sturdy back rest angle adjustment mechanism	Use some aluminum components rather than all plastic. Redesign component geometry.
Complicated wheel axle attachment mechanism	Redesign axle plate mounting geometry and axle housing
Non-quick release arm-rests	Switch to a flip-up style armrest rather than a T-style which bolted to the frame

The US PALM prototype had the following features:

1. Tilt-in-Space function with 35/10 degree posterior/anterior tilt

   Although it is recommended that the seat have 45 degree posterior tilt, the range of the Mechlok™ used was only 45 degrees. A Mechlok with 55 degree range would be used in a final product.

2. Exchangeable manual-propulsion and assistant-propulsion rear wheels

3. Reclining seat-back function with 20 degrees posterior recline in 5 degree increments
4. Adjustable leg-rest angle (0-90 degrees) and 6” of leg-rest length adjustment
5. Foot-plate plantar/dorsiflexion angle adjustment
6. Adjustable manual-propulsion rear wheel axle position: 0-4” from backrest
7. Overall weight of 32 pounds

   Although this is still fairly heavy, most products on the market weight around 40 lbs.
8. Overall size dimensions of 22” wide x 36” long x 30” high fully assembled
9. Stowage dimensions of 12” x 18” x 30” when disassembled to fit in a compact car trunk.

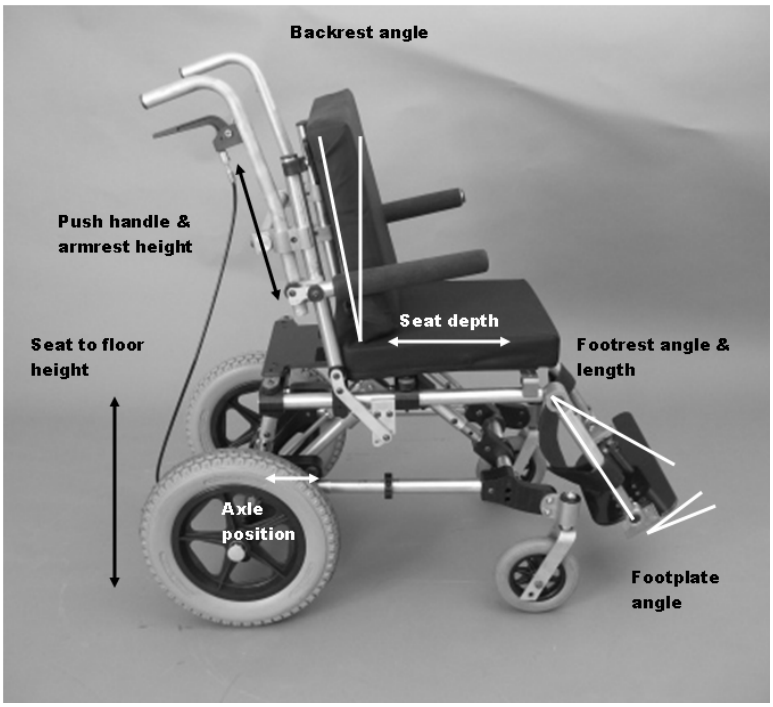


Figure 21: Side view of US PALM showing points of adjustability

6.2 FOCUS GROUP EVALUATION

To evaluate the US PALM, two focus groups were held at the Center for Assistive Technology based at UPMC (University of Pittsburgh Medical Center) with a total of ten pediatric

wheelchair seating and mobility clinicians (therapists, rehabilitation engineers, and rehabilitation technology suppliers) and three child/parent pairs. The main inclusion criterion for children was that they had a mobility disability and used a manual wheelchair as their primary means of mobility. The sample size is quite small, however for the focus group purposes, this was not critical. The main goal was for the designers to hear some end-users' opinions on the design and this was successfully achieved even without statistical significance.

6.2.1 Focus group methods

First, subjects received an oral introduction to the prototype, including an overview of its features and design, and a demonstration of the adjustments. Originally, the clinicians were to fit the wheelchair to each of the children. However, this did not occur due to unexpected difficulties with the children in the group. For instance, one child was too heavy for the prototype, approximately 130 pounds; and the parent of another child decided that she did not want her child to transfer to and try the prototype. Consequently, instead of actually fitting the chair to the child, clinicians and parents were asked to make a series of adjustments to the prototype including adjustments to the seat depth, back rest angle, leg rest angle, footrest angle, and changing the wheels from 12.5" attendant wheels to 20" push-rim wheels. Thus, clinicians and parents still had extensive exposure to the prototype as these adjustments were made, and this experience served as the basis for their evaluations.

Parents and clinicians were then asked to complete a questionnaire comprised of a series of Likert scales assessing their evaluation of the folding mechanism, ease of transport, added features and components, and the aesthetic aspects of the chair. An open-ended question provided participants with the opportunity to list any recommended changes they may have. A large majority (e.g., 70%-80%) of positive responses ("agree" or "strongly agree") on the Likert scales (after reversing scales where appropriate) for each aspect of the evaluation provided initial evidence that the prototype met the performance goals. The focus groups took approximately two hours each.

Although it was hoped that the children would provide evaluative feedback, due to cognitive limitations and the fact that the children did not sit in the prototype, this did not occur. Instead, parents and clinicians completed the evaluation questionnaire (one designed specifically

for parents and one for clinicians) after making adjustments to the chair. Then, after completing the written questionnaire, they participated in an open discussion based on the questionnaire. Audio of the discussion was recorded.

The questionnaire consisted of close-ended questions on 5-point scales addressing ease of use, appearance, and features such as adjustability. Open-ended questions probed subjects' thoughts and ideas on 5 topics: Tilt Mechanism, Seating, Appearance, Overall Function, and Overall Quality. Below is a sample close-ended question, see **Appendix A** for the full questionnaires.

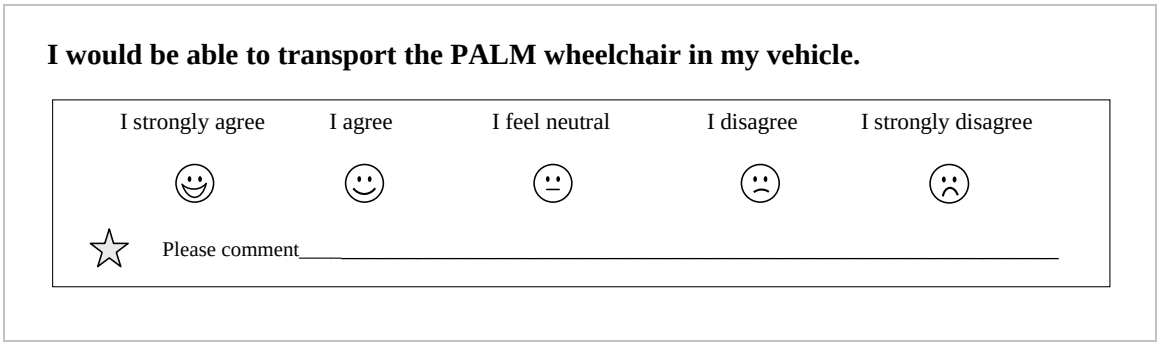


Figure 22: Sample close-ended question

6.2.2 Results

The responses to the questionnaire are summarized in **Tables 4 and 5. Table 4** shows the average ratings both clinicians and parents gave on key close-ended questions. Comments from the open-ended questions were categorized and the frequencies of comments tallied. **Table 5** shows all comments that occurred 3 or more times (i.e., at least 23% or more of the subjects made the same or similar comment).

Parents' and clinicians' ratings regarding the ease of using the tilt mechanism, switching wheels, and learning to use the wheelchair were very positive. During discussion, clinicians stated specific benefits of the US PALM tilt mechanism over similar products. These comments included the use of only one handle release for the tilt as opposed to two, the shorter wheel base

length and the tipping stability. Clinicians agreed that the ability to easily switch wheel type would be beneficial to a child as long as the wheelchair weight was low enough that he would be able to push it.

Table 4: End-users' evaluations of the US PALM

Question *1= strongly agree; 5= strongly disagree*	**Clinician**	**Parent**
1) Tilt mechanism operated smoothly	1.4 n=10	1.7 n=3
2) Easy to switch from attendant-style to push-rim wheels	1.7 n=9	1.5 n=3
3) Would be transportable in passenger vehicle	3.8 n=9	1.7 n=2
4) Learning to use chair is easy	1.7 n=10	2.5 n=3
5) Wheelchair has pleasing appearance	2.7 n=10	2.3 n=3
6) Appears high quality	2.2 n=10	3 n=3
7) Enough adjustability to accommodate propulsion needs	2.7 n=7	4.5 n=2
8) Enough adjustability to accommodate seating needs	2.25 n=8	4.5 n=2

* The means reported are based on slightly varying Ns because some subjects failed to answer some questions.

Table 5: End-users' comments about the US PALM (N=13)

Comment	Frequency
Should be more transportable in a car	6
Needs split footplate option	6
Chair needs a quick fold mechanism	5
More seating components	4
Detachable footrests	4
Use fewer Allen wrenches to make adjustments	4
Colors	3
Needs padded armrests	3
Should be lighter weight	3
Needs more quick releases	3
Needs a quick recline mechanism	3

Parents' ratings on adjustability seemed less favorable because of specific issues with their children. Responses to the open-ended questions and comments during the discussion revealed that, in one case, the child frequently used a power add-on unit for her manual wheelchair and because the US PALM did not have this feature, it received a low rating. In the other two cases, the children were unable to self-propel under any circumstances, therefore the parents stated that they did not feel the feature was necessary. Parents explained that their unfavorable ratings of seating adjustability stemmed from the fact that the chair did not have enough additional seating supports such as thigh abductors and a headrest attached to it. They also stated their opinion would change if these items were added. This was not surprising because little design thought was put towards the seating system. The majority of the design effort in this phase was directed to the overall concept of the chair and the seating was left as a simple planar seat.

The prototype required the removal of screws in order to break down for transport. Because it is not a quick procedure, clinicians gave less favorable ratings in terms of transportability. Interestingly though, the parents gave the chair high ratings in this area, because

they all owned vans which could easily transport the chair. Both clinicians and parents said that they would have rated the chair higher on appearance had the prototype been painted a bright color and had the chair been made to look more child-like or like a stroller.

Not surprisingly, subjects' open-ended comments summarized in **Table 5** closely parallel their responses to the close-ended questions. The most frequent open-ended comments centered on transportability, ease of folding, and the need for additional footplate and seating components. The final PALM work attempted to address some of these comments.

6.3 TESTING

6.3.1 Method

ANSI/RESNA testing was carried out at the Assistive Technology Evaluation Laboratory at the Human Engineering Research Laboratories (HERL). For the tests it was equipped with standard 12.5" attendant-style rear wheels with injection molded wheels and "flat-free" solid tire inserts and 6" by 1" caster wheels. Two of parts of the ANSI/RESNA testing (Parts 01 & 08) are particularly relevant to the safety and operation of the wheelchair.[39] Part 01 is a determination of static stability **(Figure 23)** and involves placing an appropriate-sized wheelchair test dummy in the wheelchair and testing to see whether or not it will tip backward on an 8% slope. A failure is seen when the wheelchair becomes unstable at the 8% slope. The least stable and most stable axle positions were tested for this test. For the purpose of simulating a child's weight, the PALM wheelchair was tested with the lightest test dummy- 50 kilograms.

Figure 23: Static stability test of PALM v2

Part 08 is a determination of static strength, impact strength, and fatigue strength (i.e., double-drum testing, and curb drop testing). [39] In the static strength tests, parts of the wheelchair (e.g., footrests, anti-tipper devices, etc.) are subjected to a constant force required in the standards. Impact strength testing includes applying dynamic forces to the wheels, casters, hand-rims, armrests, backrests, and seat. This testing also involves dropping an unloaded wheelchair one meter above the ground and dropping a dummy loaded wheelchair ten centimeters from the ground. The double-drum testing **(Figure 24)** consists of two rollers, which roll at a speed of 1 meter per second (one roller turns slightly faster to avoid exciting harmonies).

Figure 24: US PALM on double drum test machine

The 50 kg dummy loaded wheelchair is balanced over the rollers with a swing-arm attached to the rear axles to stabilize it while testing. Curb-drop testing uses a device that repeatedly lifts and drops a dummy loaded wheelchair from 5 centimeters high onto a hard surface. In the past, ultra light wheelchairs have been tested by running the double-drum test for 200,000 cycles (one revolution of the rear roller) and the curb-drop test for 6,666 drops.[40] A Class III failure is permanent damage, deformation, or failure that affects the ability to use the wheelchair. [39] During testing, wheelchairs are monitored every 10,000 cycles and every 300 drops. **Table 6** describes the tests performed and their order.

Table 6: ANSI/RESNA tests performed

	Test #	Test Standard	Description
1st	Part 05	Determination of Overall Dimensions, Mass, and Turning Space	Overall length, width, height, folded width, weight & turning radius of chair
2nd	Part 07	Determination of Seating and Wheel Dimensions	Dimensional information needed to fit a chair to a rider. Uses standard methods of measurement
3rd	Part 01	Determination of Static Stability	Stability of wheelchair when resting on a sloped surface
4th	Part 08	Static, Impact, and Fatigue Strength	Strength and durability of a wheelchair.

6.3.2 Results

The PALM v2 prototype performed well in achieving the following results:

- ANSI/RESNA Static and Impact Strength Tests: Pass
- ANSI/RESNA Double-Drum Fatigue Test: Completed 200,000 cycles.
- ANSI/RESNA Curb-Drop Fatigue Test: Completed 6,666 drops.
- ANSI/RESNA Static Stability: Comparable results to competitive products.

Part 01 (static stability testing) was performed for the least and most stable positions of the casters and rear axle positions. All tipping angles for the PALM were higher than 19°, with the smallest tipping angle at 19.1°, which is 11.1° higher than the typical ANSI/RESNA standard result of 8°. These results are very comparable with other competitive manual wheelchairs. [40]

Part 08 testing was conducted on a pass/fail basis for the static, impact and fatigue strengths. All of the components passed the static loading tests with a force applied of 735 N. All impact strength tests were conducted on the prototype, and it passed all of them. The fatigue strength tests (the double-drum and curb-drop tests) were performed last because of their

destructive nature. The PALM was tested on the double-drum tester and completed 200,000 cycles without failure, thus passing the test. For the curb-drop test, 6666 drops were completed without failure, thus passing that test as well. The prototype was not tested to failure on these two tests.

6.3.2.1 Weight and dimensions

The tested prototype weighed 32 lbs (including attendant-style rear wheels and footrests) and had a seat width of 13" (330.2 mm). **Table 7** below contains the dimensions of the prototype when in its standard upright position. As can be seen in the Table, the dimensions of the PALM easily fall under the maximum dimensions allowed by ANSI/RESNA Standards.

Table 7: Dimensions of US PALM prototype

	US PALM	**ANSI/RESNA max dimensions**
Overall Length	736 mm	< 1200 mm
Overall Width	533.4 mm	< 700 mm
Overall Height (backrest in upright position)	812.8 mm	< 1090 mm

6.3.2.2 Comparison to test data for other wheelchairs

Fitzgerald and her colleagues used the double-drum test and the curb-drop test to examine the fatigue life of 61 wheelchairs (25 depot chairs, 14 lightweight chairs, and 22 ultralight chairs). [41] Fifty-six percent of those wheelchairs had a Class III failure and did not pass the fatigue test (completing both the 200,000 cycles on the double-drum and 6,666 curb-drops). The failure rates for depot chairs, lightweight chairs, and ultralight chairs were 80%, 57%, and 27%, respectively. In passing these two tests, the PALM's performance exceeded that of the vast majority of depot chairs, a majority of lightweight chairs, and 20% of its ultralight counterparts.

Because the PALM was built in a machine shop using prototyping materials and methods, the test results do not necessarily correlate to that of an equivalent but mass-produced

product made with factory materials and methods. For example, injection molded Polyethelene parts will not have the same structural strength as CNC machined Delrin. Nonetheless, it was useful to test the prototype. Durability and fatigue data can be a useful tool during an iterative design and prototyping process and not simply at the end stage of product development when a design is ready for market.

6.4 U.S. PHASE CONCLUSION

The results of the US PALM Phase were a strong initial indication of the viability, practicality, and value of the US PALM. Although the design criteria were met, ANSI/RESNA test results were outstanding and the focus group evaluations were mostly positive, they also included invaluable feedback regarding remaining shortcomings of the design. This set the stage for the final Phase in which improvements were made to bring the concept one step further towards product realization.

7.0 FINAL DESIGN AND DEVELOPMENT PHASE

Feedback from the focus groups conducted in the US PALM phase provided invaluable information regarding where improvements in the design could be made. This feedback served as the basis for the Final PALM design criteria. The result of the final Phase is an “alpha” or “presentation” prototype that is easier to use, more aesthetically pleasing, has better functionality and safety features and is one step closer to a pre-production prototype.

7.1 FINAL PHASE DESIGN

The two innovations which distinguish the PALM from other pediatric wheelchairs currently available in the U.S. market are a new center-of-gravity tilt-in-space mechanism and a modular design using plastic injection molded nodes to join the chair. These features were conceived in the India phase and remained essential to the final phase. Another difference between the Final PALM and existing products is the use of color on the wheelchair. Although it is a simple aspect of the design, color aids in making the wheelchair seem less institutional, medical and disabling. It appears more like a stroller and thereby more appealing. Aesthetics is a critical element of pediatric wheelchair design. Although a wheelchair may be highly functional and beneficial to a child, if it is institutional-looking or unappealing aesthetically, it is less likely to be purchased or prescribed. Improvements to the design in this phase were made based on the US PALM focus group comments, ANSI/RESNA testing and changes to prototyping methods.

7.1.1 Final Phase design objectives

Final Phase design objectives were to:

1. Improve ease of folding mechanism
2. Reduce weight
3. Improve ease of use
4. Improve comfort
5. Improve seating system
6. Consider design for manufacturability
7. Improve aesthetics

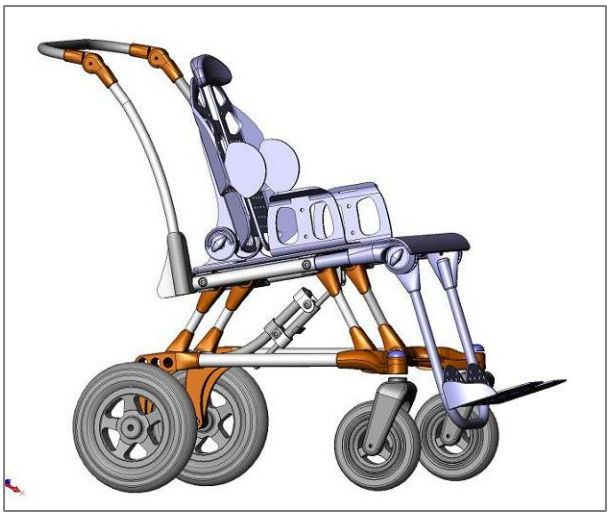


Figure 25: Concept drawing for final PALM

7.1.2 Design improvements

During the US PALM focus groups, specific features and components were identified as worth including to improve ease of use for caregivers and children, comfort, and therapeutic benefits of the chair; tool free adjustments, five degrees of anterior tilt in the seat for easier transfers, split footplate to accommodate leg length discrepancies, side guards, ergonomic push handles, padded armrests, an accessory bag and a removable seat that unlocks from the base. The plastic components were designed for simple one-step CNC milling with Delrin. This required blocky shapes **(Figure 27).** The Final PALM prototype was designed as an industrial design prototype, the materials and forms are closer to those used for mass-manufactured products, look more finished and are further optimized for lighter weight. **(Figure 26)**

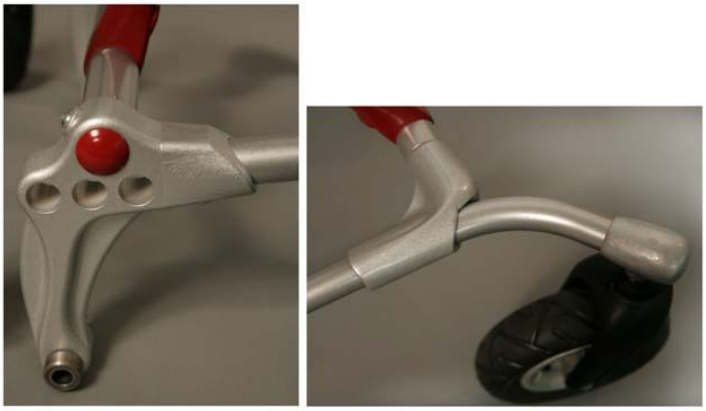


Figure 26: SLA plastic components, final PALM phase

Figure 27: Machined Delrin plastic components, US PALM phase

7.1.2.1 Objective 1: Improve ease of folding mechanism

To break the US PALM prototype down for transport, several screws had to be removed and tools used. In the US PALM focus groups, clinicians clearly noted this drawback. To rectify this, a tool-free break down process was achieved through 1) the use of knobs, 2) the design of an improved folding mechanism and 3) a removable seat. **(Figure 28, 29)** The removable seat allows the wheelchair to be more easily transported in a vehicle and potentially the seat could be used on other bases in different environments. A chair that breaks down into two pieces allows the chair to be more easily transportable, because the separate pieces are more manageable separately than lifting the whole chair in one piece. The assembled chair weight is 28 pounds.

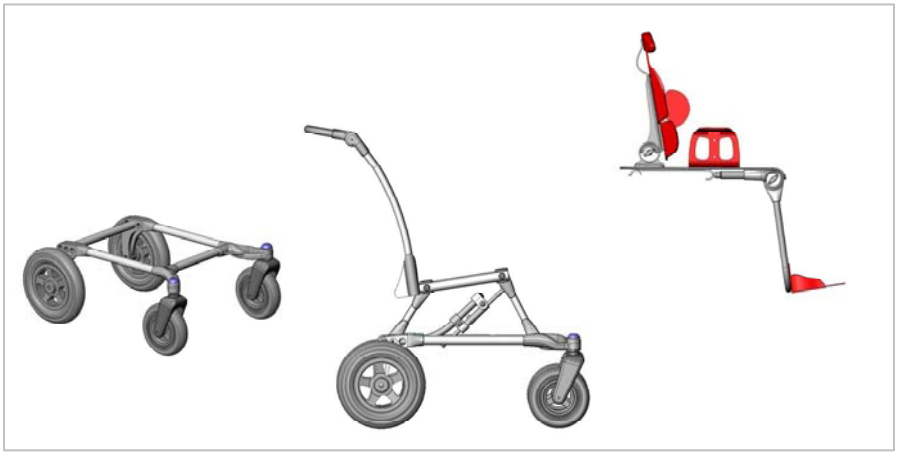


Figure 29: Concept drawing of removable seat

Folded dimensions:

L=26”, W=23”, H=18.5

Total chair weight= 28 lbs

Figure 28: Process of dismantling Final PALM for transport

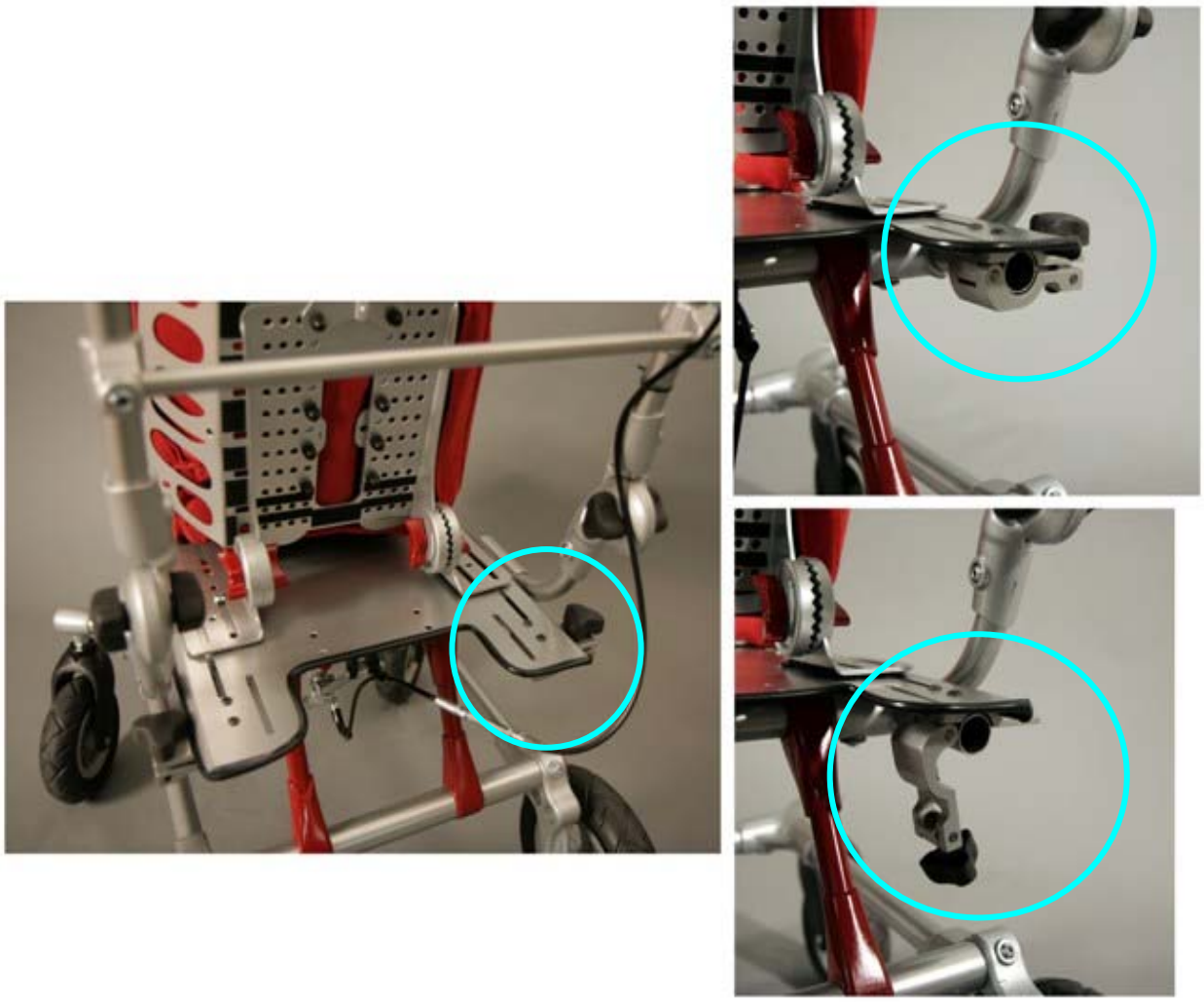


Figure 30: Close-ups of clamp releasing seat assembly

The two clamps at the rear of the seat are unscrewed and the clamps released **(figure 30)**. Then the seat is pushed forward to release the tube plugs **(figure 31)**. The seat can then be lifted off the base. Other methods could be used for releasing the seat which might be quicker. This is a strong and simple mechanism however it is a four-step process. The next design phase should explore the possibilities of a one or two step quick-release mechanism. In order to make it even more transportable, the leg rests could have a quick-release folding mechanism allowing them to fold under the seat.

Figure 31: Image showing seat pushed forward to release tubes from locking plugs.

7.1.2.2 Objective 2: Reduce weight

This was achieved by minimizing the amount of tubing and by streamlining the design of the plastic components. The US PALM weighed 32 pounds when fully assembled including wheels and footrest. Compared to currently available pediatric tilt-in-space wheelchairs, this was on the light side. However, it was still not ideal. The Final PALM weighs 28 pounds. Weight will likely be reduced further when the design is optimized for mass production; however, addition of accessories will add weight.

Table 8: Final PALM dimensions

	Final PALM	**ANSI/RESNA max dimensions**
Overall Length (from push handle bracket to foot rest)	812 mm	< 1200 mm
Overall Width	584 mm	< 700 mm
Overall Height (floor to push handle bracket)	965 mm	< 1090 mm

7.1.2.3 Objective 3: Improve ease of use

During the US PALM focus groups, features and components were identified as worth incorporating to improve ease of use, comfort, and therapeutic benefits of the wheelchair. The following features were incorporated into the design:

- Small amount of anterior tilt in the seat to allow for easier transfers
- Split footplate option in addition to the single footplate to accommodate leg length discrepancies that are often present within the target population
- Side guards and ergonomic push handles
- Self-contained removable seating system

The following features were noted as important in the US Phase focus groups; however, they were not incorporated into this final prototype:

- Removable leg rests for easier transfers
- An adjustable length split seat pan to further accommodate this need.

- Adjustable angle armrests to accommodate the change in trunk angle when the back rest is reclined.
- Quick release caster to allow for a larger caster wheel to be used outdoors.
- Activity tray
- Platform for ventilator
- IV pole
- Hooks to carry things during transport
- Accommodation of a power add-on unit
- Different size chair for larger child that would incorporate 2 Mechloks^{TM} and larger wheels and would be tested to a higher weight capacity.

Key design features in the final phase which improve ease of use for the caregiver are: 1) Velcro removable and washable upholstery **(Figure 32),** 2) ergonomic push handles**,** 3) removable seating system, and 4) wider caster spacing for easier transfers.

The final PALM upholstery is an aesthetic model and could not actually be used. However, it is a key to giving the look and feel of a final product and has a couple features which should be included in any final design. First, it is easily removable and washable and second, it is colorful. The next iteration should consist of a more durable prototype with foam wrapping entirely around each sheet metal component and more Velcro or snaps to firmly hold the fabric to the metal. The upholstery should allow for a small range of adjustability, however, it should be made available in many sizes and ordered based on a child's measurements. The majority of the adjustability is in the seat frame. Likely, during the life of the wheelchair, the upholstery should be replaced when it is worn or excessively soiled. As obvious as this feature seems to therapists and parents, many pediatric wheelchairs have non-removable upholstery that can only be cleaned with a hose or sponge.

Figure 32: Upholstery adheres to seat frame with Velcro, is removable and washable.

Figure 33: Images of backrest with upholstery

An adjustable handle angle affords an ergonomic pushing position. A common feature in most strollers and some wheelchairs on the market, it is a key feature to include in a care-giver friendly design.

Figure 34: Adjustable handle angle

Wider caster spacing has two main benefits; 1) wider caster spacing allows for easier transfers close to furniture, and 2) less interference with the foot rests. When the US PALM leg rest angle was at 90 degrees, the leg rest interfered with the rotation of the casters. This is often a problem in wheelchair design and was greatly reduced with the wider caster spacing. With the casters in a trailing position, the width of the front of the chair is 23 inches. This is still narrow enough to fit through doorways. Wheelchairs typically do not exceed a 25 inch width. The wide caster spacing also gives the wheelchair a stable base. This improves maneuverability and safety on rough terrain.

7.1.2.4 Objective 4: Improve comfort

Comfort for the rider was addressed through the design of the seat, range of adjustability, and upholstery. Comfort for the caregiver was addressed through the design of ergonomic push handles, transportability and the knob design. Larger casters were used on the final prototype to improve its rolling capability over rough terrain and to increase shock absorption.

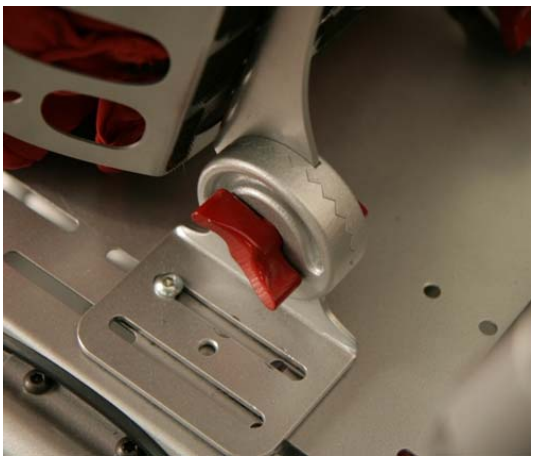


Figure 35: Ergonomic knob design

7.1.2.5 Objective 5: Improve seating system

The seat design on the US PALM prototype was not fully evaluated, thus it remained simple planar seating in the prototype. The final PALM seating design is in its first full-scale iteration. Therefore it is conceptual in nature. In the final phase, the seat was designed as a contoured modular unit with adjustability in seat depth, seat back angle, seat back width, lateral side support position, seat back height, and independent foot rest length and angle. **Figure 42** illustrates the points of adjustability on the prototype. **Figure 43** illustrates the mechanism used for angle adjustments. The handle bar adjustment point uses a standard OEM quick button adjustment mechanism. **Figure 40** shows all the components built for the final PALM prototype. Additional components such as adjustable height armrests, larger lateral supports, different headrests, pommel and seat belt would need to be available in order to fully evaluate the seating system with a child.

Figure 36: Seat moving through range of tilt and recline

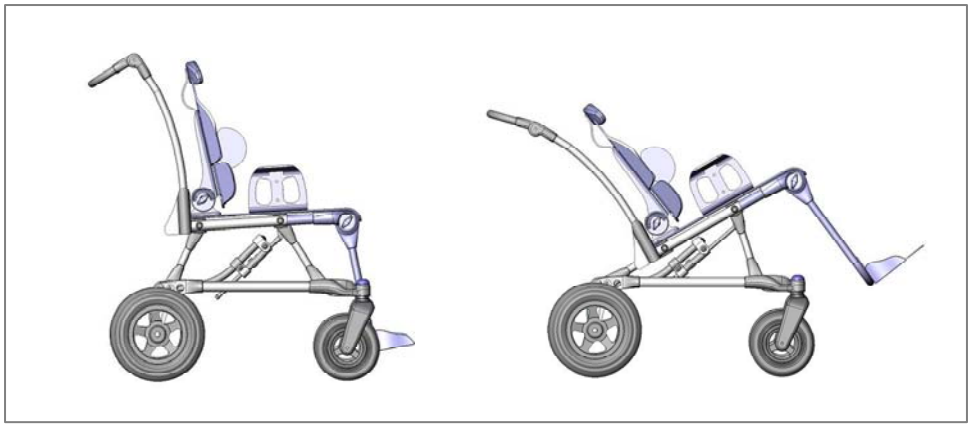


Figure 37: CAD concept model of tilting seat

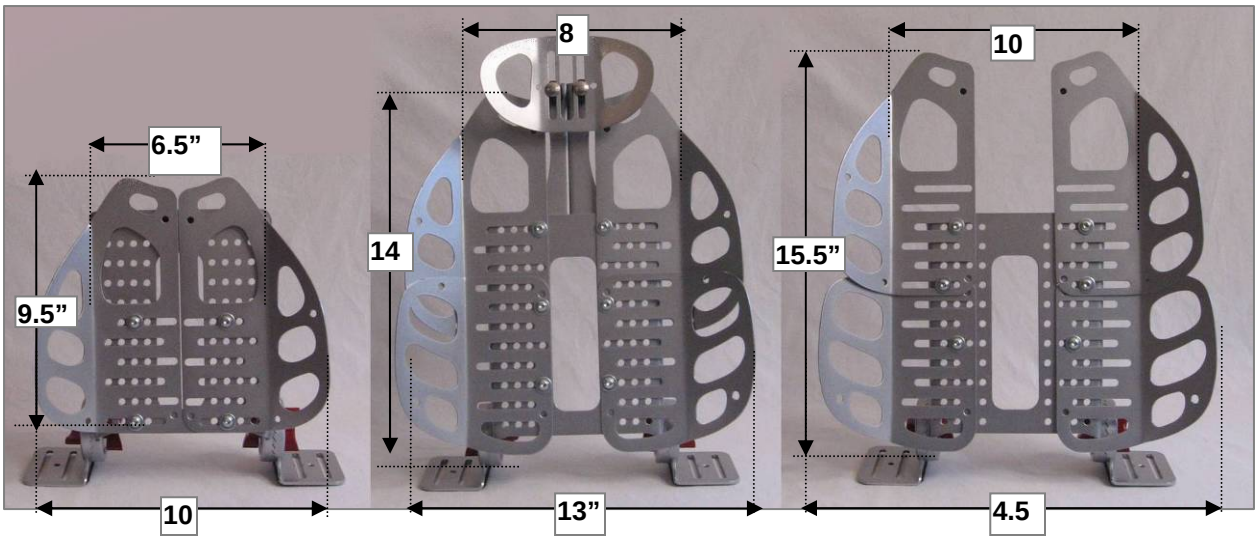


Figure 38: Images of backrest showing smallest, medium and largest configuration.

Figure 39: Images of seating components with and without upholstery

Figure 40: Close-up of adjustment mechanism used at back rest recline and leg rest angle points.

The US PALM model had some adjustments not present in the Final PALM. The seat to floor height adjustment was removed. This adjustment was removed to simplify the manufacturing process and reduce points of weakness in the frame. In addition, the seat to floor height is at a good level. It is lower than most pediatric tilt-in-space chairs. The low seat-to-floor height in combination with 10 degrees anterior tilt allows a child to more easily perform a stand-pivot transfer if they are able. In addition, the height is sufficient for children to be at eye-level with peers and fit under tables for activities. The low center of gravity also helps the chair to remain more stable on rough terrain and slopes.

Plantar/dorsiflexion angle adjustment was removed simply to improve the ease of manufacturing. This adjustment should be added in the next iteration. Adjustable height armrests should also be added. The side supports on the final PALM prototype have a slot built in that could accommodate an adjustable arm pad. **Figure 42** illustrates the points of adjustability on the prototype. The circles indicate points of rotation and arrows indicate linear adjustments. The tilt geometry had to be redesigned again for the final PALM. Although the US PALM tilt worked smoothly and maintained a stable CoG, the rear linkage point was too low and the pusher could kick the bar while pushing the chair from behind. To remedy this, the rear linkage arm was shortened and the pivot point placed closer to the seat. With this change, the ergonomic push handles and the large soft wheels, the final PALM is much more comfortable to push.

Figure 41: Back reclined

Figure 42: Side view of final PALM with upholstery removed to show underlying structure. Illustrates points of adjustability

7.1.2.6 Objective 5: Improve aesthetics

Although focus group participants said the PALM looked "sturdy," "sleek" and "high-tech," they also noted that the chair needed to look "more child-like" and "colorful" and "more fun." One focus group discussion centered on the aesthetic of the stroller and the reluctance parents often feel when it is time to transition their child from a stroller to a wheelchair that is more capable of meeting their seating needs. Clinicians commented that parents tended to see strollers "cute" whereas they tended to see wheelchairs as "scary." This often leads parents to keep their child in a stroller long after the functional needs of the child have surpassed what a stroller could offer.

The Final PALM attempts to mimic as much of the pleasing "stroller aesthetics" as possible while maintaining all the features and functions of the earlier version. This was accomplished by streamlining the shapes, using color, and creating a "visual language" amongst

all the wheelchair's components. The use of SLA rapid prototyping allowed the parts to be made much more streamlined allowing the design to look and feel much more like a final product.

Figure 43: Final PALM prototype

8.0 FINAL PHASE FOCUS GROUP

The final PALM focus group followed the same format and used the same questionnaire as the US Phase. The goal was to evaluate the design features of the final PALM prototype.

The responses to the questionnaire are summarized in **Tables 9 and 10. Table 9** shows the average ratings both clinicians and parents gave on key close-ended questions. Comments from the open-ended questions were categorized and the frequencies of comments tallied. **Table 10** shows all comments that occurred 2 or more times (i.e., at least 22% or more of the subjects made the same or similar comment). **Table 11** compares averages of responses to the close-ended questions between the U.S. PALM phase and the Final phase.

As in the U.S. PALM phase, parents' and clinicians' ratings regarding the ease of using the tilt mechanism and learning to use the wheelchair were very positive. Large self-propulsion wheels were not used during the focus group, therefore there were no comments regarding ease of switching between wheels.

Responses on all other points; appearance, quality, propulsion and seating were improved from the earlier phase. The only significant change between the two focus groups is the response to the question of attractiveness of the wheelchair which showed a significant improvement with a p-value of 0.008 using the mann-whitney test. Mann-whitney was used because the sample size is so small. In future work, two larger sized focus groups should be held with the same wheelchair, and compare between them in order to validate the questionnaire.

One interesting finding from the focus group is that transportability was more of an issue in the second group. In the first group, all of the parents stated that they owned vans; therefore transportation of the wheelchair would not be difficult, even though it couldn't be dismantled without the use of tools. The Final PALM focus group parents were much more concerned about transportability in a car trunk and thought the base needed to collapse into a more compact size for easy transportation in a trunk. During the focus group, the Final PALM collapsibility was

demonstrated prompting a substantial discussion on the issue of collapsibility. Because the earlier model was not collapsible, no such discussion took place. It is possible that the focus of the discussions during the focus groups affected the features on which participants decided to focus their critique, thereby skewing the questionnaire comments towards different design features.

The most useful aspect of the focus group was the discussion and the open-ended comments given in the questionnaire **(Table 10)**, because these formats allow participants to offer their own creative ideas and nuanced opinions. In this way, qualitative research is highly useful to the design process. The comments should drive the next series of design refinements made to the PALM for the Beta prototyping stage.

Although this focus group sample size is quite small and the data is qualitative in nature, the focus group did provide useful feedback on the design. Focus groups are by nature subjective and therefore are used to stimulate new ideas and gauge user opinion on a new design rather than as hard facts regarding a design's quality and usefulness. In conclusion, although there are still improvements to be made, the Final PALM design is a significant improvement over the previous prototype and holds promise as a potential product.

Table 9: End-users' evaluations of the final PALM

Question (1= strongly agree; 5= strongly disagree)	**Clinician**	**Parent**
1) Tilt mechanism operated smoothly	1.14 n=7	2 n=2
2) Would be transportable in passenger vehicle	2.83 n=6	4 n=2
3) Learning to use chair is easy	2 n=7	2 n=2
4) Wheelchair has pleasing appearance	1.71 n=7	2 n=2
5) Appears high quality	2.14 n=7	2.5 n=2
6) Enough adjustability to accommodate propulsion needs	3.33 n=3	2 n=2
7) Enough adjustability to accommodate seating needs	2 n=6	2.5 n=2

* (clinician N=7, parent N=2) the means reported are based on slightly varying Ns because some subjects failed to answer some questions.

Table 10: End-users' comments about the PALM Phase II v3 (N=9)

Comment	**Frequency**
Should be more transportable in a car	9
Needs footrests that move out of the way	7
Needs stronger seat components	4
Positive comments about tilt	4
Upholstery should cover edges of components	3
Needs secure non-removable parts (like knobs)	3
Needs more anterior tilt	2
May need anti-tippers	2
May need 22”wheels instead of 20”	2
Needs footplate angle adjustment	2
Needs more secure upholstery	2
Seating is hard to adjust	2

Table 11: Comparison between average close-ended responses from US PALM and Final PALM

Question (1= strongly agree; 5= strongly disagree)	**US**	**Final**	**change**
Tilt mechanism operated smoothly	1.55 n=13	1.57 n=9	+0.02
Would be transportable in passenger vehicle	2.75 n=12	3.42 n=8	+0.67
Learning to use chair is easy	2.1 n=11	2 n=9	-0.1
Wheelchair has pleasing appearance	2.5 n=13	1.86 n=9	-0.64
Appears high quality	2.6 n=13	2.32 n=9	-0.28
Enough adjustability to accommodate propulsion needs	3.6 n=9	2.67 n=5	-0.93
Enough adjustability to accommodate seating needs	3.38 n=10	2.25 n=8	-1.13

9.0 NEXT STEPS

The final PALM prototype is a demonstration model. In order to bring the design to the next level, optimization and refinement is needed. There are four levels of work that need to be done; 1) design changes for Beta prototype, 2) testing for Beta prototype, 3) steps to take for pre-production prototype and 4) user trials.

9.1 DESIGN CHANGES FOR BETA PROTOTYPE

Issues raised in the focus group should be assessed for their importance and feasibility. For example, using captive screws, rather than the removable knobs and bolts at the pivot adjustment points, is a simple solution to a relatively important problem. Additional components such as lap tray, seat belt and sunshade will need to be designed as well. The feasibility of these changes needs to be addressed before the chair is finalized in a Beta-prototype.

The design issues that must be addressed are in two categories below, most critical and less critical.

9.1.1 Critical changes

- Durability of seating components

  The seat components are in their first iteration, therefore, testing does not make sense at this time. Some changes should be made prior to testing. For example, the seat

back panels should be machined from 0.125” aluminum, because there is too much flex in the 0.0625” and the pieces are unlikely to withstand testing. In order to test the seat, the 50 kg test dummy may need to be adapted. Because the seat back is contoured, the large flat back of the current test dummy may not appropriately load the backrest. The 50 kg dummy used in the US PALM tests was made by removing weight from the adult sized dummy; therefore its dimensions did not change except in lower leg length. This should be addressed prior to testing.

- Seat back

  The seat attachment bracket holding the seat back to the seat bottom plate should be reinforced. Upon completion of the prototype, it seems that the attachment of those two components may not be rigid enough. It makes sense to address this prior to testing.

- Push handle brace

  The push handles were braced together via two brackets and a tube. This would be made stronger if the brace were a welded bent tube rather than a bolted bracket. This was not done in the final prototype simply due to time and resource limitations. This is a fairly simple change that would add needed strength to the push handle assembly.

- Brakes

  Brakes need to be added. An OEM stroller brake may be sufficient. The scissor-type wheelchair brake should not be used, but rather one that the caregiver can operated with one foot, braking both rear wheels simultaneously, or a handle and cable actuated brake.

- Flip-up foot plates

  This feature was suggested many times during the focus group and was deemed highly important for the ease of transfers. A split footplate is necessary to accommodate leg length discrepancies, and it could be made interlocking to add strength to the footplates.

- Captive screws and knobs replace removable knobs at pivot points

9.1.2 Less-critical changes

- Seat removal system; ease of use

  Seat removal is currently a 4 step process: unscrew first clamp, unscrew second clamp, push seat forward releasing plugs, lift seat off rotating slightly to allow clearance between push handles. To improve usability this process should ideally be simplified to a one or two step process.

- Quick release leg rest

  A quick release mechanism should be placed at the leg rest pivot joint. When the seat is removed, the leg rests should be able to quickly fold up under the seat bottom plate. This will improve transportability.

- Quick release push handle folding mechanism

  The push handle folding could be made easier if a quick release replaced the current knob and screw mechanism. The OEM quick release button used at the push handle angle adjustment point could be used for the handle folding as well. However, the strength of this part should be tested with cyclic loading. Although this mechanism is simple and quick, it may not be strong enough to withstand the forces placed on the push handle.

- Push handle folding

  The overall dimensions of the base could be reduced for transportability by approximately 6 inches, if the push handle adjustment bracket and pivot point were placed closer to the seat.

- Upholstery

  Because the upholstery was simply an aesthetic model, it is inappropriate for testing. The material used is a polyester ultra-suede material. It was chosen for its look and feel and because it was available at the local fabric store. A fabric should be chosen with the appropriate durability, breath ability and wash ability characteristics. It is

unlikely that this fabric could be found locally, but rather would be available through industrial supply catalogs.

- Modify rear plastic joint geometry in order to use 22” self-propel wheels
- Quick release back rest adjustment

  This should be adjustable via quick release mechanism or a one-handed knob type adjustment as opposed to the current configuration that requires a two-handed operation on both the left and right sides.
- Accessories

  Addition of a sun/rain shade, lap tray, seat belt and additional seating components will be critical to the success of the usability of the PALM during in-home user trials.

9.2 TESTING FOR BETA PROTOTYPE

Once the design changes have been made, the plastic components can be made using the selective laser sintering (SLS) process and an appropriate plastic. This will yield high strength parts with much less effort than would be required to re-design the parts for molding even with a soft-tooled process. A second prototype with SLS parts and the aforementioned design changes should be tested with a modified 50 kg test dummy. The test dummy should be dimensioned based on the anthropometric data used to develop the wheelchair design. [38] It may be more appropriate to use a pediatric crash test dummy for this test, rather than the ISO test dummy used to load wheelchairs during the ANSI/RESNA durability and fatigue tests. The wheelchair push handles should be tested with a cyclic loading test machine. Information on performing this test may be available through stroller testing standards. Although this test is a variation on the ANSI/RESNA standards, the durability of the plastic quick-release parts at the push handles needs to be tested and the single load applied during the ANSI/RESNA test may not be enough to verify durability.

9.3 USER TRIALS

Multiple Beta prototypes could be manufactured and used for in-home user trials. This would be a useful step prior to pre-production prototyping because more information can be gathered than is possible in a focus group. Data logging devices could be used to monitor the wheelchair usage and distance traveled to validate the design.[42] Data logging devices can also be used to monitor the use of tilt-in-space seating. Studies with the Beta prototype should include comparison with other comparable products and usability studies. Blinded comparisons could be done between a beta prototype and commercial products

9.4 STEPS FOR PRE-PRODUCTION PROTOTYPE

Once the Beta prototype design and testing is completed, a pre-production prototype must be developed. This will require design optimization for injection molding in order to make the plastic components lighter weight and durable. The ABS-like resin used in the SLA process requires 0.2” wall thicknesses and can accommodate large solid sections. Injection molding typically requires wall thicknesses 0.1” or less and consistent thickness throughout the whole part. A suitable plastic also must be chosen based on material properties and cost. This can be outsourced at reasonable cost to a rapid injection molding company. Once the PALM has been outfitted with these parts, ANSI/RESNA testing must be performed again.

In addition, the design of some components will need to be modified in order to minimize the number of different parts needed on the chair. Making many different types of plastic parts will be necessary when injection molding, due to tooling costs.

9.5 FUTURE DESIGNS

Below is a list of some future concepts that could be incorporated into the design or stem from this project. These would likely be done after the PALM has been successfully marketed.

- The feasibility of a power seat tilt and/or recline should be investigated. This could be a very useful feature for children to gain some independence in their seating.
- Because pediatric tilt-in-space wheelchair users often ride in school buses, the prototype may need to be tested for crash worthiness and the frame will need to be assessed for a four-point tie down system.
- Ideally, this design would weigh less than 25 pounds. In order to achieve this, carbon fiber could be used for the seat components instead of the machined aluminum sheet used in the Final PALM prototype.
- Retrofitting the chair with power assist wheels
- Scaling the seating system for adult use
- Development of other wheelchair designs using the same injection molded components
- Technology transfer back to India where the project began

Because the focus groups were immensely helpful in the design of the PALM, future product development projects of this type should incorporate user input even earlier in the design process. User input at the initial concept stage may have proven useful to the design team. Although it is challenging to hold focus groups when only conceptual models are available, users' ideas can be tapped via other methods in a charette format or simply by critiquing existing products in order to reveal design opportunities. [6,43] These methods can help designers avoid pitfalls and uncover new ideas.

10.0 DISCUSSION

As a versatile, affordable tilt-in-space pediatric wheelchair, the PALM could fill a need not currently met by existing pediatric wheelchairs. In addition to enriching the U.S. pediatric wheelchair market, the PALM could also benefit the international wheelchair market, particularly in developing countries where there is a great need for high-quality low-cost wheelchairs. The PALM was designed to be versatile enough to be manufactured using lower cost materials in developing countries and higher end materials in developed countries, all the while using the same injection molded components. Use of the injection molded components would further reduce cost and increase manufacturing precision by eliminating the need for weld jigs.

Design for developing countries is often undertaken as a humanitarian endeavor. However, the India wheelchair project concepts were developed that are both innovative and applicable in the U.S. market. This raises the question of whether the product development process used for assistive devices by large U.S. manufacturers somehow inhibits innovation. Is it possible that the cost and contextual constraint problems of the developing country inspire a different level of design thinking? Products developed for the developing world context under the umbrella of humanitarian and charitable causes could prove to be useful elsewhere in the world. In fact, the success of these products in the U.S. market could aid in funding projects in developing countries for which the ideas were first conceived. It is hoped that the design developments made during the U.S. phases of this project will be transferable back to the Indian context and allow that project to continue, since that is where the vast need remains.

There are inspiring examples of projects in which a consumer product in the U.S. market is used to fund a conjoining humanitarian cause. One case of this is the iBOT mobility system, a high-end power wheelchair for people with mobility disabilities. The Segway personal transporter, designed by the same company for use by able-bodied users and sharing the same core technology as the iBOT, fits into a much larger market but utilizes many of the same

components as the iBOT. The Segway subsidizes the manufacture of the iBOT which would otherwise be unrealistically expensive in any context. Another example is Kids Up, Inc. a for-profit company which designs pediatric wheelchairs for the U.S. market and distributes through Sunrise Medical. This company supports a non-profit organization, ROC Wheels, that designs, manufactures and provides pediatric wheelchairs in developing countries.

Although the need for high quality pediatric wheelchairs is much more extreme in developing countries; it is an issue that still needs attention in the U.S. and other developed countries. It is clear that this issue is not simply one of technology and design, but also of policy, funding, human rights, culture, and environment. In fact, the technology problem is most likely the simplest problem to solve. The author and the team involved chose to address the design aspects of the problem but acknowledge the great need for attention to the complex societal and political issues that allow such problems to persist.

APPENDIX A. FOCUS GROUP QUESTIONNAIRES

The following questionnaires were developed for the PALM design project. Three questionnaires, one each for child, parent, and clinician, are included. Even though the child's questionnaire was never used during a focus group, due to cognitive limitations of the pediatric participants, it is included as evidence of the work done.

PALM Wheelchair Questionnaire for Children

Demographic Information

Please answer the following questions about yourself.

DOB: _____/_____/_____
(MM) (DD) (YY)

Gender: ☐ Female ☐ Male

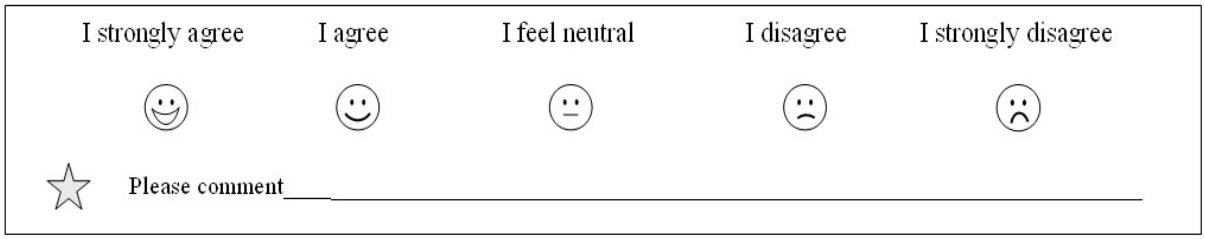
Ethnicity: ☐ African -American
☐ Asian -American
☐ Hispanic
☐ White
☐ Other

---------- Parents, please read directions! ----------

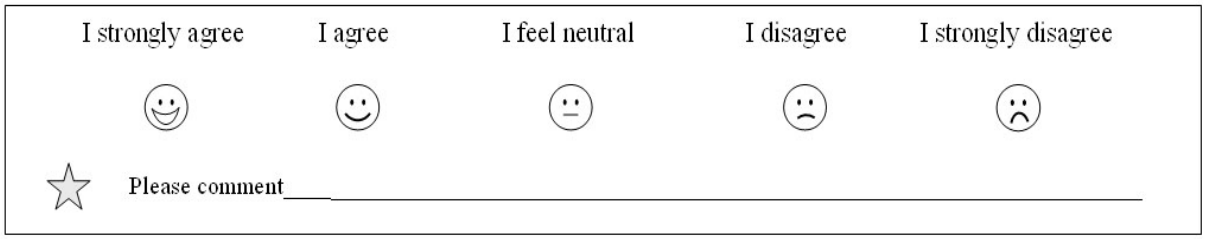
Directions to parent:

- If your child is able to comprehend and respond to the questions please circle or help them to circle the response that best indicates their opinion.
- If you have any comments or your child is unable to comprehend, respond or if the question does not apply to them, circle the ☆ symbol in the response box and comment on the line provided.

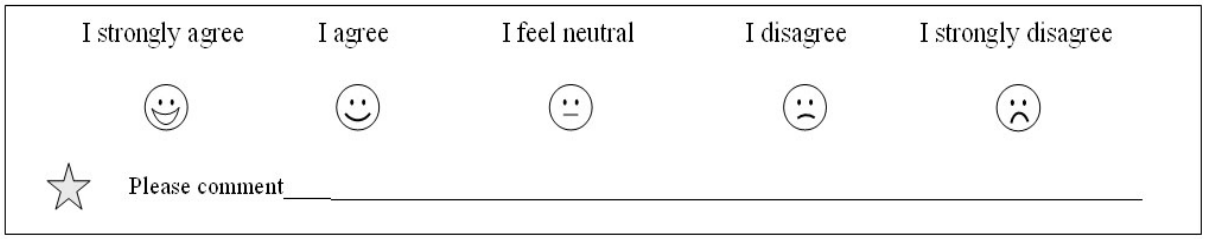
1) I like the way the PALM wheelchair looks.



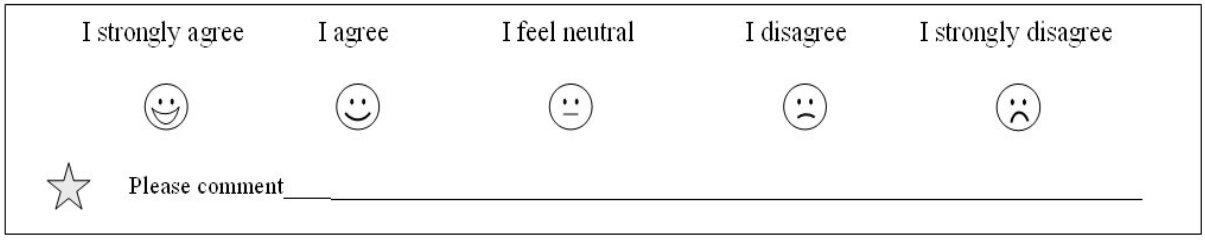
2) The PALM wheelchair looks better than my own wheelchair.



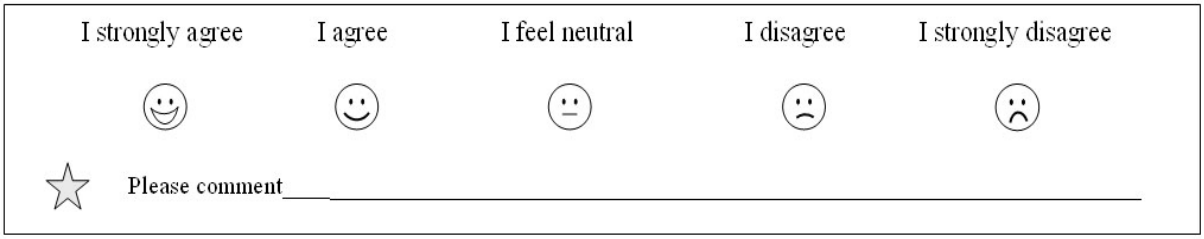
3) I would like to have the PALM wheelchair.



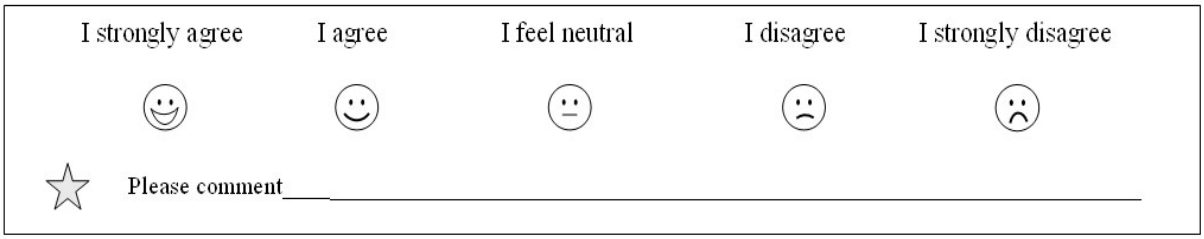
4) The PALM wheelchair could fit me well.



5) I feel safe and secure in my own wheelchair.

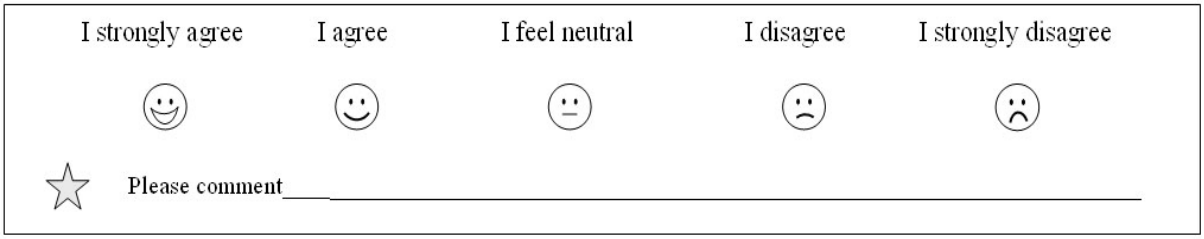


6) I feel comfortable in my own wheelchair.

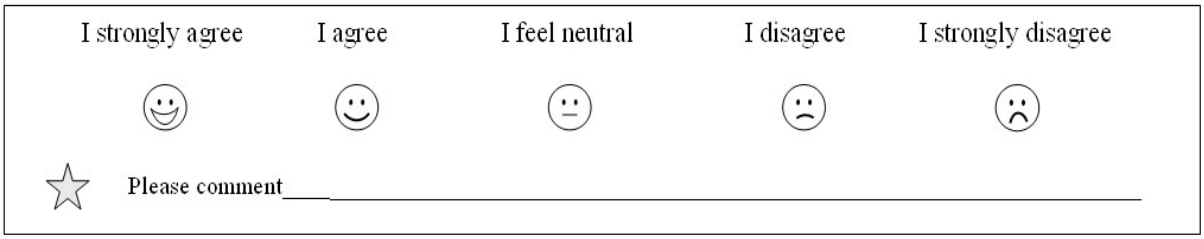


If your child was able to sit in the PALM wheelchair, please answer # 7-10 then skip ahead to 15. If your child was unable to sit in the chair skip 7-10 and answer the remaining questions.

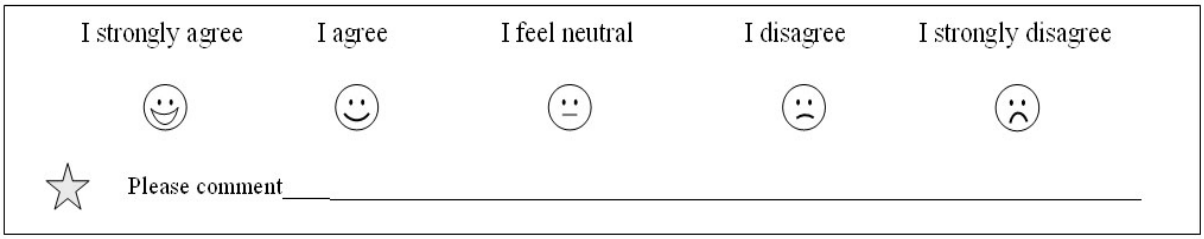
7) When the seat was tilted, I felt safe and secure.



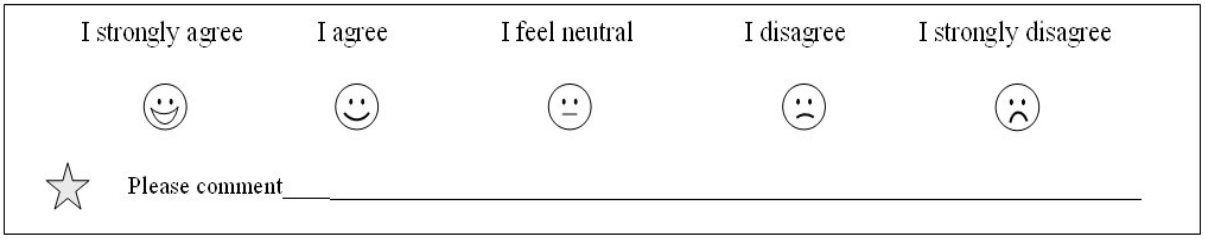
8) The chair was easy for me to propel.



9) When the seat was tilted, I felt comfortable.



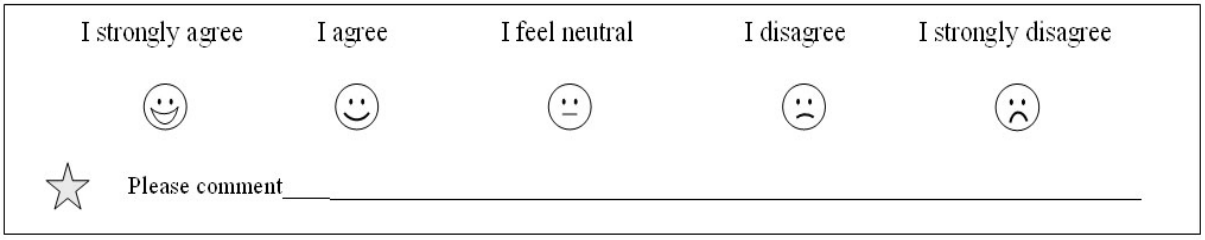
10) My body feels more comfortable when I'm in my own wheelchair than the PALM wheelchair.



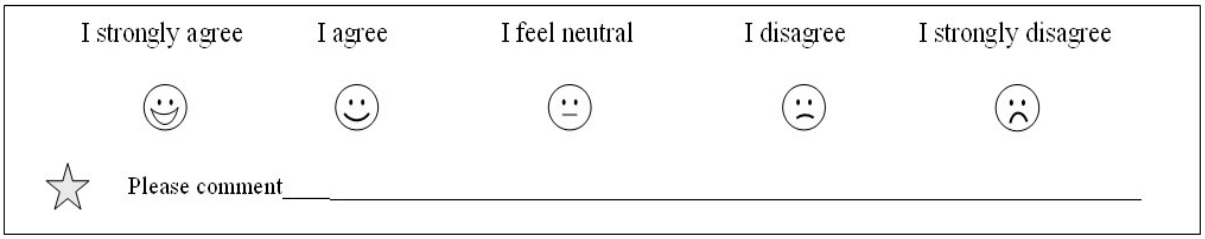
.....

Answer 11-14 only if your child was unable to sit in the PALM wheelchair. Otherwise, please skip ahead to 15.

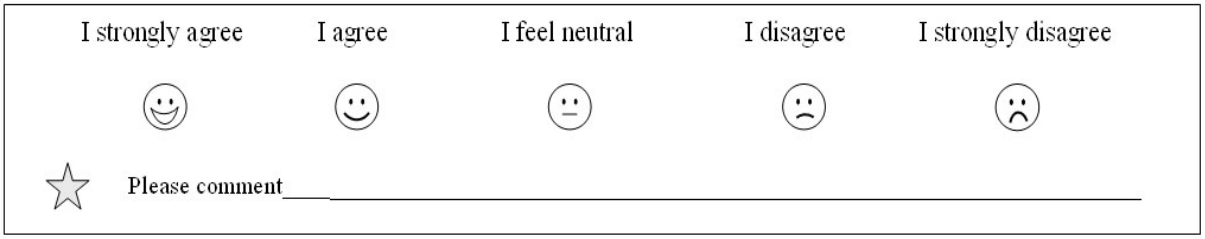
11) The PALM wheelchair chair looks comfortable when it is tilted.



12) The PALM wheelchair looks safe and secure when tilted.



13) The PALM wheelchair looks like it would be easy for me to self-propel.



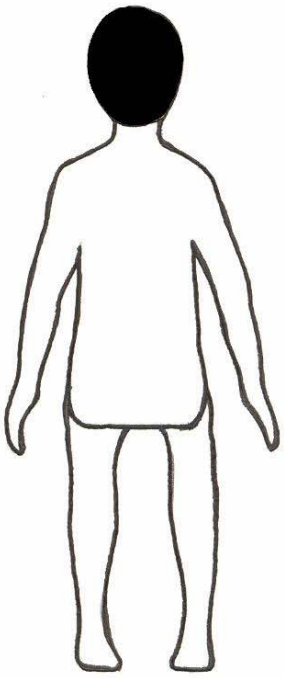
14) The PALM wheelchair looks more comfortable than my own chair.

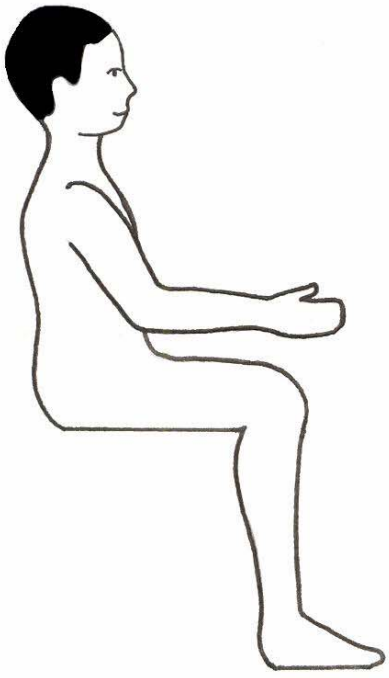
I strongly agree	I agree	I feel neutral	I disagree	I strongly disagree
				

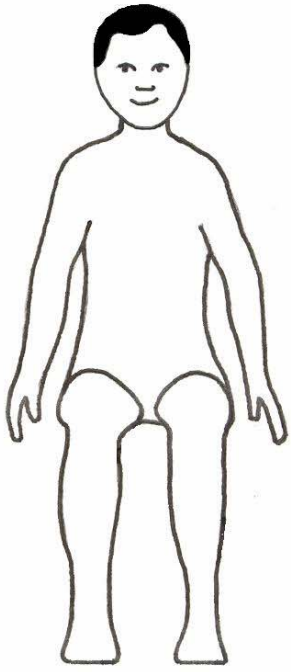
 Please comment_____

.....

15) If you experienced pain or discomfort while seated in the PALM wheelchair draw a circle on the picture around the areas where you felt the discomfort.







16) For each item, please rate the importance of the following features in regards to pediatric wheelchairs.

1= very important
2= somewhat important
3= not very important

☐ **Comfort**	☐ **Transportability**
☐ **Appearance**	☐ **Promotes function**
☐ **Independent mobility**	☐ **Improves participation**
☐ **Adjustable tilt and/or recline**	☐ **Fun**
☐ **Safety**	☐ **Growth adjustability**
☐ **Postural support**	

17) Considering these 3 aspects of the PALM Wheelchair, is there anything you would change if you could? Please explain your answer**.**

Tilt mechanism:

Seating:

Appearance:

Overall function:

Quality:

☺ Thank you very much for your time. ☺

We appreciate your participation!!

PALM Wheelchair Questionnaire for Parents

Demographic Information

Please answer the following questions about yourself.

DOB: _____/_____/_____
(MM) (DD) (YY)

Gender: ☐ Female ☐ Male

Ethnicity:
☐ African -American
☐ Asian -American
☐ Hispanic
☐ White
☐ Other

Please answer the following questions about your child.

Disability: _____

If Spinal Cord Injury, Please Indicate Level: _____

Date of Injury or Onset of Disability: _____/_____/_____
(MM) (DD) (YY)

How many years has your child used a wheelchair? _____

Was your child able to sit in the PALM Pediatric wheelchair today? Yes ☐ No ☐

Does your child use more than one wheelchair? Yes ☐ No ☐

.....

The following questions are regarding your child's PRIMARY wheelchair. This is the chair in which they spend most of their time and in which they are most active.

1) How is the wheelchair propelled? (check one)
☐ "Standard" self-propelled
☐ Power Assist (power add-on, pushrim activated)
☐ Foot propelled
☐ Attendant Propelled

2) If the chair is attendant propelled, what features does it have?
☐ Manual tilt ☐ No features
☐ Power tilt ☐ Other _____

3) What other accessories does your wheelchair have? (Check all that apply.)
☐ Portable ventilator
☐ Side supports
☐ Power add on, such as Efix or Power Assist hubs

4) Make (brand) of your primary wheelchair: (Please look at label on your wheelchair if unsure)
☐ Action/Invacare ☐ Pride
☐ Everest and Jennings ☐ Sunrise/Quickie
☐ Kuschall ☐ TiSport
☐ Otto Bock ☐ Other: Please list _____
☐ Permobil

5) Model of your primary wheelchair: _____

6) Date of receipt of primary wheelchair: _____/_____/_____ (best guess if unknown)
(MM) (DD) (YY)

7) Is this your child's first wheelchair? Yes ☐ No ☐

.....

Please answer the following questions with your child's "primary" wheelchair in mind

8) What types of **support straps** does your child use? Check those that apply or describe in the space below, if the strap is not listed.

☐

☐ Backpack type shoulder harness

☐ X- Type shoulder harness

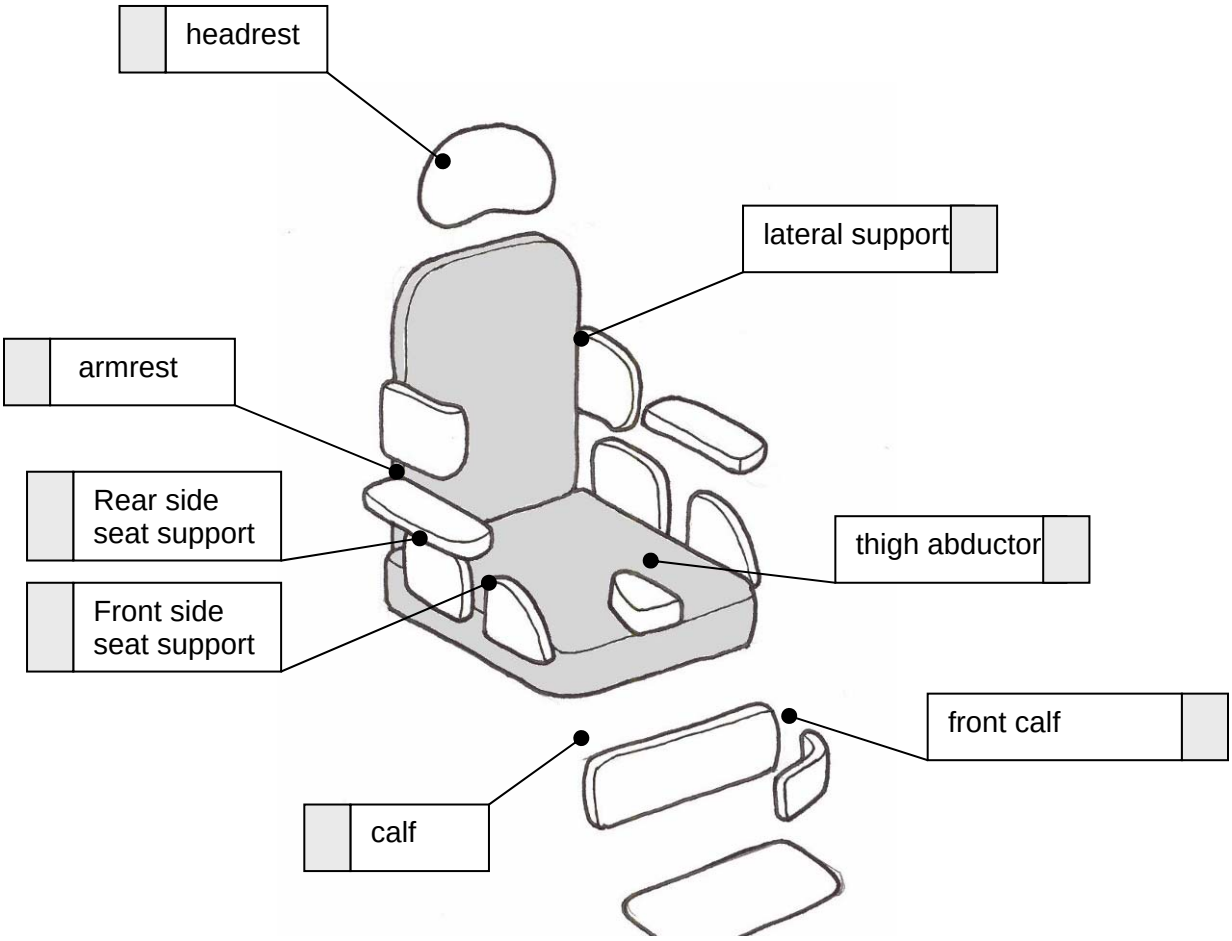
☐ ☐ ☐

9) What types of **postural supports** does your child use on their primary wheelchair? Check the gray box next to the label of the postural support.

If additional supports are used which are not in the diagram. Please explain on the lines below.

_____

_____



10) What type of seat cushions does your child use?

- ☐ Custom molded
- ☐ Air filled cells
- ☐ Standard foam
- ☐ Gel
- ☐ Gel and foam
- ☐ Honeycomb
- ☐ Fluid flotation
- ☐ Varilite
- ☐ Other _____

Please answer the following questions about your child's activities.

11) On a TYPICAL DAY, how many hours is your child out of bed? _____ Hours

In a TYPICAL WEEK *during the school year*, how many days does your child get out of your house and go somewhere? _____ Days

In a TYPICAL WEEK *during vacation or summer break*, how many days does your child get out of your house and go somewhere? _____ Days

In your home, does your child have independent access to their sleeping area, kitchen, bathroom, telephone, TV (or radio)? Yes ☐ No ☐

12) How many hours per week does your child spend in recreational activities such as sports, exercise and playing outdoors? _____Hours

13) How many hours per week does your child spend watching TV, playing video games, working on the computer or listening to the radio? _____ Hours

.....

For each statement below please circle the response that best indicates your opinion If you have any comments please circle the ☆ symbol in the response box and comment on the line provided.

17) The tilt mechanism operated smoothly.

I strongly agree	I agree	I feel neutral	I disagree	I strongly disagree
				

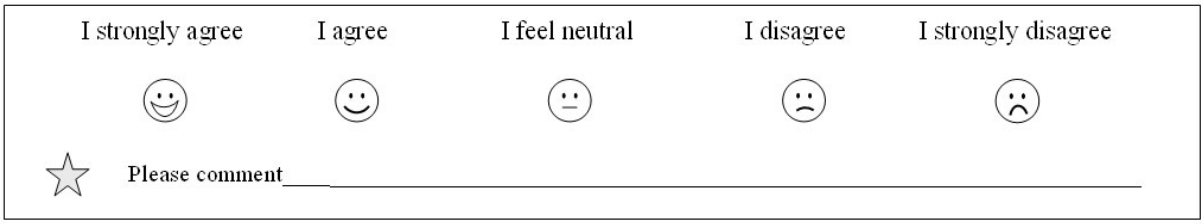
☆ Please comment_____

18) There were points during the tilting process where I could not easily work the mechanism.

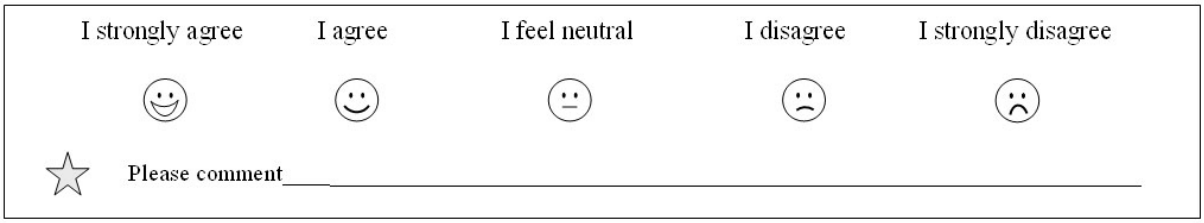
I strongly agree	I agree	I feel neutral	I disagree	I strongly disagree
				

☆ Please comment_____

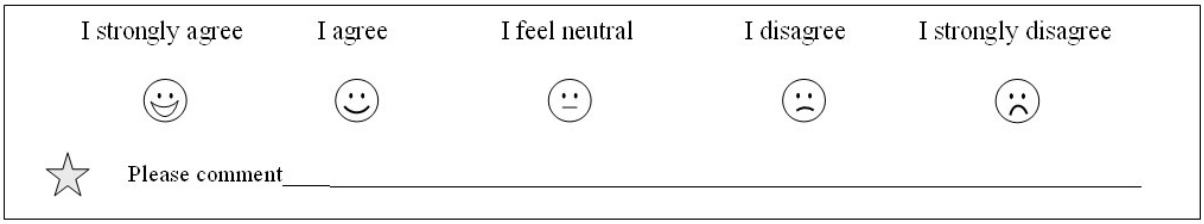
19) It was easy to switch from attendant-wheels to push-rim-wheels.



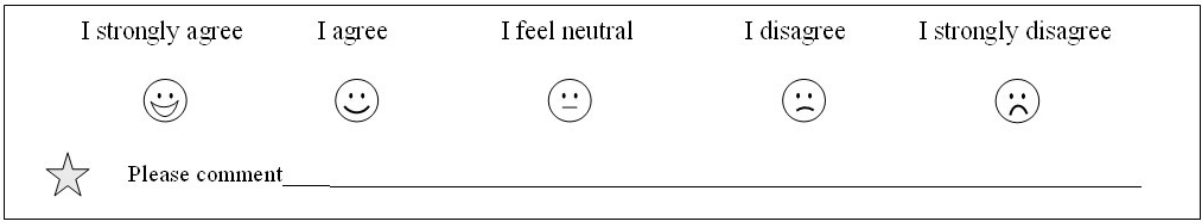
20) I would be able to transport the PALM wheelchair in my vehicle.



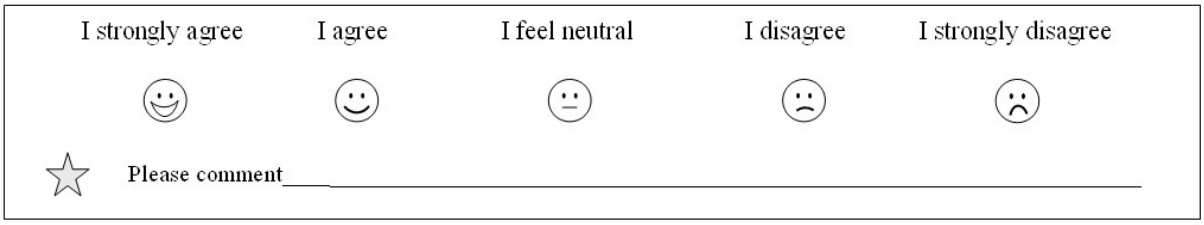
21) Learning to manipulate the PALM wheelchair was easy for me.



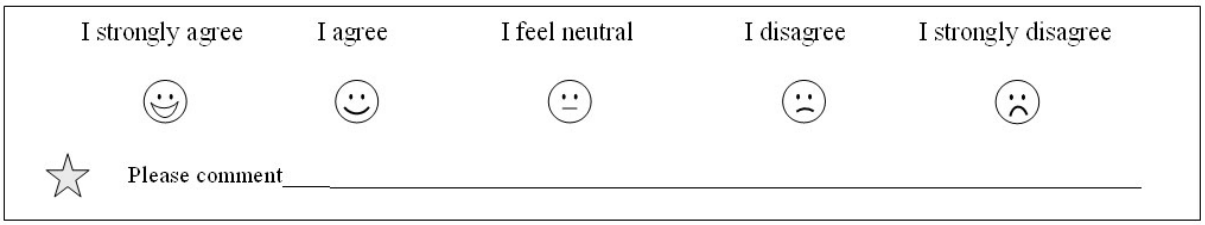
22) The wheelchair has a pleasing appearance.



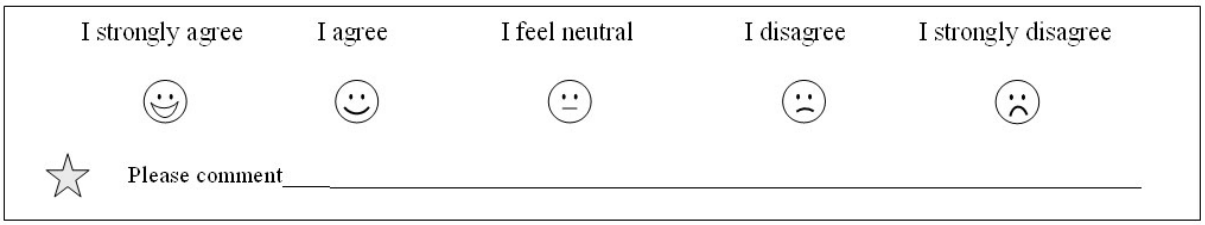
23) The chair is more attractive than most manual tilt-in-space pediatric wheelchairs I have seen.



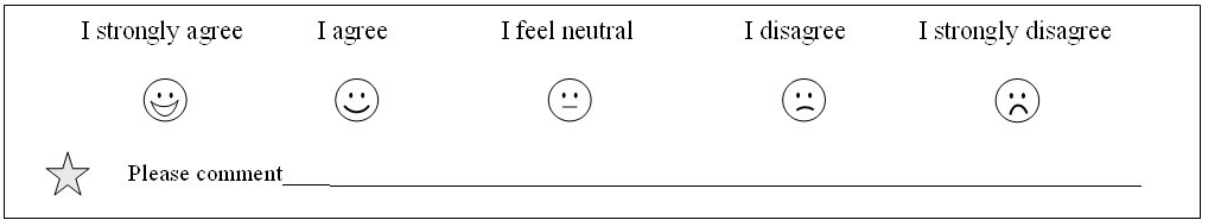
24) The PALM wheelchair looks like a high quality wheelchair.



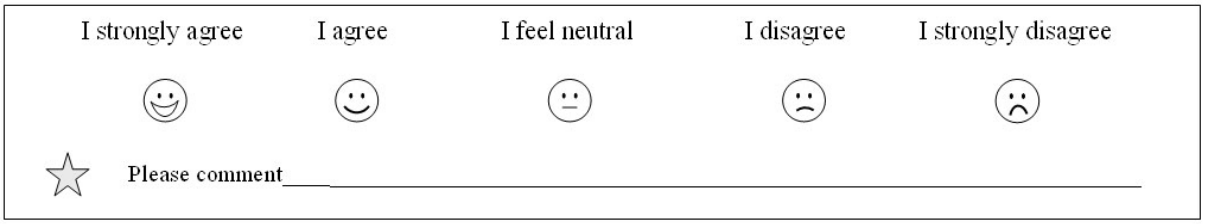
25) The PALM wheelchair has enough adjustability to accommodate my child's propulsion needs.



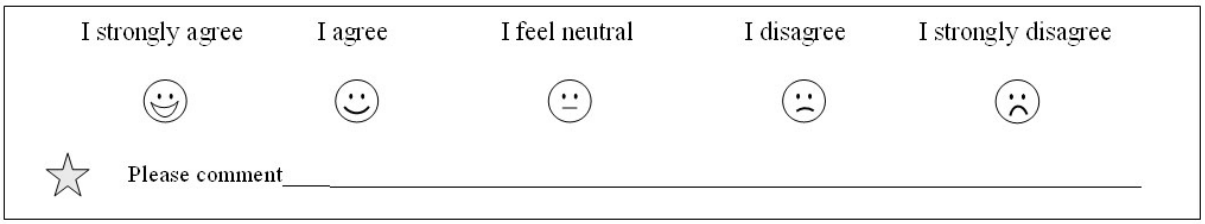
26) The PALM wheelchair has enough adjustability to accommodate my child's seating and positioning needs.



27) The PALM wheelchair was comfortable for me to push.



28) I would buy PALM wheelchair for my child.



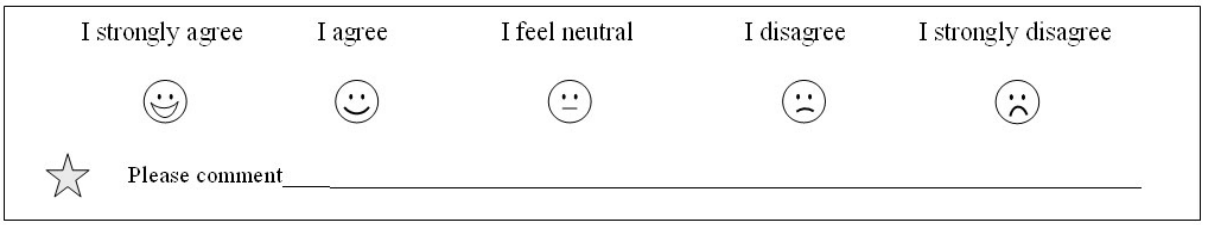
29) I would pay between_____ dollars to buy the PALM wheelchair. (Please circle the dollar range)

$100 to $300	$300 to $600	$1200+
$600 to $900	$900 to $1200	

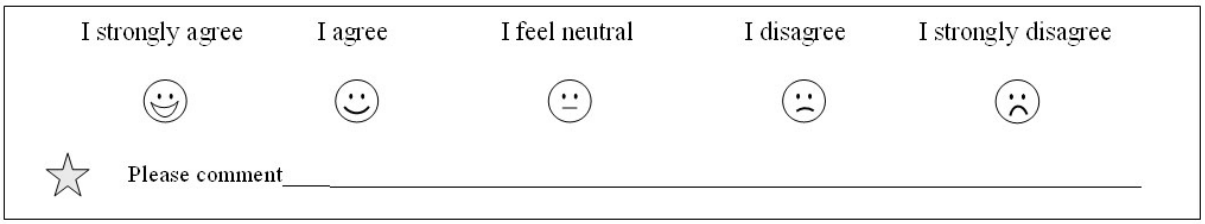
.....

If your child was able to sit in the chair, answer questions 30-33 and then skip ahead to 37.
If the child was not able to sit in the chair, skip 30-33 and go to question 34.

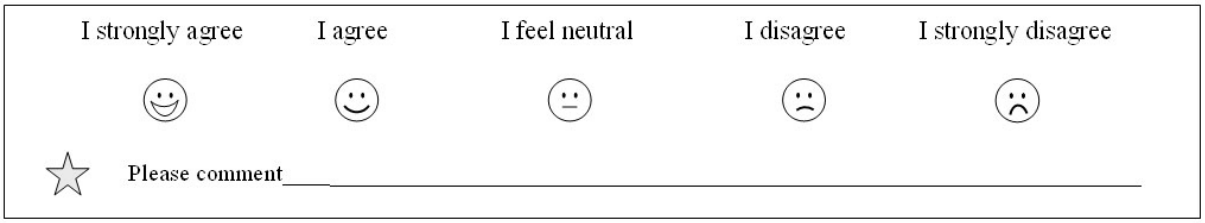
30) When the chair is tilted, my child seems comfortable.



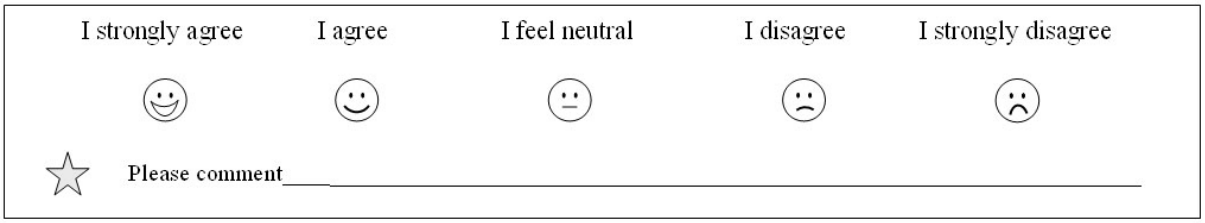
31) When the chair is tilted, my child seems safe and secure.



32) The chair seems easy for my child to propel.

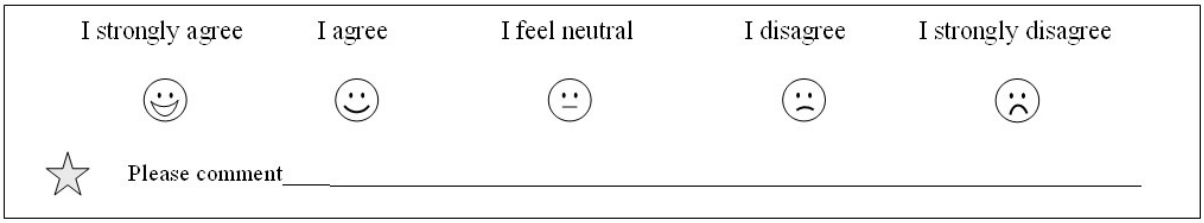


33) My child seems to more comfortable when sitting in this wheelchair than in his/her own chair.

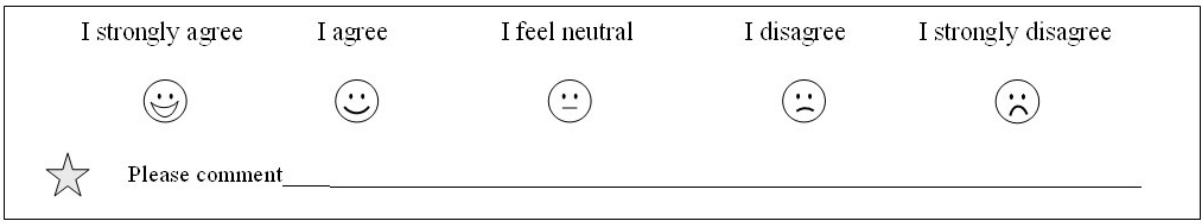


Please go to question 37.

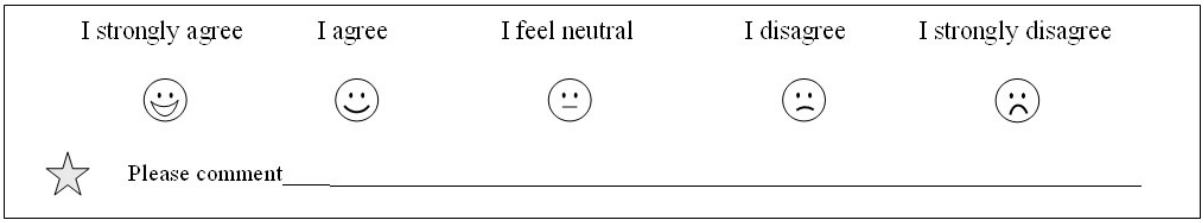
34) The chair looks safe and secure when it is tilted.



35) The chair looks easy for a child to self-propel.



36) The chair looks more comfortable than my child's own chair.



.....

37) For each item, please rate the importance of the following features in regards to pediatric wheelchairs

1= very important
2= somewhat important
3= not very important

___ Comfort
___ Appearance
___ Independent mobility
___ Adjustable tilt and/or recline
___ Safety
___ Postural support
___ Transportability
___ Promotes function
___ Improves participation
___ Fun
___ Growth adjustability

38) Considering these 3 aspects of the PALM Wheelchair, is there anything you would change if you could? Explain your answer.

Tilt mechanism:

Seating:

Appearance:

Overall function:

Quality:

☺ Thank you very much for your time. ☺
We appreciate your participation!!

PALM Wheelchair Questionnaire for Clinicians

Demographic Information

Please answer the following questions about yourself.

DOB: _____/_____/_____
(MM) (DD) (YY)

Gender: ☐ Female ☐ Male

Ethnicity:
☐ African -American
☐ Asian -American
☐ Hispanic
☐ White
☐ Other

1) Rate your knowledge on each of the following topics: record the appropriate number in the box.

1= very knowledgeable
2= some knowledge
3= no knowledge

___ Clinical needs of pediatric wheelchair users

___ Clinical needs of wheelchair users in general

___ Technical aspects of wheelchairs in general

___ Technical aspects of pediatric wheelchairs specifically

2) What is your professional background? Check all that apply

___ Medical Doctor

___ Physical Therapist

___ Occupational Therapist

___ Physical Therapist

___ Rehabilitation Engineer

___ Rehabilitation Tech Supplier

___ Rehabilitation Counselor

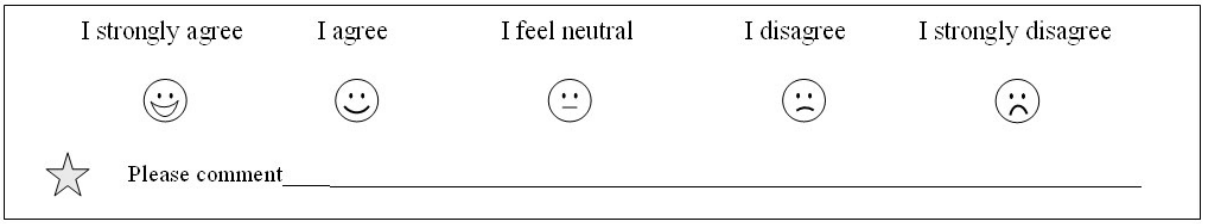
___ Other _____ (describe)

3) By what means have you gained most of your knowledge of pediatric wheelchairs? Check all that apply

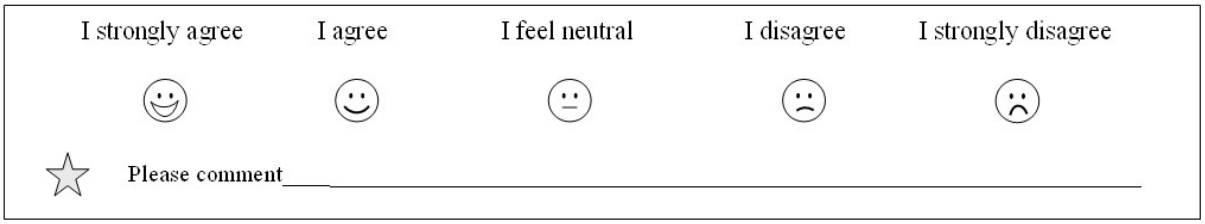
___ Clinical Experience
___ Coursework and/or non-clinical training
___ Engineering experience
___ Journals, books, websites, professional publications

For each statement below please circle the response that best indicates your opinion. If you have any comments please circle the ☆ symbol in the response box and comment on the line provided.

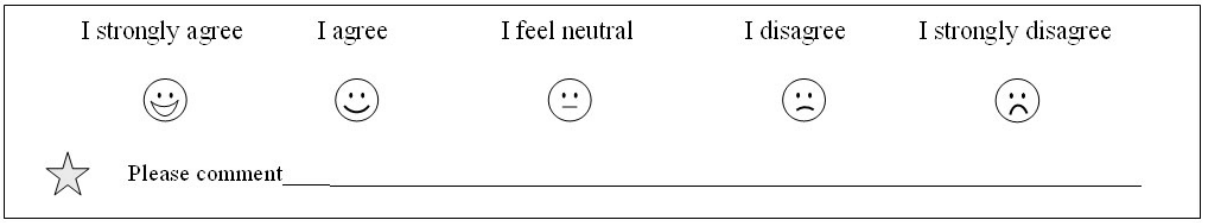
4) The tilt mechanism operated smoothly.



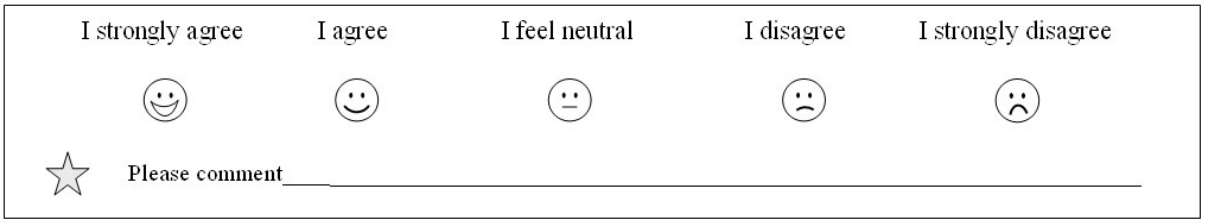
5) There were points during the tilting process where I could not easily work the mechanism.



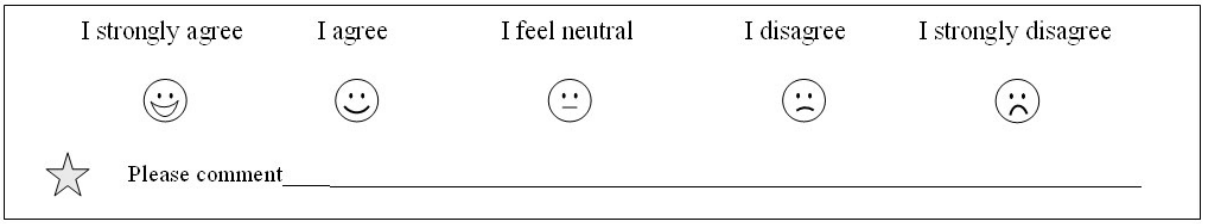
6) It was easy to switch from attendant-wheels to push rim-wheels.



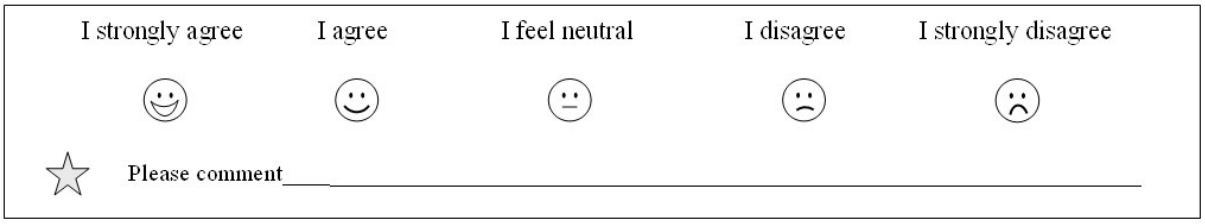
7) The PALM wheelchair was easy to adjust in order to fit the child.



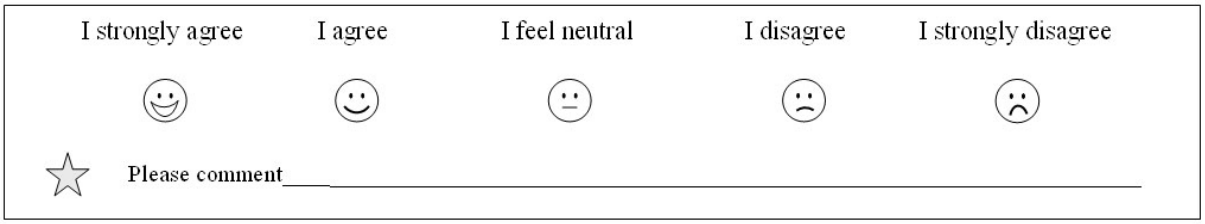
8) The PALM wheelchair could be transportable in a passenger vehicle.



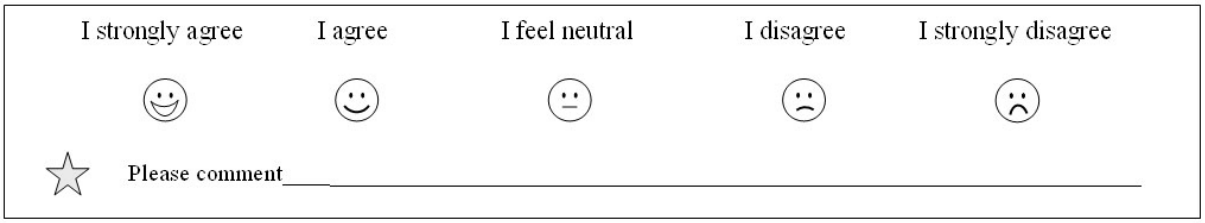
9) Teaching someone else how to use the PALM wheelchair will be easy to do.



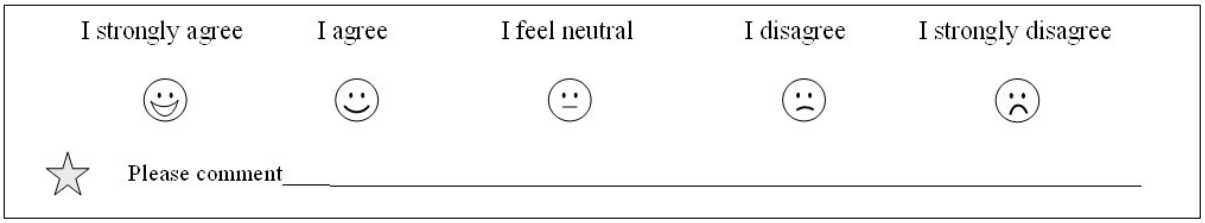
10) The PALM wheelchair has a pleasing appearance.



11) The PALM wheelchair is more attractive than most manual tilt-in-space wheelchairs that I have seen.



12) The PALM wheelchair looks like a high quality product.



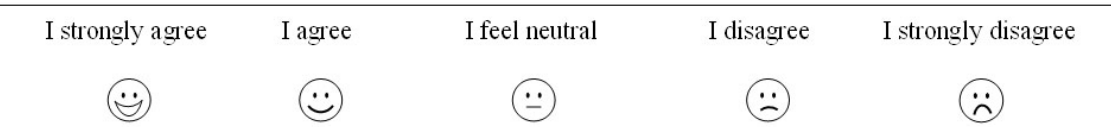
13) When the chair is tilted, the child seems comfortable.

I strongly agree | I agree | I feel neutral | I disagree | I strongly disagree

Please comment_____

14) When the chair is tilted, the child seems to be safe and secure.

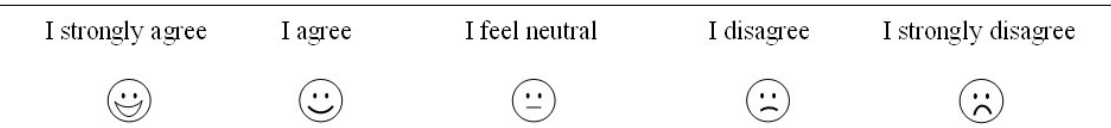
I strongly agree | I agree | I feel neutral | I disagree | I strongly disagree



Please comment_____

15) The chair has enough adjustability to accommodate the child's propulsion needs

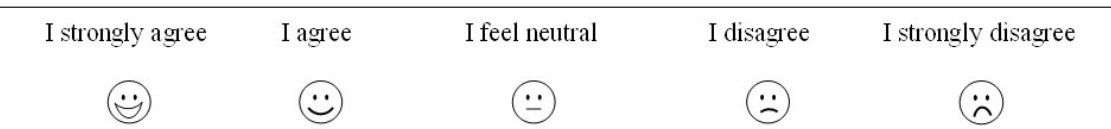
I strongly agree | I agree | I feel neutral | I disagree | I strongly disagree



Please comment_____

16) The chair has enough adjustability to accommodate the child's seating and positioning needs

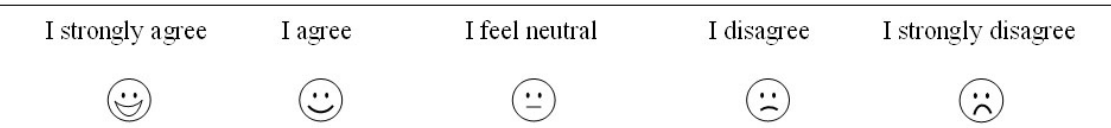
I strongly agree | I agree | I feel neutral | I disagree | I strongly disagree



Please comment_____

17) The chair is easy for a child, who is able, to self-propel.

I strongly agree | I agree | I feel neutral | I disagree | I strongly disagree



Please comment_____

18) Please rate the importance for each of the following features in regards to pediatric wheelchairs.

1= very important
2= somewhat important
3= not very important

☐ **Comfort**	☐ **Transportability**
☐ **Appearance**	☐ **Promotes function**
☐ **Independent mobility**	☐ **Improves participation**
☐ **Adjustable tilt and/or recline**	☐ **Fun**
☐ **Safety**	☐ **Growth adjustability**
☐ **Postural support**	

19) Considering the following 3 aspects of the PALM wheelchair, is there anything you would change if you could? Please explain your answer.

Tilt mechanism:

Seating:

Appearance:

Overall Function:

Quality:

Other:

☺ Thank you very much for your time. ☺
We appreciate your participation!!

APPENDIX B. FOCUS GROUP TRANSCRIPT

The following discussion transcript was recorded during a focus group dated May 2007 as part of the U.S. PALM work. Three discussions were recorded in all, the most recent focus group is included here as evidence of the work.

PALM focus group discussion transcription

Monday May 31, 2007

C= focus group coordinator speaking

S= Clinician subject speaking

P= Parent subject speaking

S a pin or something like that so that if it does come off you have a pretty good idea where it goes

S if the foot rests adjusted separately I think it would help

C different angle adjustments?

S you can adjust the height right? But the angle you can't?

C not independently

S so I think independently, the angle adjustment would be good

C and I'd like to have this mechanism here as well so that this is a quick release

S I'm all for a headrest that doesn't poke me in the chest and have a big beam sticking out of it

S yeah that would be good

S You said something about being able to put other people's cushions on here not necessarily use these. You weren't necessarily designing the cushions you were designing the frame more

C right

S I like how all your cushions come off easy. I think that if it's too difficult than they don't take them off and clean them

S yeah but if it's too easy then they get lost

S that's true

S I was thinking that if there was some kind of snap like with those side pieces. If they came down and snapped onto the frame it would be a little bit harder to get off but it would still be easy enough to wash

S I noticed that these were all velcroed together which might help keep them from getting lost. Something that makes it easy to get off but also something that makes it stay on.

S seat cushion usually that's not too much of a problem, but the side things. I'm thinking of one in particular. His feet never stop. That cover would be off in two seconds. Yeah he's got some athetosis and he just never stops moving. That cover would be gone and we'd be like, where'd it go?

S so this is really for height?

C yeah this is so you can adjust the height and you can remove this panel if you had a toddler size and then just use the top panel, slide it all the way down and in

S so it's still just one cover

C yeah the cover you'd have to buy one for the specific size of kid

S seatbelts?

C I didn't design that into it but it's on all other chairs so it should be.

S so do you think? We have a lot of kids with extreme tone, more involved, a lot of times. I'm just kind of wondering about the whole frame.

C yeah I just put this on with one bolt on to make it easy for you guys to adjust

S let me give you an example, like the footplates in particular we have kids that are just really strong and can stand and these footplates they get bent and oftentimes we just have to continually replace them and there's a little adjustment where the screw comes out and pops the plate angle up a little bit… I'm just kind of wondering about the general thickness or something.

S yeah like in this back here. Some of them are pretty powerful there

C this would need to be tested

S what kind of material is this?

C this is aluminum

S Which makes it lighter weight.

C maybe the seat back needs to be made out of this thickness here, like the footplates

S was this also designed to be able to make it a wider headrest or is this bar just for strength?

C just for strength

S all the pressure's going to be up here, this might need to be stronger (referring to length of lever arm on headrest)

inaudible

S I was just thinking that sometimes the kids will get their arms kinda out and around and oftentimes the laterals will kinda get their hands caught or their arm will dig into the lateral. If the upholstery maybe wrapped around more.

S the headrest too and this is well as this because even though this has padding on this side they'll push down on top of this and that will really dig in

S will there be an option to put a tray on?

C yeah, I didn't make one, but I put some slots here and with some different upholstery it is something that I think it's something important to have or maybe an arm pad.

S If you put a cushion would the height change? (pointing to side supports)

C yeah that would probably need to. I was thinking that this could be a receptacle for a different kind of armrest as well if you needed a different arm rest height there

S yeah that's true

S and how many pounds did you say?

C well this one hasn't been tested but this one would be up to 100 pounds

S I mean the weight of it to take it apart,

C the total weight of the chair? This model is 28 lbs. a lot of that is, these are really solid injection molded parts, and if these were injection molded then it could be lighter weight

S have you ever tried to put it in a trunk?

C I have put it in my trunk but I do have a hatchback

P I don't think that would fit in my mom's car, she actually has to take her's apart to fit in her car and I don't think that would fit in my mom's car, that's what we always look at when we look at chairs

P I bought my care purely because this fit in the trunk

P I drive a pacifica without the 3rd row seat so that I don't have to take this apart and I can just put it in. It's a convenience thing to not have to take the wheels off.

P and you said you can put big wheels on the back if they want to self propel

C Yeah although I think probably a kid who self-propels wouldn't need tilt-in-space seating but at least that's what we got out of the last focus group but the idea is that you could take some of the same components and build different chairs out of them

S that's the whole point of having a modular chair

S so is this meant to come all the way back here (pointing to backrest)

C yeah it can go all the way back

S It's like a really cool recumbent bike

S there's no adjustability in the angle of these foot rests?

C plantar dorsiflexion? No

Inaudible

S this folds extremely flat

S like a regular stroller?

S about 28 inches. It's not all the way up but… (measuring from seat back to footplate with leg rests up)

S I like the knobs because you can twist them. I like the actual shape

S the knobs need to be attached to the bolt

C I could use a captive screw so that it wouldn't get lost. Do you think it would be useful to have a push button quick release at those points where I have a knob?

S how gummed up do they get with like syrup?

C maybe we should do that in testing? Pour syrup on them

S some of the tube feeding formulas and things like that

S also how much force can those take, because for the footplates, they're going to put a lot of force on those.

S sometimes when you try to break the screws loose you can't because it's crusted with food

S I have a regular stroller that has these things and when I went up over a curb it cracked

C really? Where?

S right in here (at the joint) and my daughter is 30 lbs

C that's kind of upsetting because I took these off another pediatric wheelchair

S this was a regular stroller so I don't know but it is the same sort of thing. I had it in a wheelie going up a curb. The company told me that it's not meant for curbs, but that's what you have to do.

S Do you think this chair could get enough weight to actually tip backward?

C you mean, does it need anti-tippers?

S yeah, there are not tippers and I was just kind of wondering

inaudible

C If you guys feel you've gotten enough of a feel for the chair, then you can work on filling out the questionnaire

S Is there also a way that you could color code the adjustments? Like height, because there are so many different holes there. Like if you had all reds for this height range to make it easier for those of us who making the adjustment.

Inaudible

S Even our most dependent kids still stand sometimes and I was just thinking about how to get the leg rests away I mean

S well she pushed it back all the way to do transfers but I don't know if those footrests, but she said they adjust independently height wise, could they swing away that way? Like could you make a release so that whenever you flip them up they could swing out to the side

C I didn't put a lot of thought into it, I can show you how the height adjusts though.

S Is there a plate underneath there to hold them together?

C yeah (shows foot plate height adjustment)

S oh ok, but once those are set at a height then they can't do that

C I'm thinking though that if it were a quick release then you could have that
But would the bar be in the way?

S no because if you tilted it all the way up (anterior tilt). Oh but then the wheels would be in the way

S could the footplates swing inside? Underneath the chair? The wheels would be in the way then

C yeah, we could do that.

S yeah because what happens when you get the kid and everything's ready and then you realize you're still 4 inches away from the toilet? And then the casters

C so you guys are saying that it would be best if the footplates swing away

S well most of the kids we see do some sort of stand for a short…

S well, it's something we encourage so that when they're adults they can at least stand enough to help with transfers

S so if it could swing away enough to allow for a standing pivot transfer

S well and this chair is low. I think a lot of the tilt chairs are really high therefore a lift transfer or a 2 person transfer is because it's high. But if it's low then it's actually beneficial for the kid to do a stand. This wouldn't be as good for a caregiver if they're actually picking up so I guess it depends on what kind of person you want to

S unless you could make it like a barber chair

C do you have any chairs like that

S no only the power ones, they can even take them to a standing position

S I always thought a chair should be able to somehow ramp down. If you had some type of mechanism that could do that. Not necessarily power

C like the permobil that gets down to the floor?

S what do you mean like the seat comes forward so that can sit in it and then comes back?

S I mean so that whenever they need to transfer the seat could glide down so their feet could touch the ground and help with transfers then it would slide back again and bring them to a normal working height

S aren't there feeder seats like that? With a hydraulic? I think it's marketed as a feeder or functional seat where it can go to floor height to transfer out of or at table height to be up with peers. Is that the tiger?

S yeah, the one with the seat that goes on different bases. A stroller base and then a hi/low base. Peer height, table height

S it's not a mobility device, but I think there's a lot of funding issues with it because they say you know you can eat in your wheelchair

P Hannah uses her wheelchair herself and we encourage that, but for me to push her myself to go walking. It's not comfortable. If she could have the best of both worlds and then I would love it. Like we went to Europe last year and to push that through Europe was just

absolutely awful (referring to canes on small manual pushrim chair). And look how high it is how can I be comfortable like that, where as that is more like a jogging stroller and it would be more comfortable and I like that aspect of it. I think you'd be able to market that to both self-propel and attendant

C or maybe make a push handle that could fit on a small manual wheelchair

P yeah, but she;s had a little manual chair since she was 2 years old and the other one had a big stick that stuck out. Yeah, it was a quickie…

I do like that feature of it and now that it's all upright, if you put wheels on that she could propel that herself

S It does seem like it is slanted lower. So that the front is lower. Not a perfect 90 which is helpful for a transfer, but the wheels and the footplates are a bit of a

C the casters being out in front are a problem for transfers?

S actually the side apart is nice because somebody could get in

S I'm thinking I don't know about a toilet but for a chair you could get the leg between the footplate and the caster, but then the footplates have gotta be able to come off.

P you're talking about transfer where your kids can stand up or even partially. Where I think about transfer I think of sliding because she can't stand on her feet at all. She has to go to side

S so she'd have to get those laterals off

P she needs the laterals for her back

P I like that it tilts forward, because for her that would help her to become more independent. You have to think of that even though you were looking for a very involved child. A lot of that stuff will help you know someone like my daughter to become more independent

S it is frustrating, I think the main frustrating thing about the tilts is that because they're so high you can't teach any functional things because they're so high off the ground

S I really like this chair compared to the other one, the fabric is much lighter, the design is cool. I like it (participated in 1st focus group)

S could that frame be made so that it collapsed more so that it could fit into a trunk

C so that it was narrower?

S how low does it go? Can you shrink that?

S I'm actually thinking of bringing the wheels closer laterally, those two bars on the sides, could they collapse somehow?

S well that makes the base more fragile right?

S right, but if there's a way that you could make it unlocks but when it locks back down it's reinforced

C It's possible

S We have two moms here who both express that it's a big factor

P and I'm lazy just keep that in mind. I buy cars and suvs so that I don't need to take things apart

C so what you're saying is that if the overall width could somehow collapse

S I was wondering, when it's all collapsed down, how tall is it

C do you guys have any experience with quick release casters. I thought that maybe the caster could be quick release and if the casters came off and the wheels came off then the overall height would be shorter

S as long as that center doesn't collapse down anymore then quick release casters would be a pretty good option. Like this chair, the casters are quick release, it's not actually quick but it does release. If I have someone else's car, that's an option I sometimes use.

C Does it need a tool?

S no, it's just this screw and then it comes down, it's still a pain and it takes me 20 min to remember how to put it back on

S Have you put that in a trunk?

C I do put it in my trunk, but I have a hatchback.

S I'm wondering if you actually put it in a pop-up trunk

C I haven't

S I think if you made more moveable parts in that frame, I think that would not be a good idea. Because how would you do that? You'd have to make it fold.

S that adds weight

S and those folding tilts often times there's so much movement in them that they're assymetrical. Are all of them on cables that tilt?

C all the ones that I've seen, the manual tilting

S I guess you'd have to have that. I guess that I always think as soon as you put moving parts

C so are you saying that because of the tweaking that happens in the cross frame, sometimes the tilt mechanism isn't very smooth anymore?

S yeah, all of a sudden they're no longer in alignment

S you might not get that with a footplate that's attached or with this design. I don't know. But I know that's something parents don't like with the folding tilts and they get it because they think they're going to break it down, fold it and put it in a car, but they never use it like that, because it's too hard to figure out how to get it back symmetrically and then what happens is the seat doesn't go on right and that's why they come in and the whole seat's not attached to the frame or like one tilt is up and one tilt is back and the footplates are kinda like this and so I don't like it

S and then there's cables that get corroded and it either locks into like falling or dropping backward

S could those red bars be some type of quick release that it falls on top of it, know what I mean?

C that would allow this to come down

P I think you need to make it more flat to fit into a trunk then you'd have to see how the seat would fit in. I guess you'd have to put it on it's side on top of it.

S The seat you could almost put in a seat with a seat belt

S also if you could make it so it could work as a car seat too. That would be awesome

C yeah, further down the road. This needs more design, but the idea is that it could be used as a car seat. This isn't crashworthy though

S I do think it would be interesting if the casters could come off because we're always… front casters are cumbersome for 2 reasons. 1, if you're transferring against something but also getting the leg rests out of the way

Inaudible

S One of the questions is, it's easy to switch from attendant wheels to pushrim wheels, can you do that now? Is that one of the quick release options

C it's not really applicable to this questionnaire, because we didn't do it in the focus group, but if you unscrew this bracket, and put it here then you can put on a 20" wheel.

Measure focus group participant (child's) wheelchair

P So you'd be able to take any standard wheel and put them on there?

C I also thought this would be useful for a power assist wheel

P we have those at home too. They're hard. You ever try those? She did a 360 at the mall one day trying to use them

S it must just be a learning curve though

P oh yeah, it's a huge learning curve

S you can turn them down

P also, she uses one side to propel more than the other so she…

S You can also make one the sensitive one and the other harder for the strong arm

P We take her for practice every once in a while. When we got the new wheelchair we got power assist, because they wanted to put her in a power chair and I didn't want to put her in a power chair, but the gentleman was saying she's going to rip her rotator cuffs and all those things, so I agreed to and met them half way and agreed to power assist wheels. My whole thing was that I wanted her to keep propelling

inaudible

S These adjustments are the kinds of things that are going to happen when you first put the kid in there, once the kid is in there, they're going to happen less often, so it wouldn't take as long. I'm thinking if you can start with the kid in one plane and then it can grow with them, it could technically last a very long time. Either that or you have multiple parts which increases the cost, I guess so. It's kind of a pain to do it the first time, because you've got all these pieces, but once you get it in there til they grow enough. Yeah I don't think it's too much of a hassle.

S So if you had the pushrim wheels, they'd fit into that hole. You just don't have them in there now.

C So this comes off like this (demonstrating removing wheel)

S oh ok. So if someone was going to go from one to the other, they would have two of those brackets in there. I'm thinking if it was a family and they were going to switch them, they would need to have two at what ever setting they would need to have it, so they could just switch the wheel easily.

S now if you're going to want to put 22" you're going to have another adjustment,

C yeah, because this is for 20". These holes would need to be one inch higher up for 22" wheels

S so this is designed specifically for a 20" wheel

S for some reason, the 20" wheels are hard to push. I think the 22 just makes everything easier

P and I agree, someone mentioned a seatbelt, you're gonna need a seatbelt especially when kids are propelling themselves because even when she's not moving she's freaked out if she's not strapped in and her little chair she's rolled out before too, so and I think if they're gonna propel you need to tippers too

S I don't know why but in our school we have tons of kids in tilt mechanisms with those mechlocks that are constantly broken. We do a monthly wheelchair clinic and they're constantly broken.

C really? Do you know where? The cable breaks?

S I'm not sure which part of the mechanism actually breaks. That's a good question I could ask, but both the hub locks and the mechlocks. Because most kids now have the brakes that have cables. I don't know where it is

C It's probably in the cable I would think but that's a good question

S the cables getting pulled or abused somehow

S if it's broken, it takes a while to get the part. What we do is we use those plastic zip ties and we cinch the chair down in one angle because they can't use the handles. I always thought it'd be good to have an extra cable with the chair. The guys that repair them do know.

P you ask a money question in here. I wouldn't know how much to pay for a wheelchair because you know in Pennsylvania we have the two insurances so I wouldn't know what to circle because my double insurances will cover it. I haven't paid out of pocket for any of them

P If it's under 800$ insurance isn't going to cover it anyhow. Hers just barely made the limit. They almost didn't pay for it because it didn't cost enough

S it's ridiculous because other things they won't pay for, because they cost too much

P we had to get a couple extras so that they'd cover it

C Is adjustable upholstery something that you think would be beneficial or something that you've seen with chairs?

S no.

S I'm wondering adjustable upholstery?

S I personally think that when you grow a chair, the upholstery's going to be done and you're gonna need a new piece.

C yeah, I guess it will get worn out

S yeah it really does

S I have a concern about losing those pieces (the upholstery)

S I think snaps are a good idea. Snaps that snap to the frame

S there are some chairs I'd love to clean

S we power wash some kids chairs. We take them out and power wash them in the morning and dry them all day long

S some of those upholsteries don't come off and they get dirty!

P I don't even know how her seat would come off, I'm not educated on my daughter's chair unfortunately. There are times though where she has spilled ice cream

P I'm telling you though, I'd love to have a handle like that to push

S Oh yeah

P just to go walking and things like that it would just be

S I think a lot of parents think that and I think that's what we… wasn't that one of the big feedbacks last time, a handle that was adjustable and you could just adjust like a stroller

S What about the tippers. That's a disadvantage of those tippers, when you step to tilt it back, you kill your toes

S yeah, lots of parents take them off and then you can't get them up on a curb either. It's not really functional but then when you're self-propelling you need it

S we do have lots of kids with tone who, they're not propelling but the chair's moving.

S yeah, their center of gravity is constantly changing

S we just tested this out and we like this a lot. How close you can get to a chair.

S how about a toilet

S as long as we can get the footplates up and out of the way, then we can slide this in and right next to the chair. I'll use this chair as an example

P or if the footplates were reinforced enough that they could transfer on them because it's only reinforced up to 100 lbs. I think it's long enough that if you stood on it, the chair would be counterbalanced and not tip forward

S So, depending on if you would want to make it strong enough for that. But as we were saying, if the footplates came up and out of the way for transfers, it'd be really nice.

P or if the footplates were strong enough, she could get up off the floor, she could bump up onto the footplates and then bump up onto the chair.

P that's why it's nice that you have the anterior tilt. I think you should make it for both kinds of kids in mind, because there are lots of features that I like that I would look into getting

S It's nice that it's a low chair and that's a very good thing

S yeah they're usually so high. They're focused on the caregiver's back

P we had a little quickie that was lower. The reason we got the higher chair was so that she could be eye level with her peers and still propel. I like the tilt (anterior) because I could teach her to be independent. I could tilt it and then say, so how are you going to get out of the chair?

P It's also good if you're out in the community and you need to do some hygiene things she's laying back. With no facilities, that's kind of nice.

P well I have that problem, because she's now to old to take her into the baby changing room, so now we're going into the handicapped bathroom and I end up laying her down on the floor in order to do what I need to do.

S so, a tilt-in-space would be nice because then you could do that in the tilt in space and get her up off the floor

S also though if you tilt a child who doesn't have enough trunk control. I don't think I've ever transferred somebody with an anterior tilt like that, have you?

S I can't think of any place where we'd have the ability to. I don't know of anychair that does that. The low part's good, but it is tilted forward, that's really far forward.

S but is that something that could be if needed locked so it couldn't go beyond that certain point is that what you're talking about?

S no, I'm just talking about that anterior tilt, I've just never done it

C the idea is, I didn't think about the anterior tilt being good for an independent transfer. I thought maybe that would help the caregiver, bringing the kid forward but it's interesting that you bring that up. It's something I never thought of, for a standing pivot transfer.

S It does make it easier to transfer out

S It also helps with gravity even just to push their hips forward if they could even just do that tiny bit

C that's another thing, some people said earlier that in school, a little anterior tilt can help a kid to lean closer to the table was a good thing

S yeah that's good too

C so if you have any more thought? Otherwise, I thank you for your feedback

S I'm kind of curious how a seat belt would anchor.

C I think maybe to the frame

S we have a 4 point lap belt, but I don't know how you'd anchor it with the handle the way they are now

S never attach it to the backrest. It has to adjust with them too, as you adjust the chair.

APPENDIX C. CAD DRAWINGS

Table 12: Parts spreadsheet for Final PALM prototype

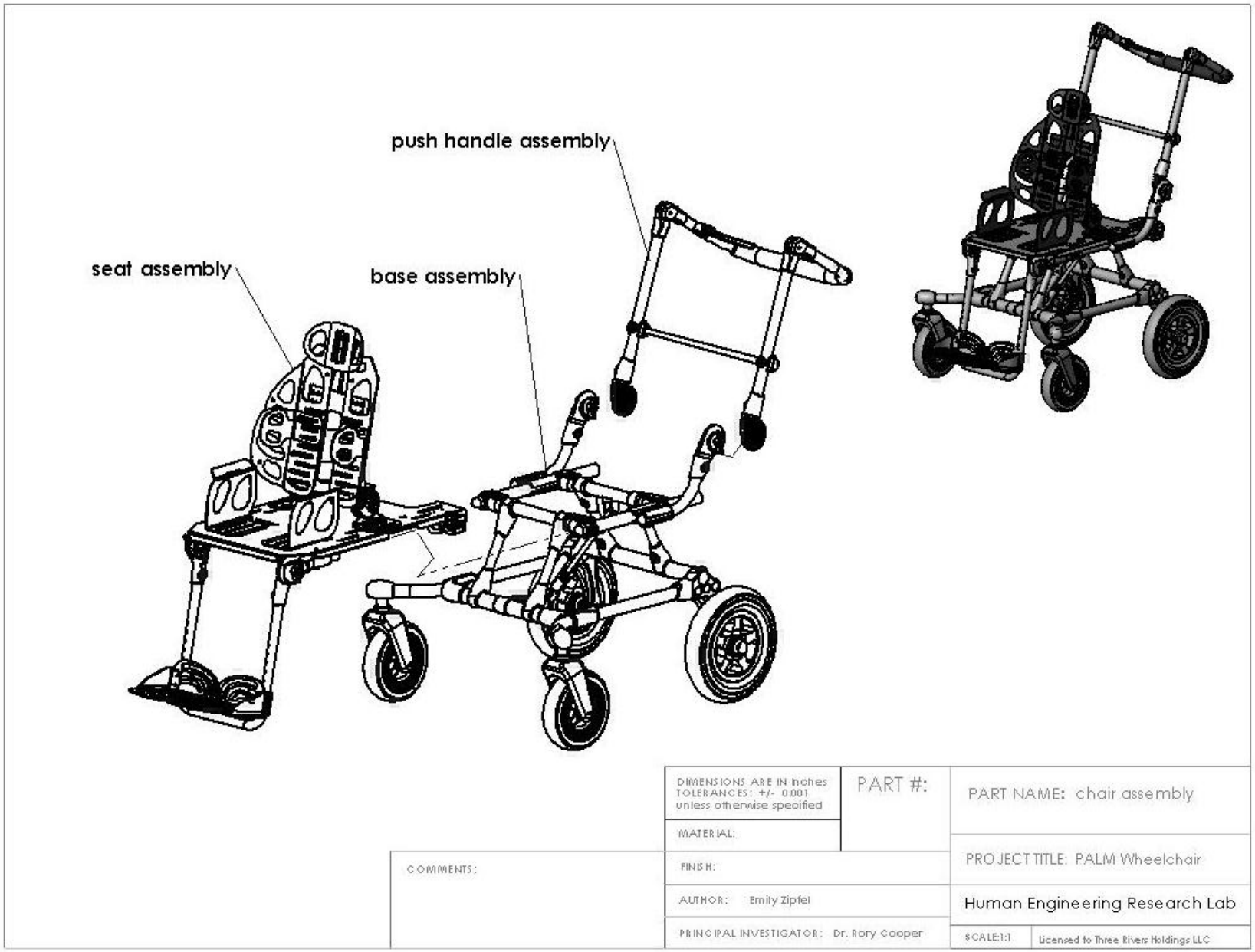
Sub-assembly name	part #	Part name	# parts	source	prototype Material	protoype stock/ hardware specs	prototyping process	drawing
Backrest								
	a1	backrest attachment bracket	2	HERL	6061 al	0.125" sheet	CNC mill, bend	x
	a2	backrest bottom panel left	1	HERL	6061 al	0.0625" sheet	CNC mill, bend	x
		backrest bottom panel right	1	HERL	6061 al	0.0625" sheet	CNC mill, bend	mirror
	a3	backrest center panel	1	HERL	6061 al	0.125" sheet	CNC mill, bend	x
	a4	backrest pivot joint	4	HERL	SLA resin		SLA	x
	a5	backrest top panel right	1	HERL	6061 al	0.0625" sheet	CNC mill, bend	x
		backrest top panel left	1	HERL	6061 al	0.0625" sheet	CNC mill, bend	mirror
	a6	headrest bracket left	1	HERL	6061 al	0.0625" sheet	CNC mill, bend	x
		headrest bracket left	1	HERL	6061 al	0.0625" sheet	CNC mill, bend	mirror
	a7	headrest plate	1	HERL	6061 al	0.0625" sheet	CNC mill, bend	x
	a8	headrest spacer	1	HERL	delrin			x
	a9	knob	4	HERL	plastic	SLA resin	SLA	x
	a10	lateral trunk support	2	HERL	6061 al	0.0625" sheet	CNC mill, bend	x
Seat								
	b1	footrest attachment bracket right	1	HERL	SLA resin		SLA	x
		footrest attachment bracket left	1		SLA resin		SLA	mirror
	b2	front cross tube	1	HERL	6061 al	0.75" OD 0.060" WT	cut, drill	x

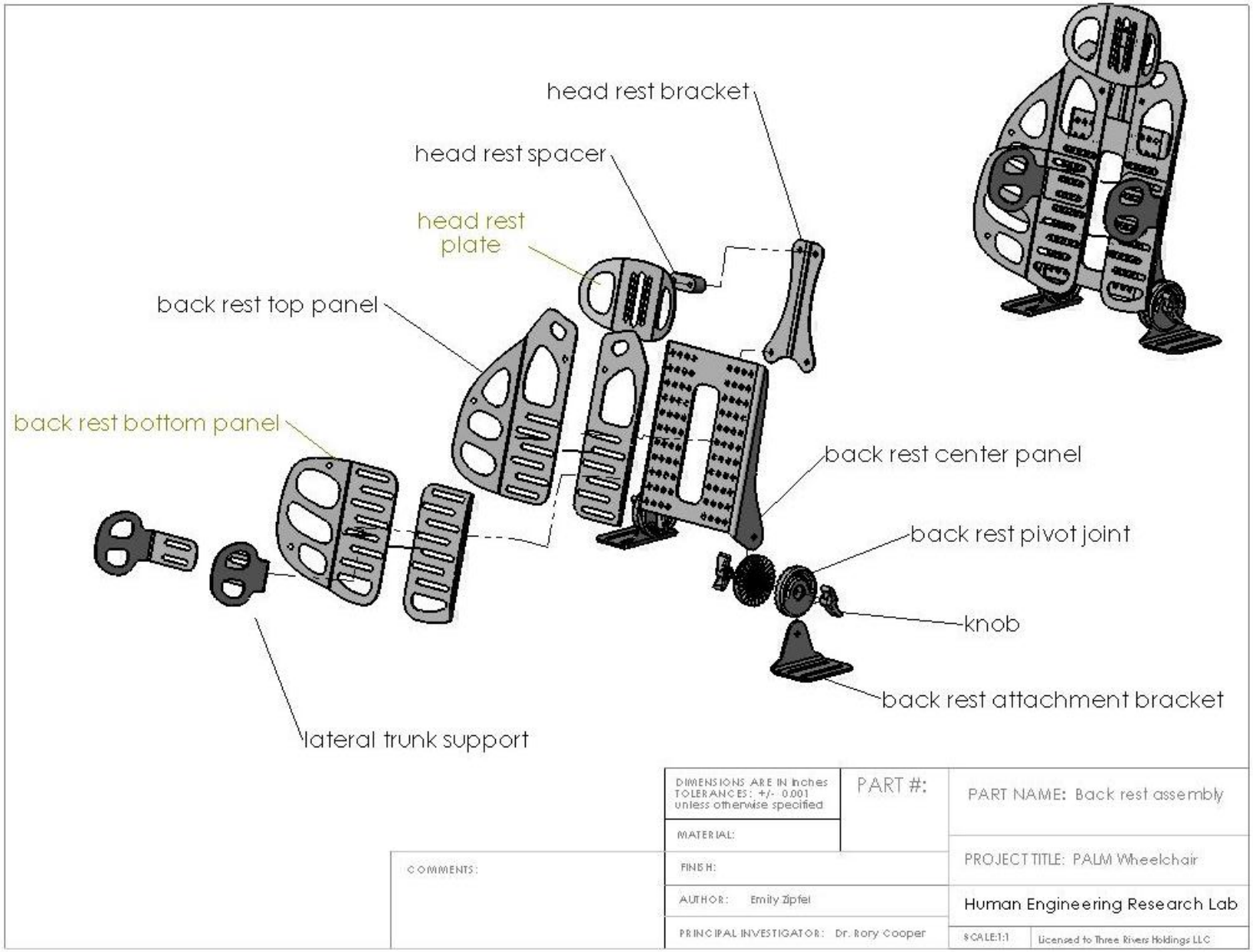
						tube		
	a9	knob	4	HERL	plastic	SLA resin	SLA	x
	b3	seat bottom plate	1	HERL	6061 al	0.0625" sheet	CNC mill, bend, manual mill	x
	b4	seat pan tube	2	HERL	6061 al	1" OD 0.060" WT tube	cut, drill	x
	b5	side support left	1	HERL	6061 al	0.125" sheet	CNC mill, bend	x
		side support right	2	HERL	6061 al	0.125" sheet	CNC mill, bend	mirror
	b6	0.75" tube plug	2	HERL	6061 al	al rod	turn, drill, tap	x
Seat clamp								
	c1	bottom clamp	2	HERL	6061 al	bar stock	edm, mill, ream, tap	x
	c2	clamp pivot block	2	HERL	6061 al	bar stock	mill, drill, tap	x
	a9	knob	2	HERL	SLA resin		SLA	x
	c3	top clamp	2	HERL	6061 al	bar stock	edm, mill, ream, tap	x
Footrest								
	d1	footplate right	1	HERL	6061 al	0.125" sheet	CNC mill, bend	x
		footplate left	1	HERL	6061 al	0.125" sheet	CNC mill, bend	mirror
	d2	footplate bracket right	1	HERL	SLA resin		SLA	x
		footplate bracket left	1	HERL	SLA resin		SLA	mirror
	d3	footrest pivot joint	2	HERL	SLA resin		SLA	x
	d4	footrest tube	1	HERL	6061 al	0.75" OD 0.060" WT tube	cut, bend, drill	x
Top Frame								
	e1	0.875" end cap	2	HERL	SLA resin		SLA	x
	e2	0.875" tube plug	2	HERL	6061 al	al rod	turn, drill, tap	x
	e3	1" top frame tube plug	4	HERL	6061 al	al rod	turn, drill, tap	x
	e4	push handle bottom tube	2	HERL	6061 al	0.875" OD 0.60 WT tube	bend, drill	x

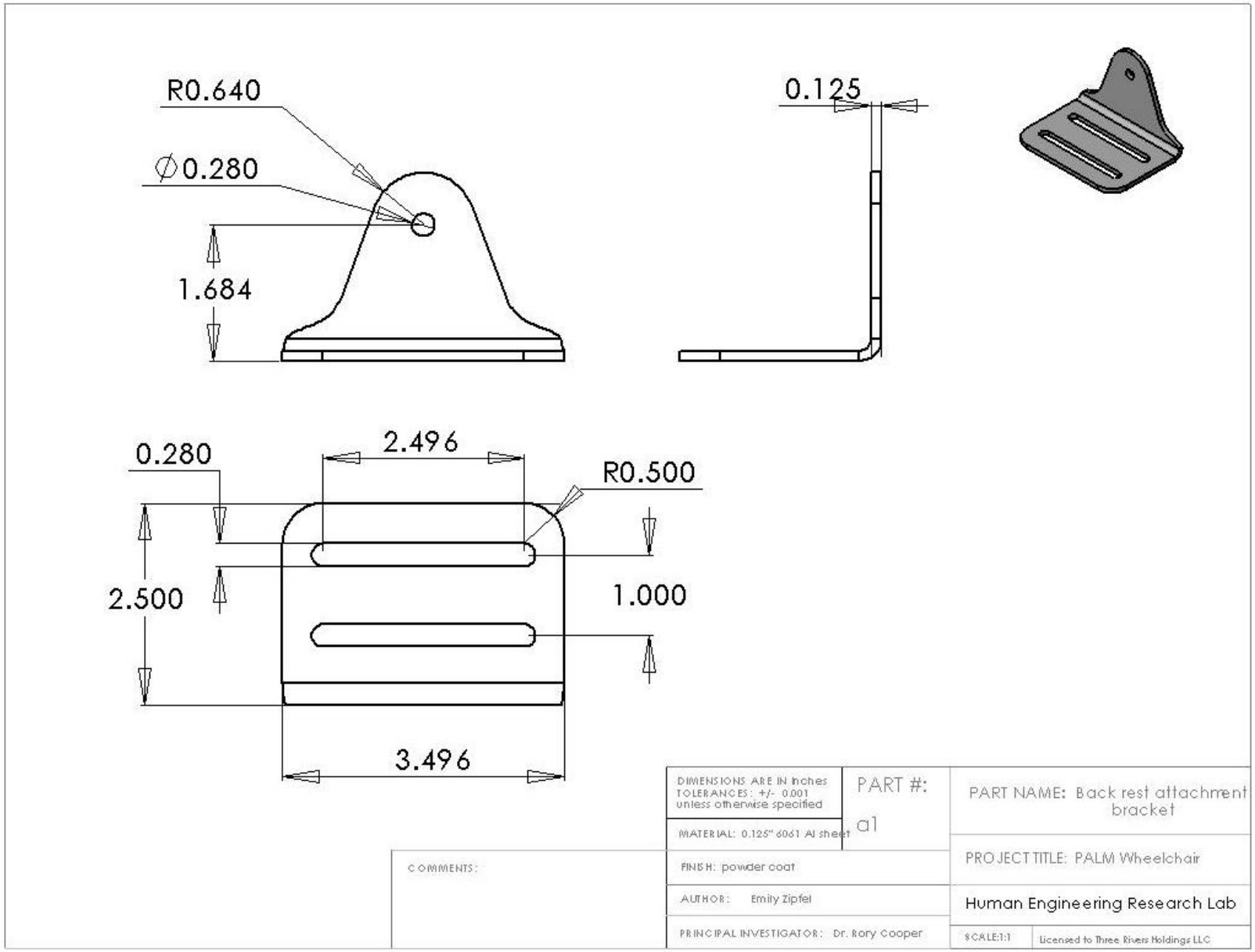
	e5	push handle bracket	2	HERL	SLA resin		SLA	x
	e6	push handle clamp	4	HERL	6061 al	bar stock	EDM, drill, tap	x
		mechlok bracket	1	OEM				
	e7	seat tube plug	2	HERL	delrin	rod	turn, drill	x
	e8	screw cap	4	HERL	SLA resin		SLA	x
	e9	top frame bracket	4	HERL	SLA resin		SLA	x
	e10	top frame front cross tube	1	HERL	6061 al	1" OD 0.060" WT tube	cut, drill	x
	e11	top frame rear cross tube	1	HERL	6061 al	1" OD 0.060" WT tube	cut, drill	x
	e12	top frame side tube	2	HERL	6061 al	1" OD 0.060" WT tube	cut, drill	x
Linkage arms								
	f1	front linkage arm	2	HERL	6061 al	0.75" OD 0.060" WT tube	cut, drill	x
	f2	rear linkage arm	2	HERL	6061 al	0.75" OD 0.060" WT tube	cut, drill	x
	f3	pivot arm joint	8	HERL	SLA resin		SLA	x
	b6	0.75" tube plug	8	HERL	6061 al	rod	turn, drill, tap	x
Mechlok assembly								
	g1	0.75" end cap	1	HERL	SLA resin		SLA	x
	b6	0.75" tube plug	1	HERL	6061 al	rod	turn, drill, tap	x
		mechlok	1	OEM				
	g2	mechlok clamp	2	HERL	6061 al	bar stock	EDM, drill, tap	x
	g3	mechlok joint	1	HERL	SLA resin		SLA	x
	g4	mechlok tube	1	HERL	6061 al	0.75" OD 0.60 WT tube	bend, drill	x
Push handle								
	e2	0.875" tube plug	2	HERL	6061 al	rod	turn, drill, tap	x
	a9	knob	4	HERL	SLA resin		SLA	x
		push handle	2	OEM				

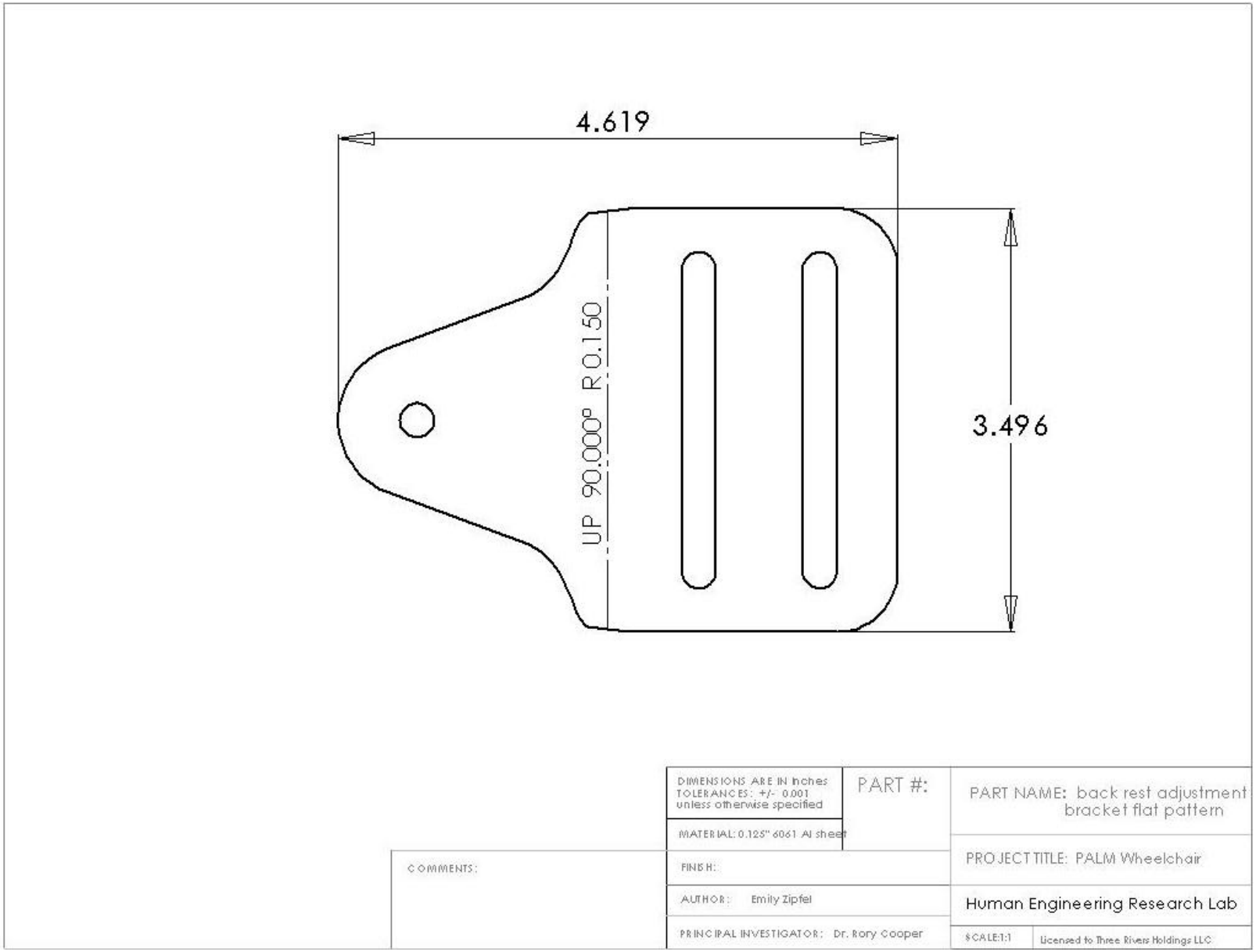
		adjustment bracket						
	h1	push handle brace bracket	2	HERL	SLA resin		SLA	x
	h2	push handle brace tube	1	HERL	6061 al	0.5" OD 0.60 WT tube	cut, drill	x
	e5	push handle bracket	2	HERL	SLA resin		SLA	x
		push handle grip	2	OEM				
	h3	push handle side tube	2	HERL	6061 al	0.875" OD 0.60 WT tube	cut, drill	x
	h4	push handle tube	1	HERL	6061 al	0.875" OD 0.60 WT tube	cut, drill	x
		locking handle	2	OEM				
		locking handle bracket	2	OEM				
	e8	screw cap	2	HERL	SLA resin		SLA	x
Bottom Frame								
	i1	1.0 tube plug	4	HERL	6061 al	rod	turn, drill, tap	x
	i2	axle insert	2	HERL	mild steel	rod	turn, thread, mill	x
	i3	bottom frame front tube	1	HERL	6061 al	1" OD 0.060" WT tube	cut, drill	x
	i4	bottom frame side tube	2	HERL	6061 al	1" OD 0.060" WT tube	cut, drill, bend	x
	i0	caster assembly	2	OEM				x
	i5	caster end cap	2	HERL	SLA resin		SLA	x
	i6	caster stem spacer	2	HERL	6061 al	rod	turn, drill, mill	x
	i7	caster tube plug	2	HERL	6061 al	rod	turn, drill, tap	x
	i8	front inside spacer	2	HERL	6061 al	1.25" OD 0.035" WT tube	cut	x
	i9	front outside spacer	2	HERL	6061 al	1.25" OD 0.035" WT tube	cut	x
	i10	front plastic joint left	1	HERL	SLA resin		SLA	x

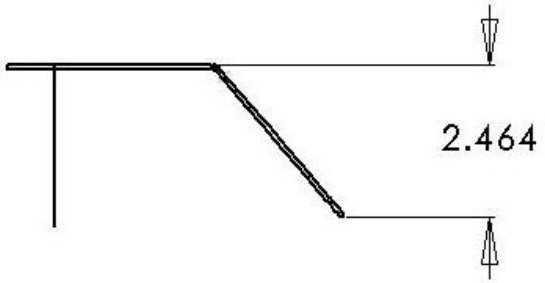
		front plastic joint right	1	HERL	SLA resin		SLA	mirror
	i11	rear inside spacer	1	HERL	6061 al	1.25" OD 0.035" WT tube	cut	x
	i12	rear joint end cap	2	HERL	SLA resin		SLA	x
	i13	rear outside spacer	2	HERL	6061 al	1.25" OD 0.035" WT tube	cut	x
	i14	rear plastic joint	2	HERL	SLA resin		SLA	x
	i15	rear wheel	2	OEM				x
	i16	wheel axle	2	OEM				x

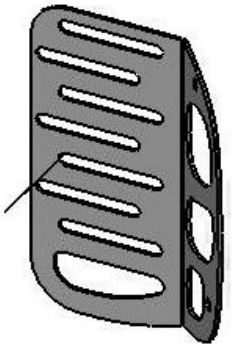

push handle assembly
seat assembly
base assembly
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
PART NAME: chair assembly
MATERIAL:
COMMENTS:
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:1
Licensed to Three Rivers Holdings LLC

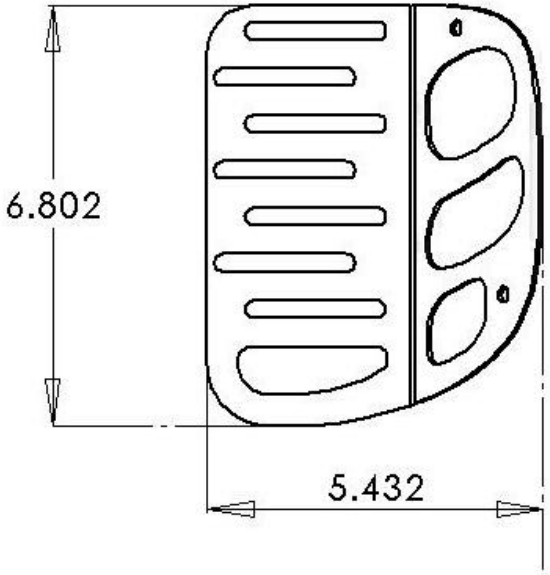

head rest bracket
head rest spacer
head rest plate
back rest top panel
back rest bottom panel
back rest center panel
back rest pivot joint
knob
back rest attachment bracket
lateral trunk support
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
PART NAME: Back rest assembly
MATERIAL:
COMMENTS:
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:1
Licensed to Three Rivers Holdings LLC

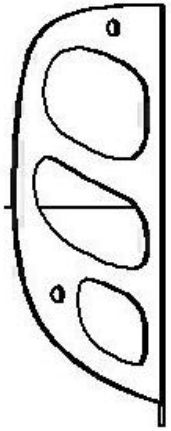

R0.640
∅0.280
1.684
0.125
0.280
2.496
R0.500
2.500
1.000
3.496
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
a1
MATERIAL: 0.125" 6061 Al sheet
FINISH: powder coat
AUTHOR: Emily Zipfel
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
COMMENTS:
PART NAME: Back rest attachment bracket
PROJECT TITLE: PALM Wheelchair
Human Engineering Research Lab
SCALE:1:1
Licensed to Three Rivers Holdings LLC


4.619
UP 90.000° R0.150
3.496
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
PART NAME: back rest adjustment bracket flat pattern
MATERIAL: 0.125" 6061 Al sheet
COMMENTS:
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:1
Licensed to Three Rivers Holdings LLC



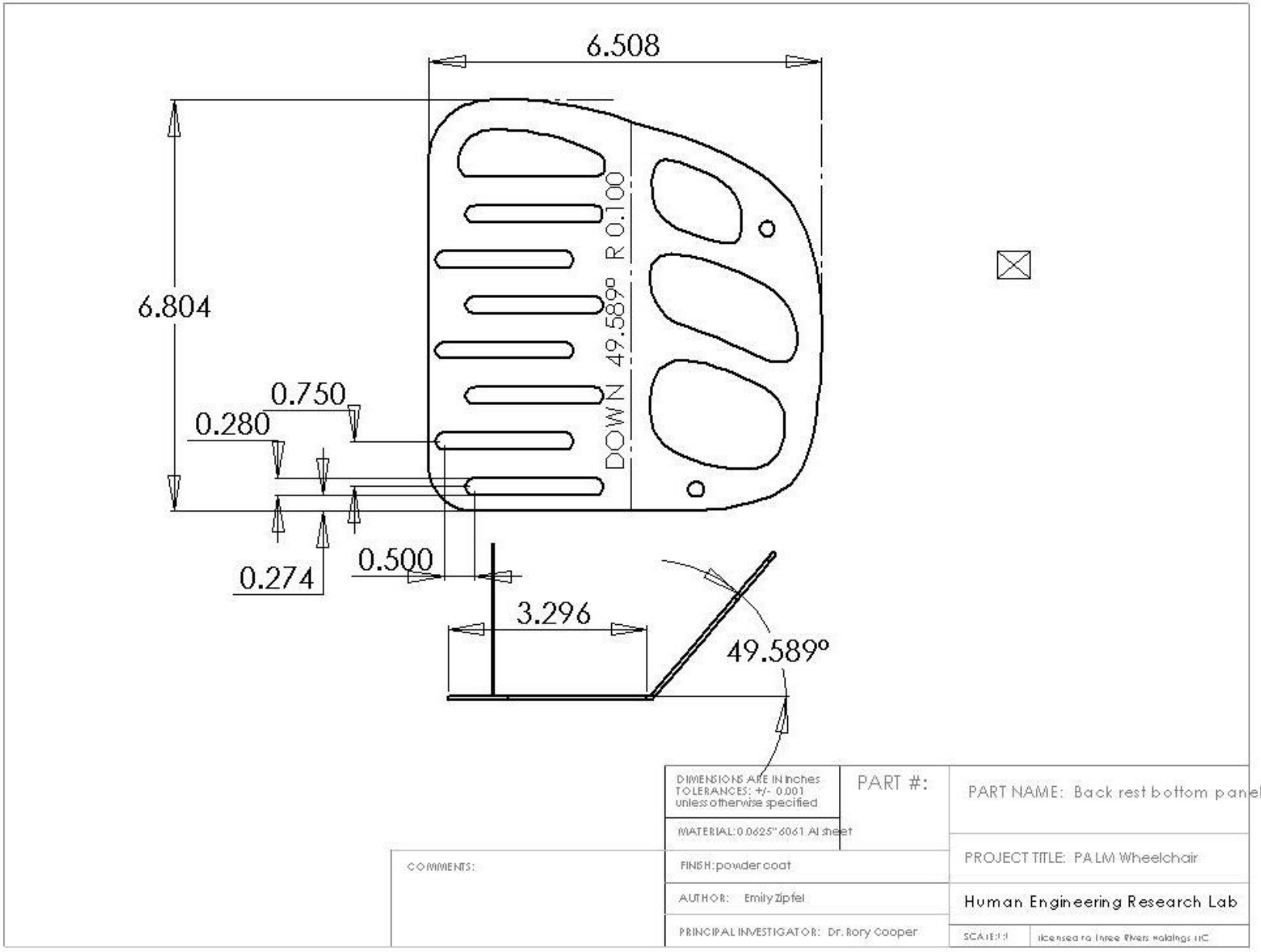


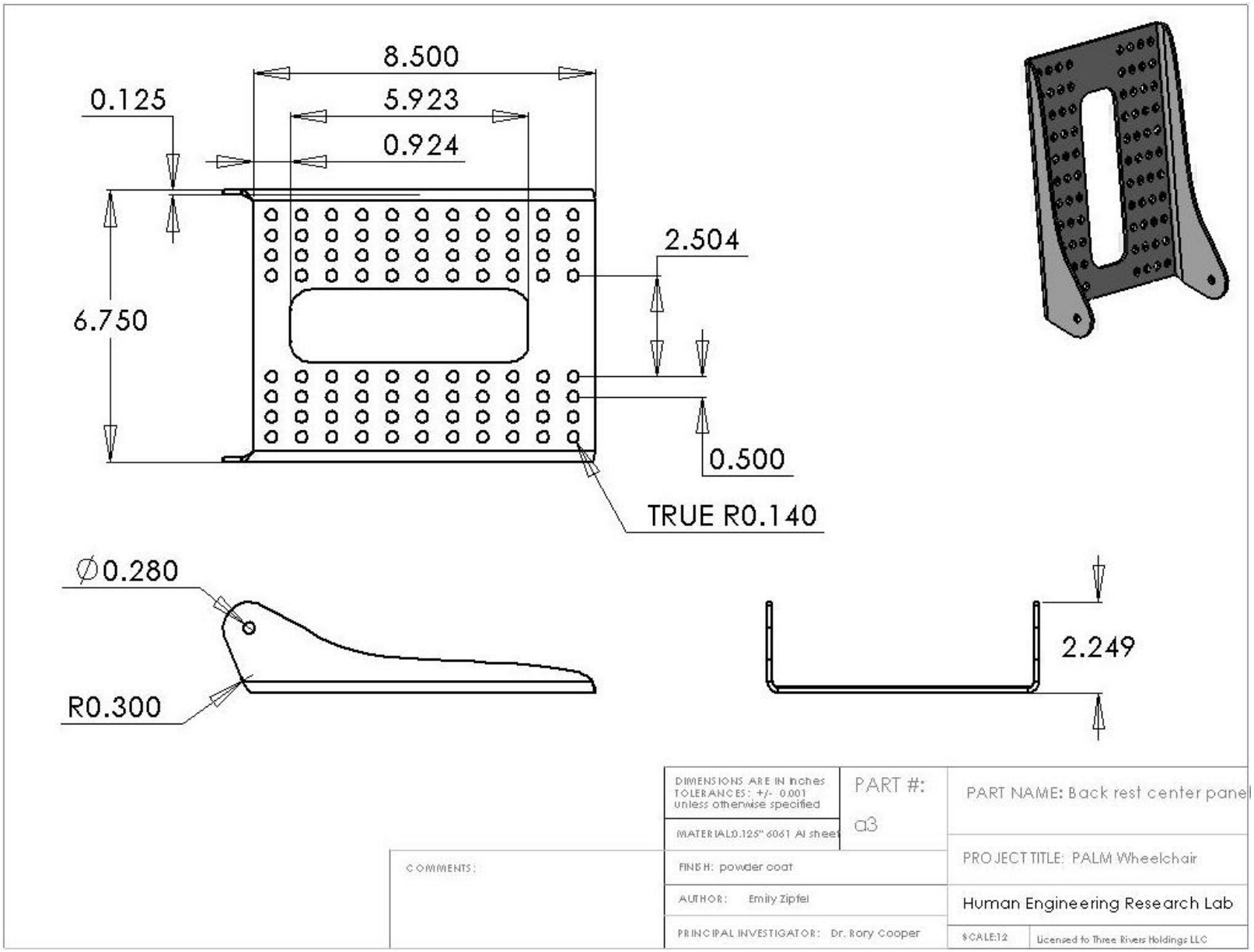


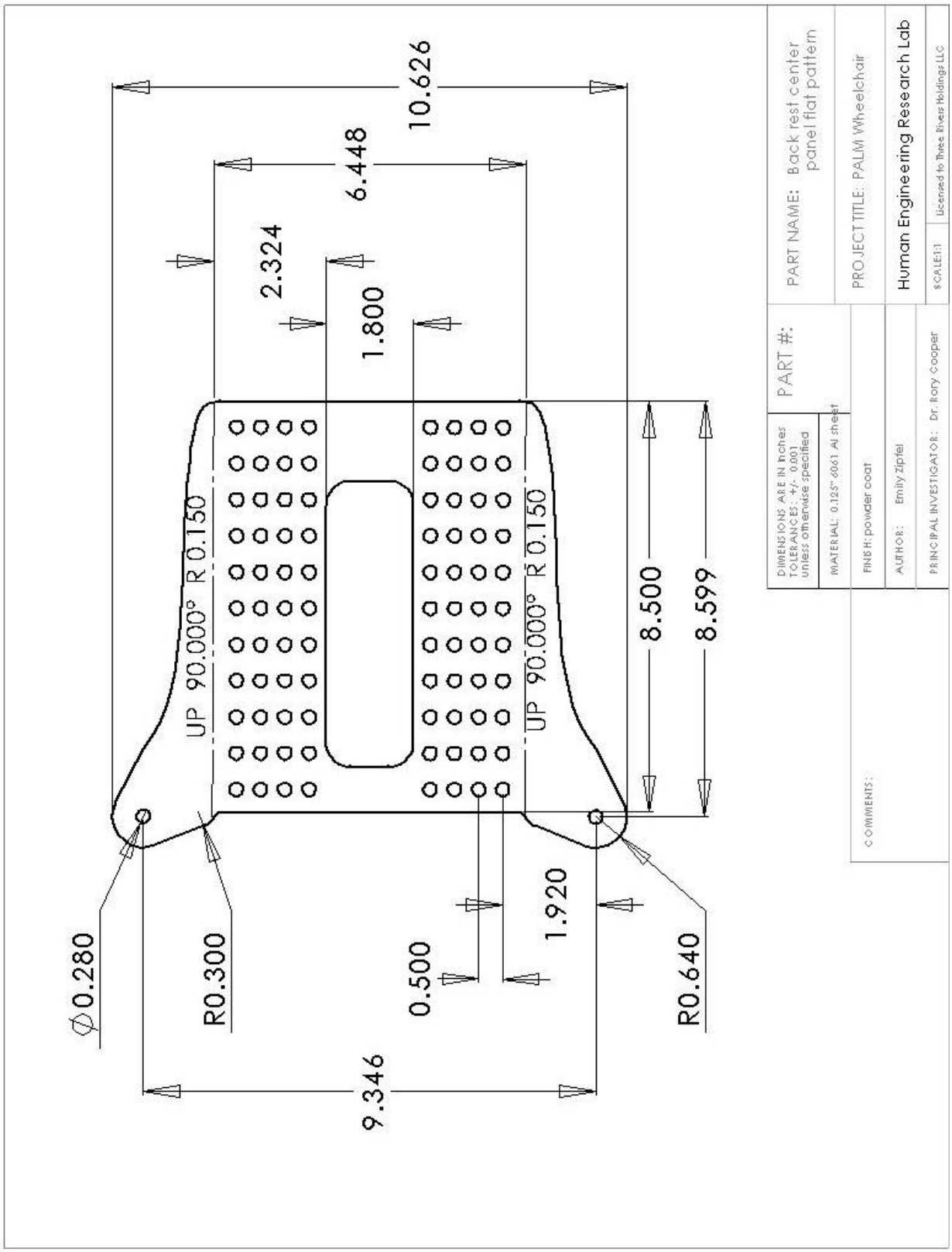


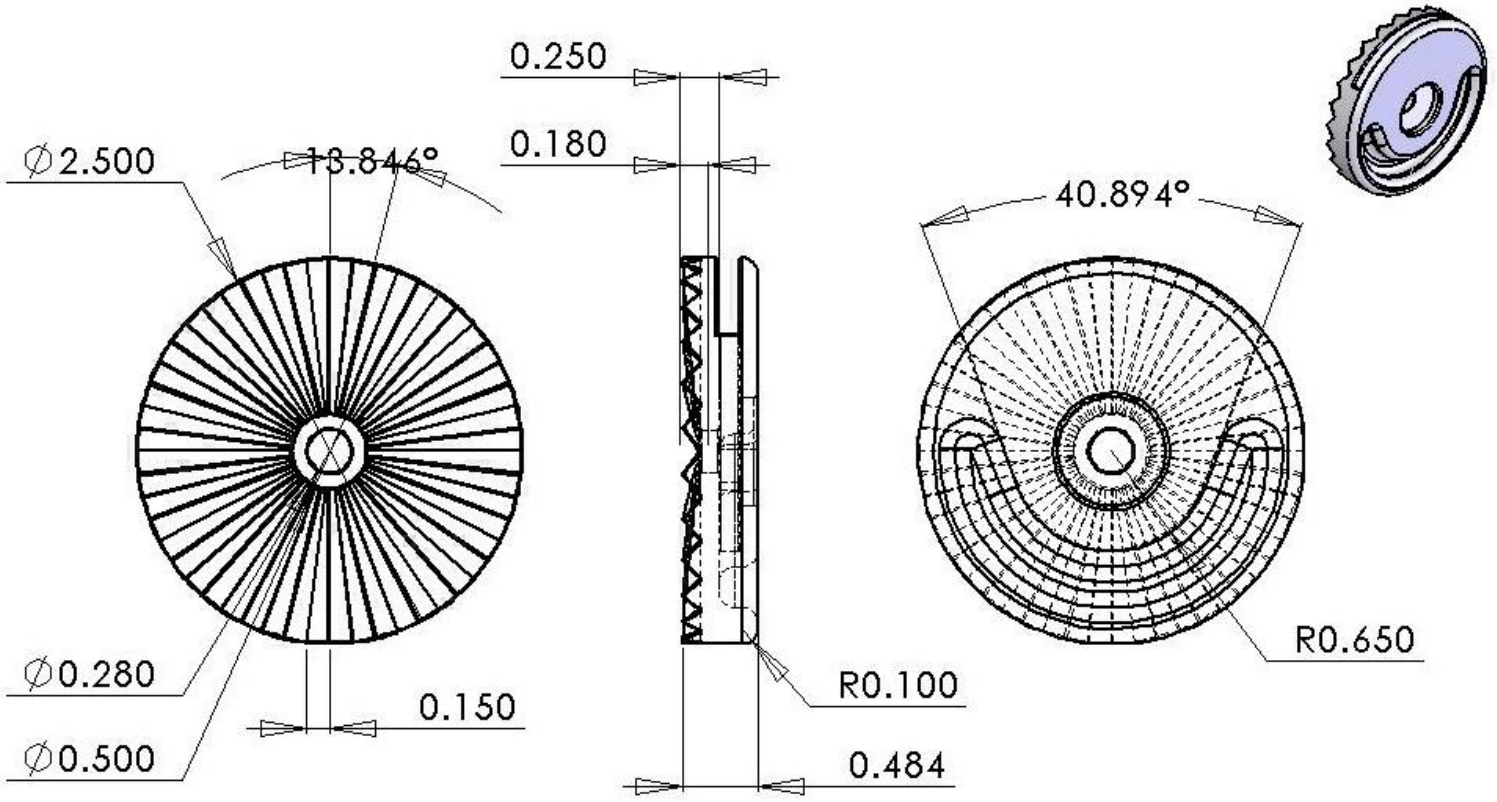
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: a2	PART NAME: Back rest bottom panel
MATERIAL: 0.0625" 6061 Al sheet		
FINISH: powder coat		PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel		Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:5	Licensed to Three Rivers Holdings LLC

COMMENTS:
Drawing shows left bottom panel, right panel must be bent to mirror right panel

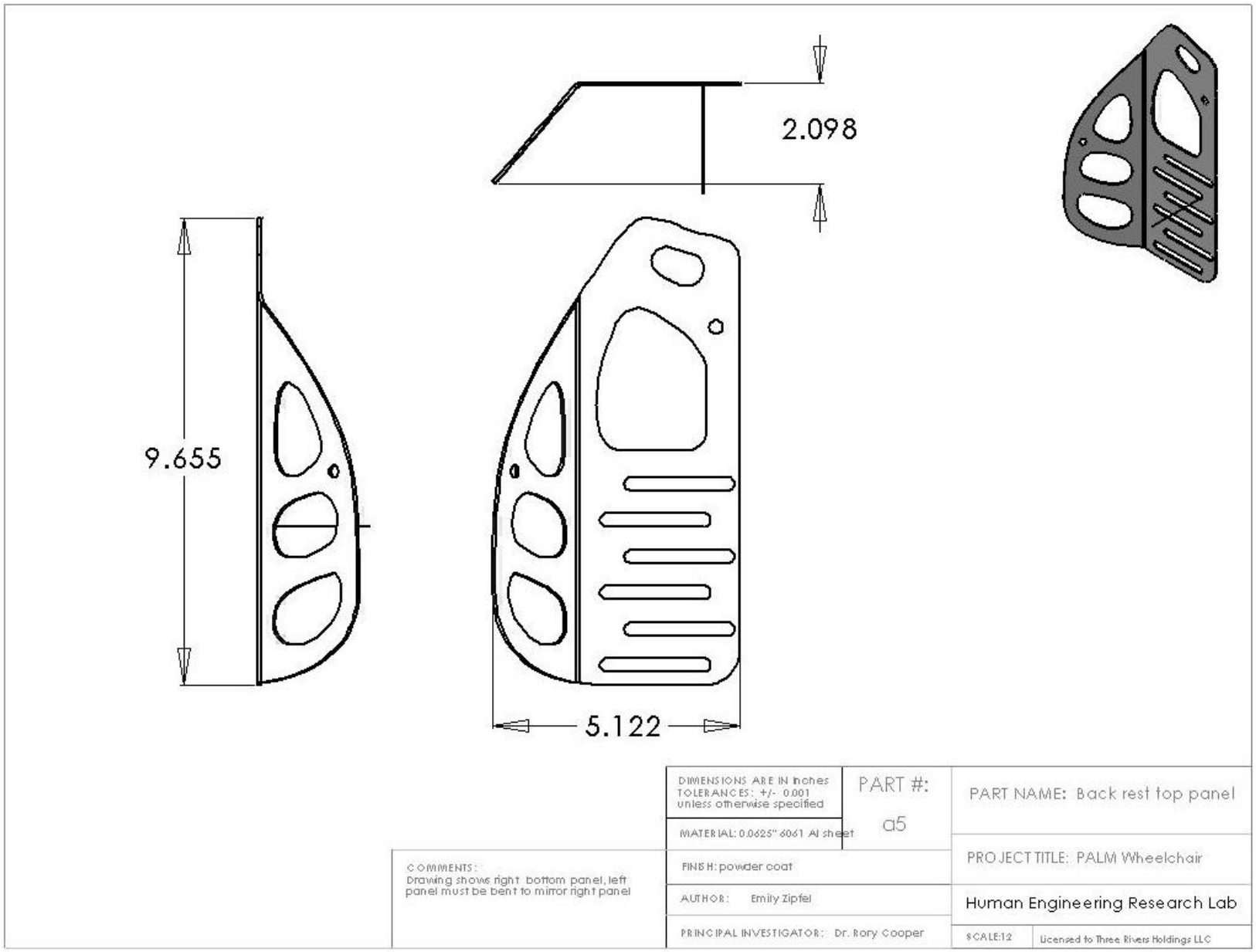

6.508
6.804
DOWN 49.589° R 0.100
0.750
0.280
0.274
0.500
3.296
49.589°
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
PART NAME: Back rest bottom panel
MATERIAL: 0.0625" 6061 Al sheet
COMMENTS:
FINISH: powder coat
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1
licensed to Three Rivers Holdings LLC


8.500
5.923
0.924
0.125
6.750
2.504
0.500
TRUE R0.140
∅0.280
R0.300
2.249
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
a3
MATERIAL 0.125" 6061 Al sheet
FINISH: powder coat
AUTHOR: Emily Zipfel
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
COMMENTS:
PART NAME: Back rest center panel
PROJECT TITLE: PALM Wheelchair
Human Engineering Research Lab
SCALE:12
Licensed to Three Rivers Holdings LLC

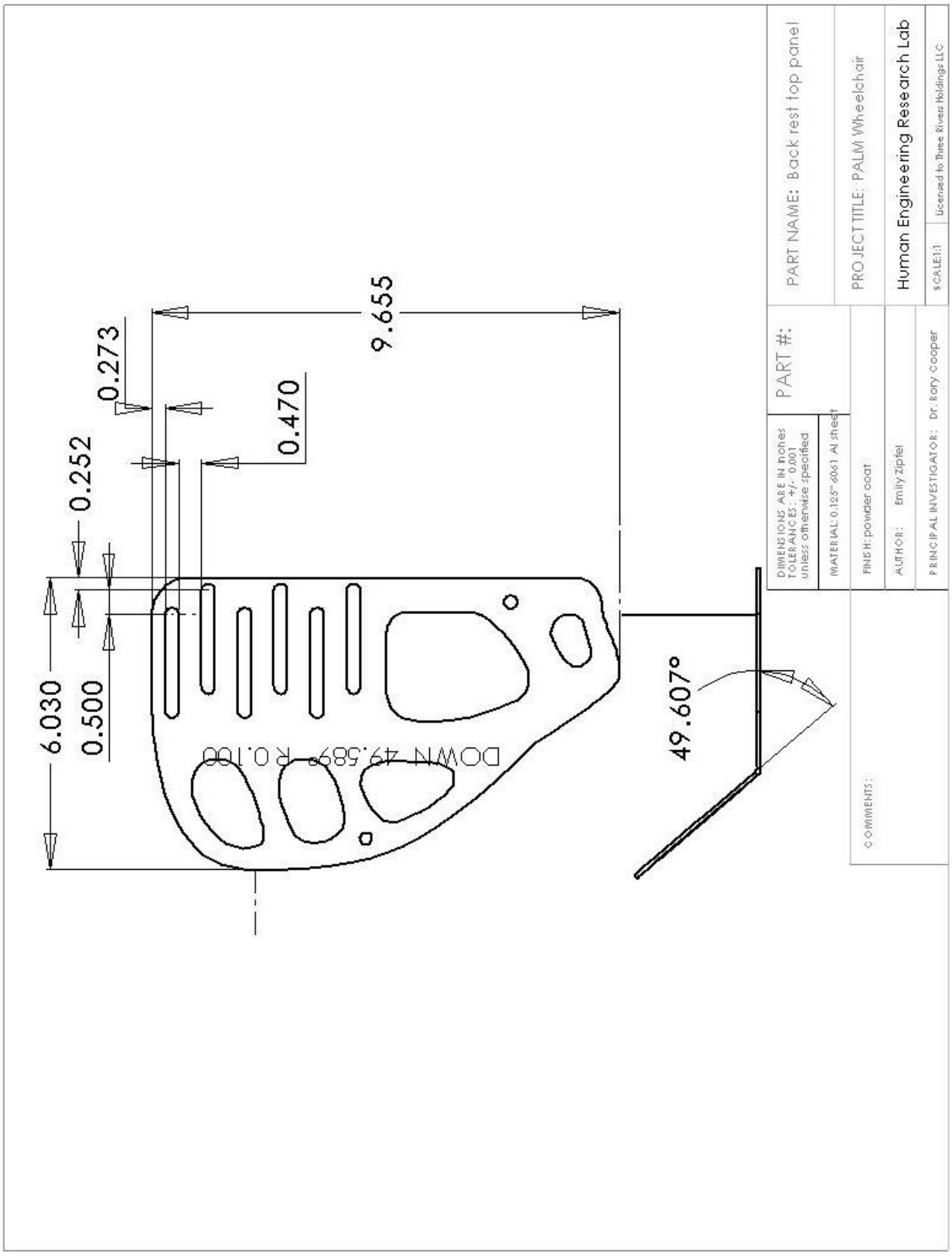

10.626
6.448
2.324
1.800
UP 90.000° R 0.150
UP 90.000° R 0.150
8.500
8.599
Ø0.280
R0.300
0.500
1.920
R0.640
9.346
DIMENSIONS ARE IN inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
PART NAME: Back rest center panel flat pattern
MATERIAL: 0.125" 6061 Al sheet
PROJECT TITLE: PALM Wheelchair
FINISH: powder coat
AUTHOR: Emily Zipfel
Human Engineering Research Lab
COMMENTS:
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:1
Licensed to Three Rivers Holdings LLC

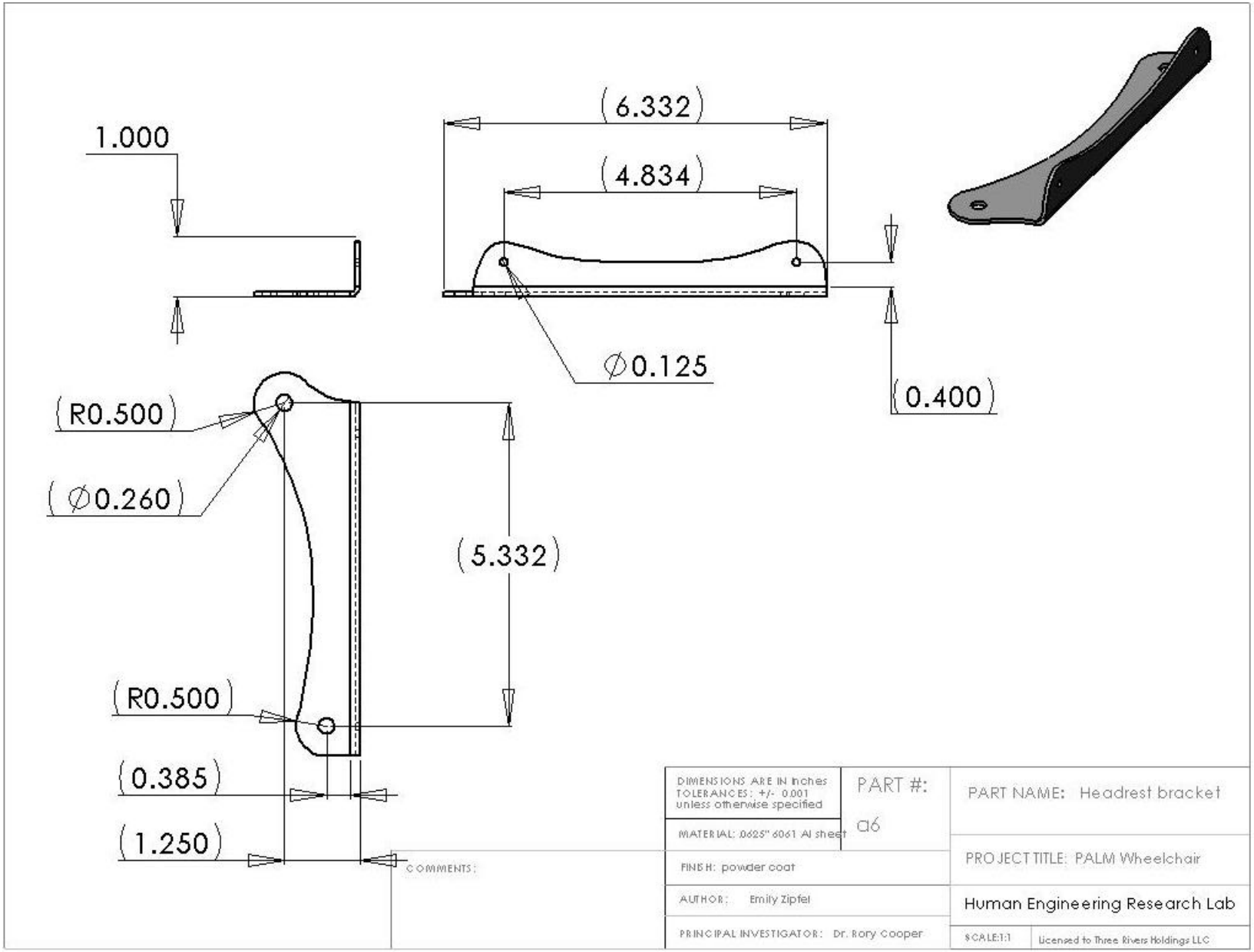


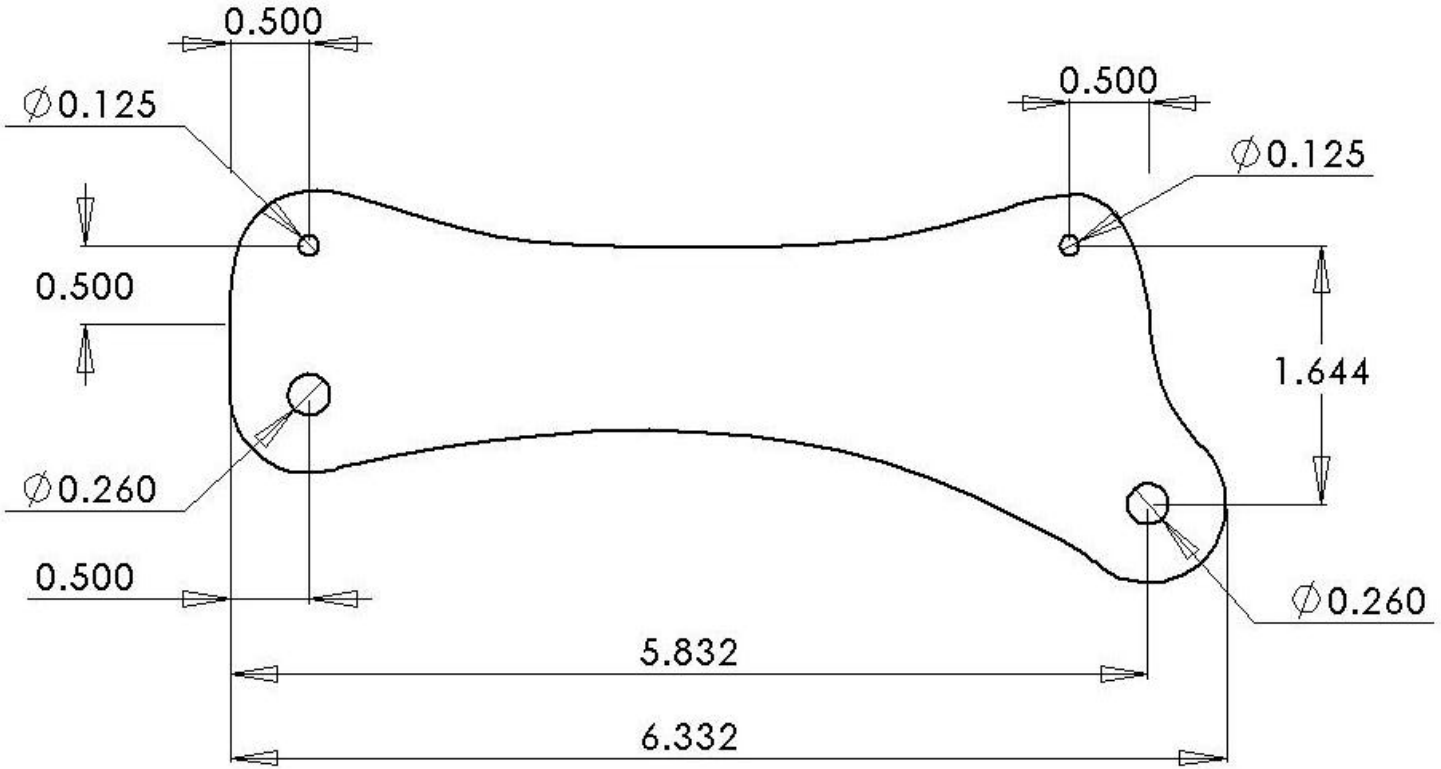
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: a4	PART NAME: Back rest pivot joint
MATERIAL: plastic		
COMMENTS:	FINISH:	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:1 Licensed to Three Rivers Holdings LLC



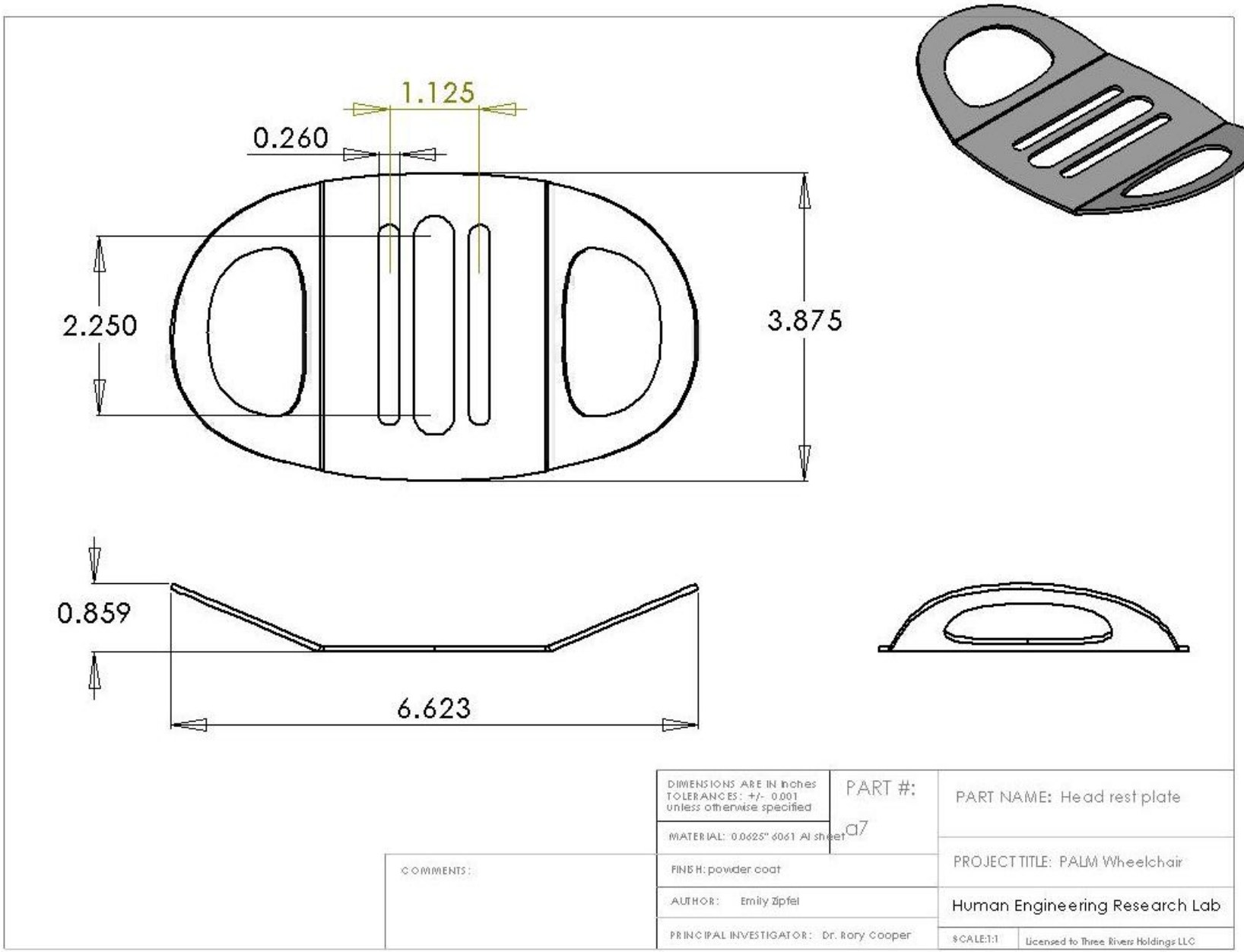
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: a5	PART NAME: Back rest top panel
MATERIAL: 0.0625" 6061 Al sheet		
COMMENTS: Drawing shows right bottom panel, left panel must be bent to mirror right panel	FINISH: powder coat	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:2 Licensed to Three Rivers Holdings LLC


9.655
0.273
0.470
0.252
6.030
0.500
DOWN 49.589° R0.100
49.607°
PART #:
PART NAME: Back rest top panel
PROJECT TITLE: PALM Wheelchair
Human Engineering Research Lab
DIMENSIONS ARE IN inches
TOLERANCES: +/- 0.001
unless otherwise specified
MATERIAL: 0.125" 6061 Al sheet
FINISH: powder coat
AUTHOR: Emily Zipfel
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:1
COMMENTS:
Licensed to Three Rivers Holdings LLC

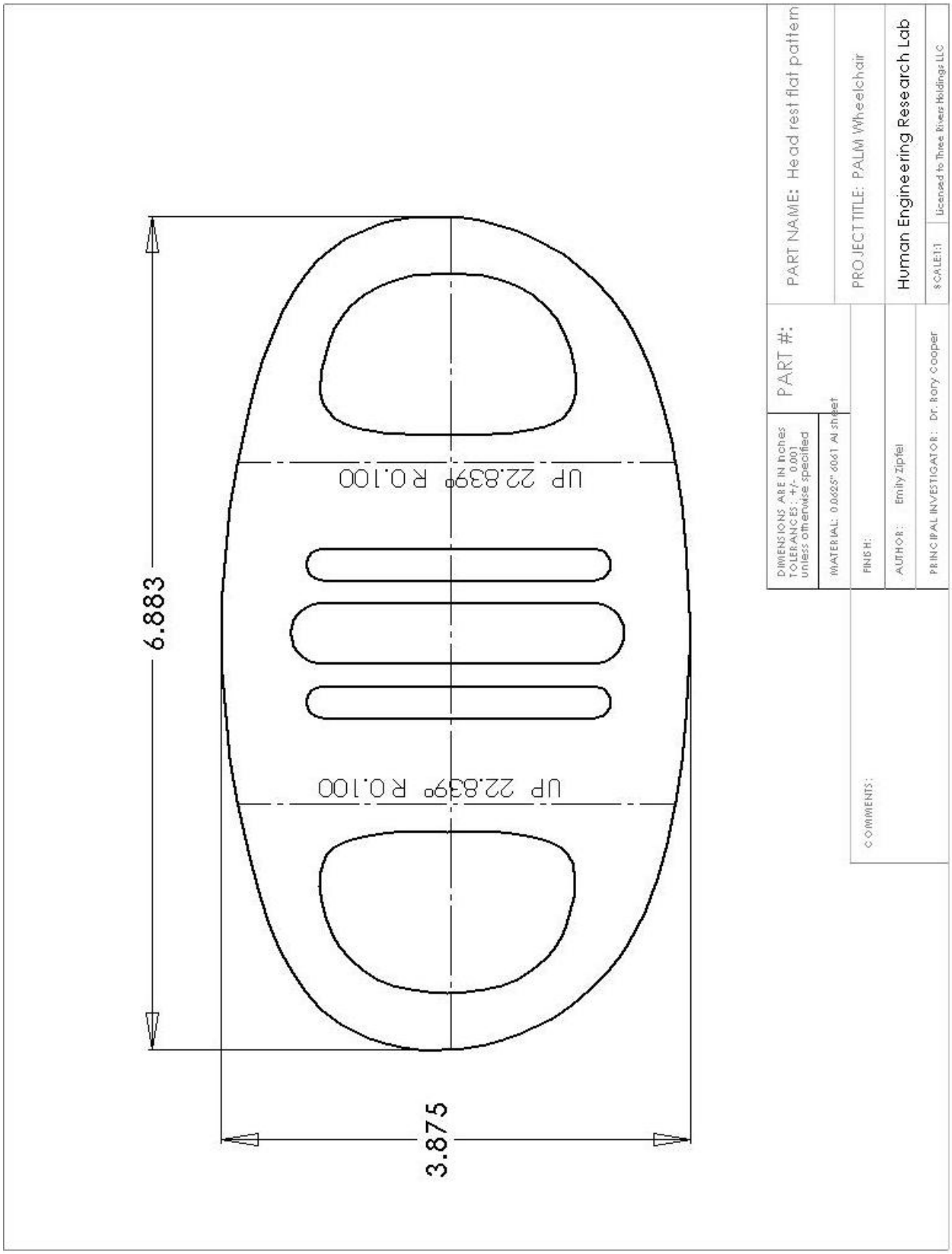

1.000
6.332
4.834
Ø0.125
0.400
R0.500
Ø0.260
5.332
R0.500
0.385
1.250
COMMENTS:
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
a6
PART NAME: Headrest bracket
MATERIAL: .0625" 6061 Al sheet
FINISH: powder coat
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:1
Licensed to Three Rivers Holdings LLC

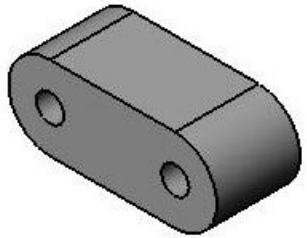


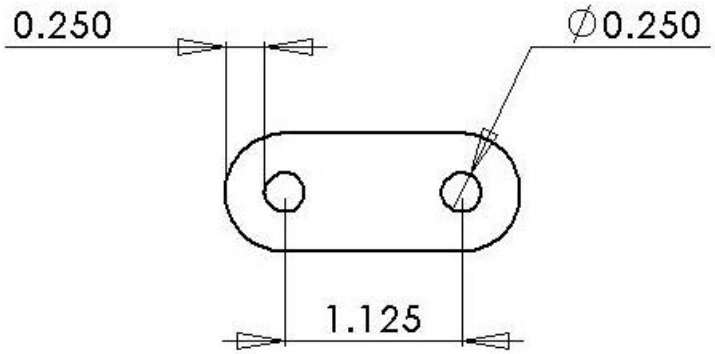
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #:	PART NAME: Headrest bracket flat pattern
MATERIAL: .0625 6062 AL sheet		
COMMENTS:	FINISH:	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:1 Licensed to Three Rivers Holdings LLC

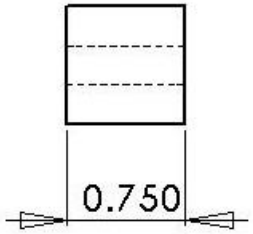


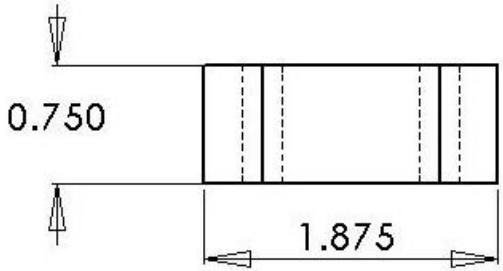
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: a7	PART NAME: Head rest plate
MATERIAL: 0.0625" 6061 Al sheet		
COMMENTS:	FINISH: powder coat	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:1 Licensed to Three Rivers Holdings LLC


6.883
3.875
UP 22.839° R0.100
UP 22.839° R0.100
PART NAME: Head rest flat pattern
PART #:
PROJECT TITLE: PALM Wheelchair
Human Engineering Research Lab
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
MATERIAL: 0.0625" 6061 Al sheet
FINISH:
AUTHOR: Emily Zipfel
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:1
Licensed to Three Rivers Holdings LLC
COMMENTS:

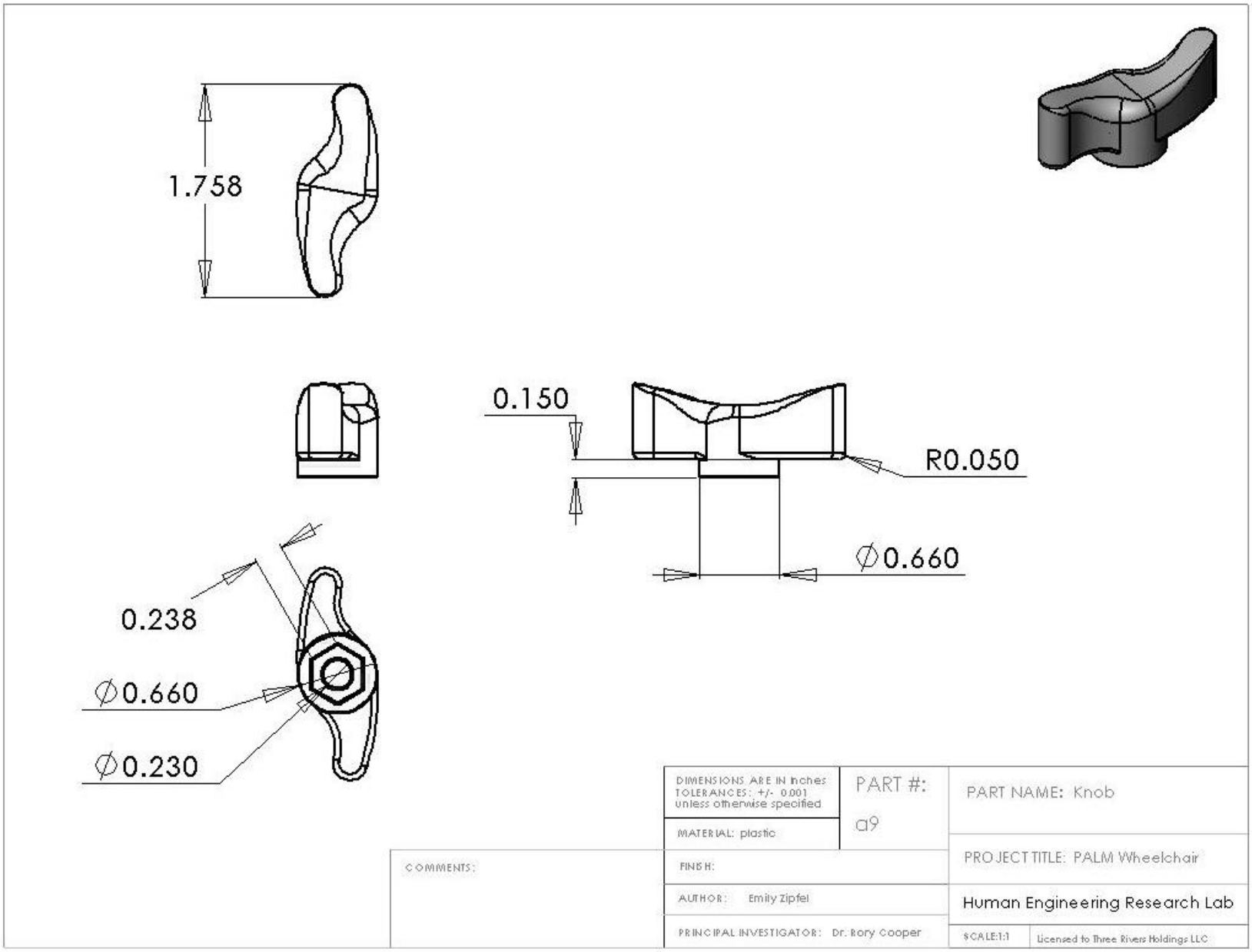


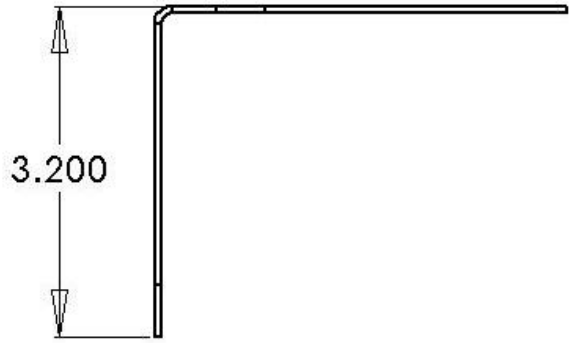


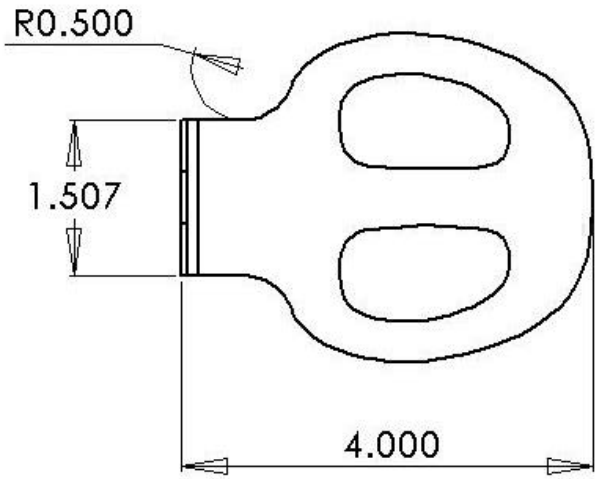


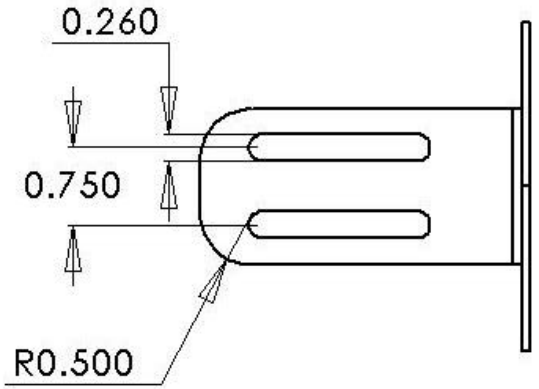


DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #:	PART NAME: head rest spacer
MATERIAL: delrin	a8	
COMMENTS:	FINISH:	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:1

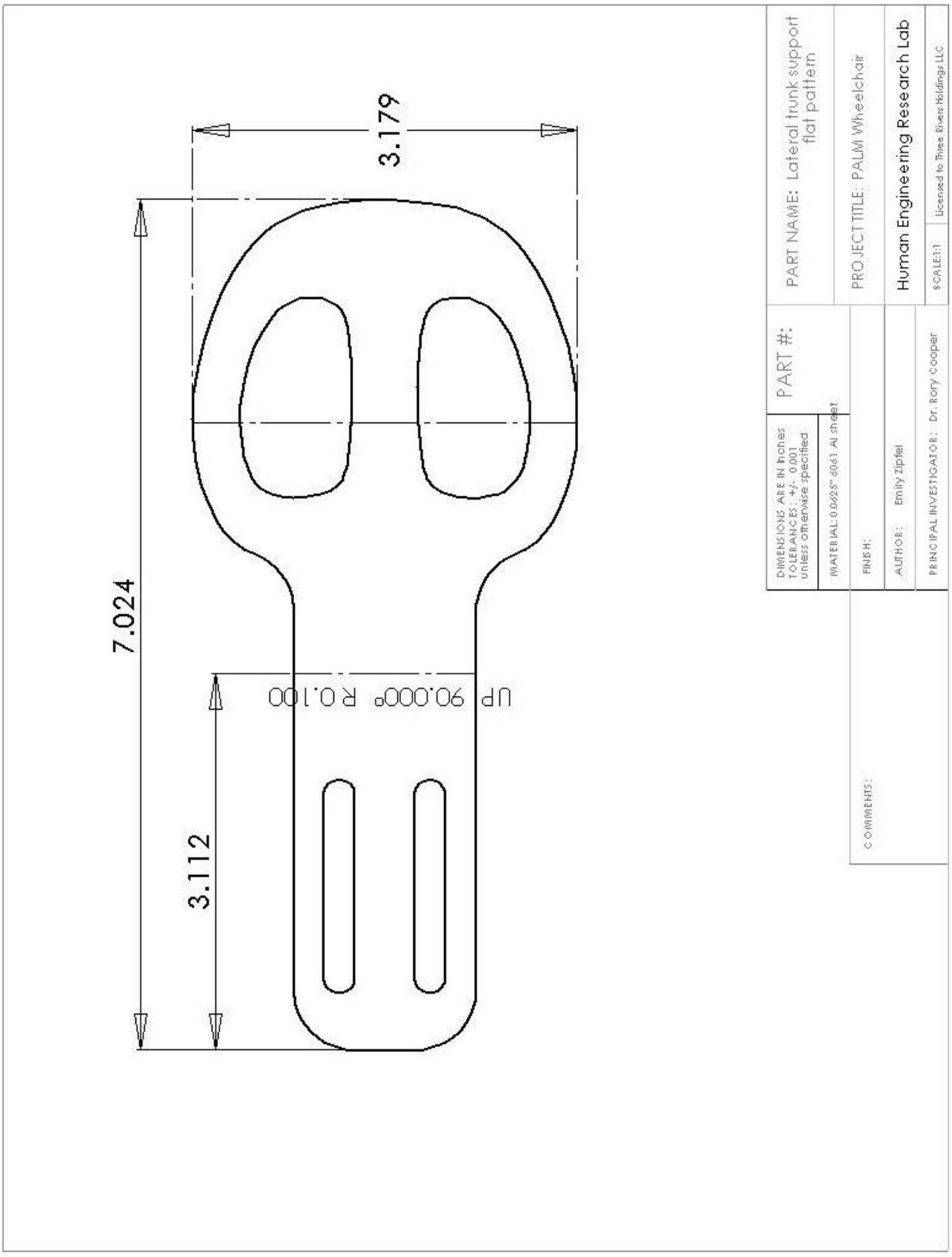

1.758
0.150
R0.050
∅0.660
0.238
∅0.660
∅0.230
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
Unless otherwise specified
MATERIAL: plastic
FINISH:
AUTHOR: Emily Zipfel
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
COMMENTS:
PART #:
a9
PART NAME: Knob
PROJECT TITLE: PALM Wheelchair
Human Engineering Research Lab
SCALE:1:1
Licensed to Three Rivers Holdings LLC

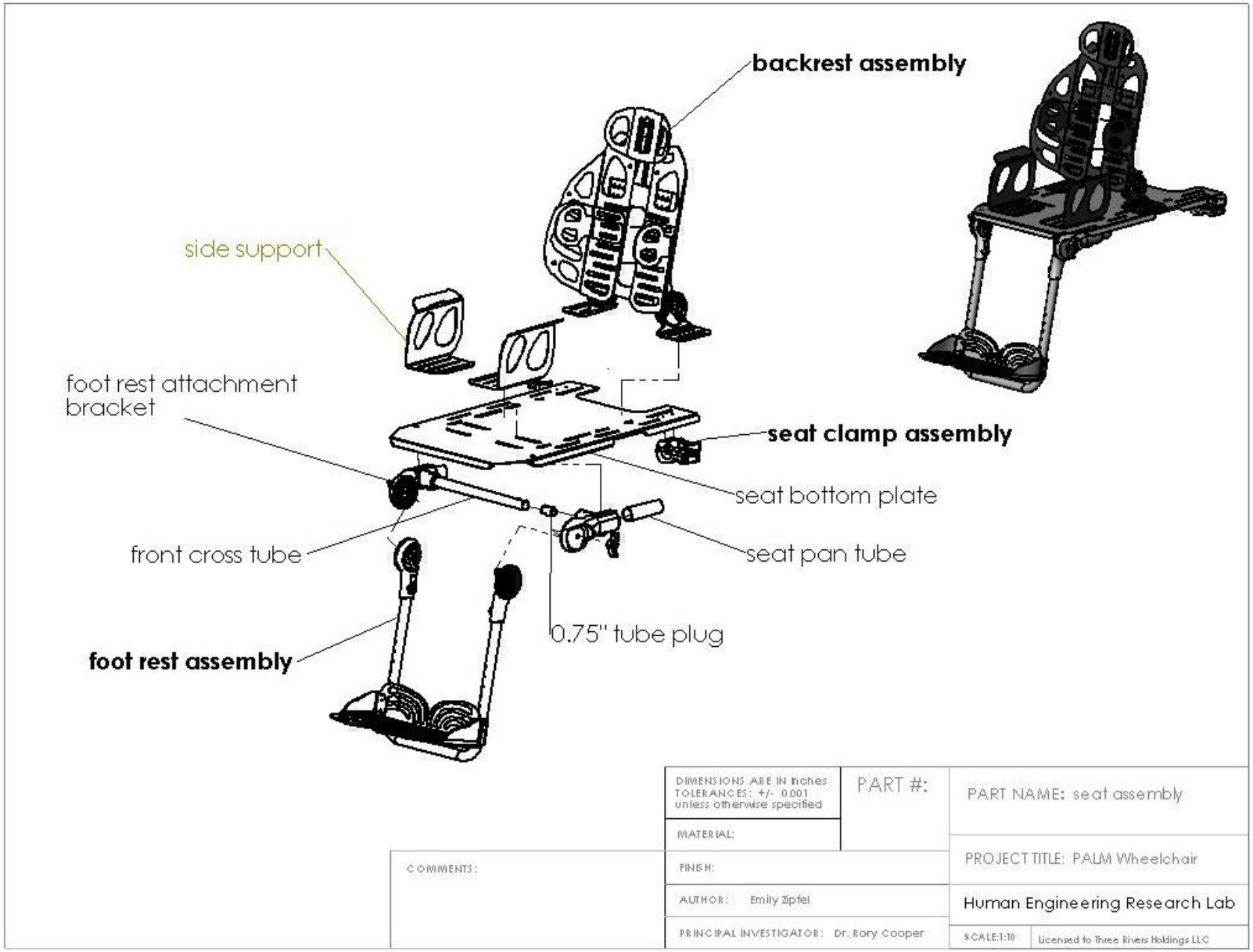


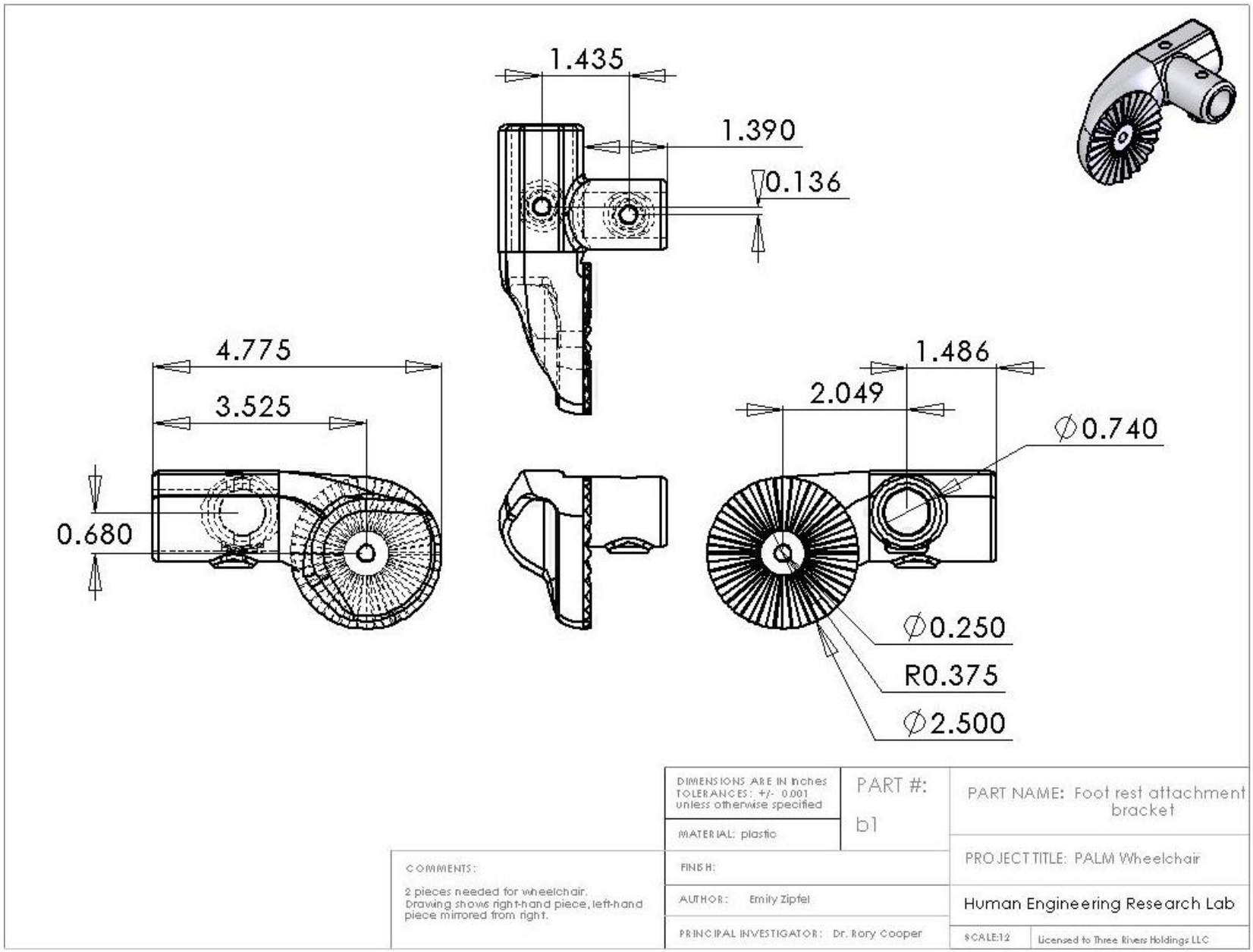


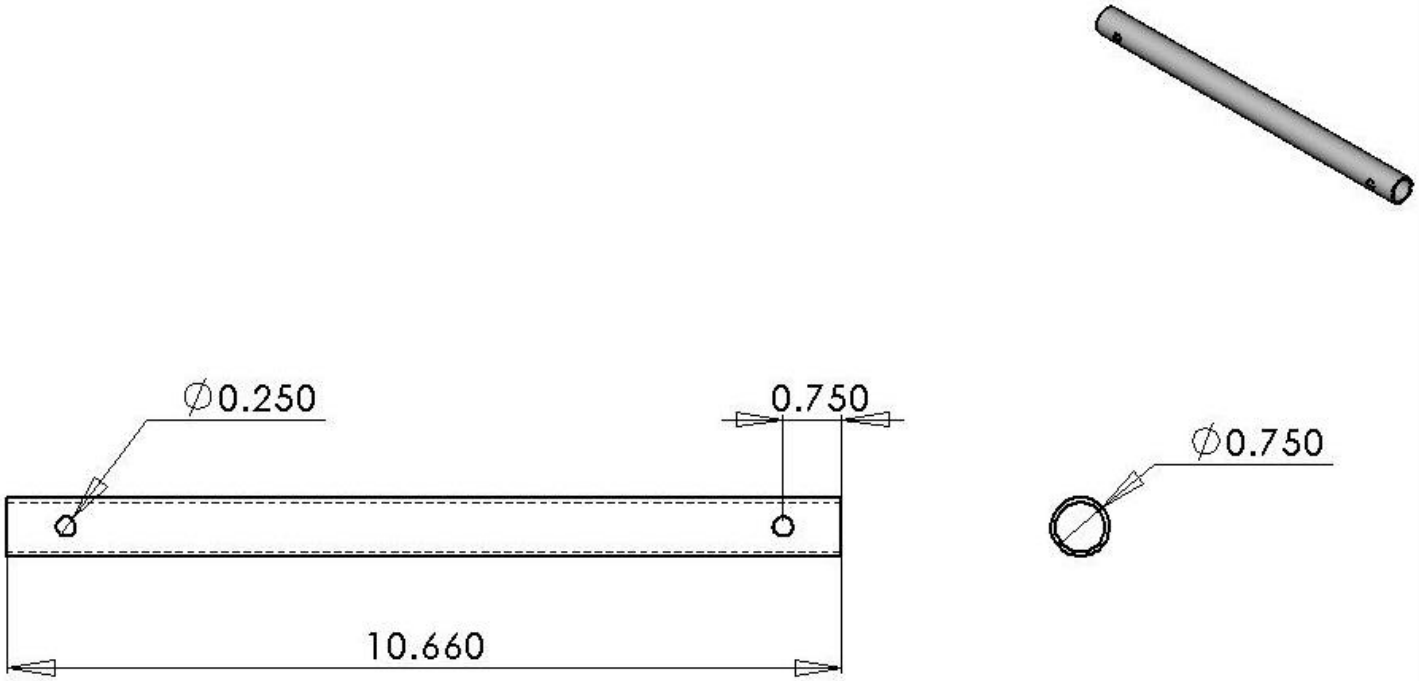


DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: a10	PART NAME: Lateral trunk support
MATERIAL: 0.0625" 6061 Al sheet		
COMMENTS:	FINISH:	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:1 Licensed to Three Rivers Holdings LLC

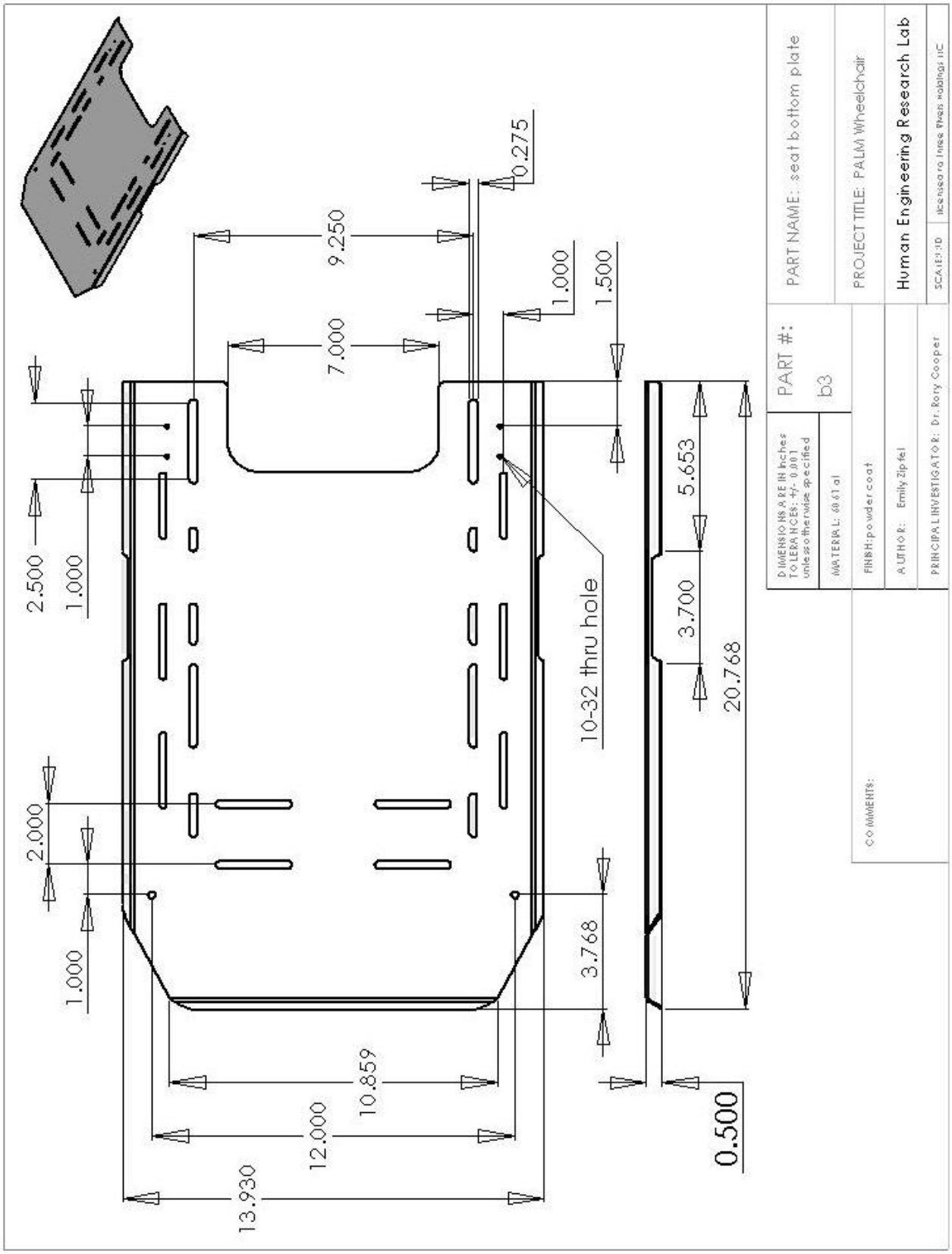

3.179
7.024
3.112
UP 90.000° R 0.100
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
PART NAME: Lateral trunk support flat pattern
MATERIAL: 0.0625" 6061 Al sheet
PROJECT TITLE: PALM Wheelchair
FINISH:
Human Engineering Research Lab
COMMENTS:
AUTHOR: Emily Zipfel
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:1
Licensed to Three Rivers Holdings LLC

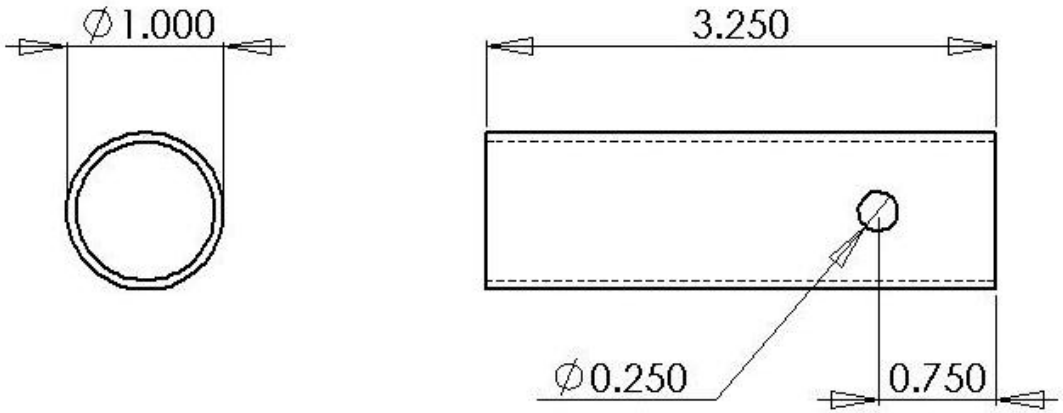

backrest assembly
side support
foot rest attachment bracket
seat clamp assembly
seat bottom plate
front cross tube
seat pan tube
0.75" tube plug
foot rest assembly
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
PART NAME: seat assembly
MATERIAL:
COMMENTS:
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:10
Licensed to Three Rivers Holdings LLC


1.435
1.390
0.136
4.775
3.525
0.680
1.486
2.049
∅0.740
∅0.250
R0.375
∅2.500
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
b1
PART NAME: Foot rest attachment bracket
MATERIAL: plastic
COMMENTS:
2 pieces needed for wheelchair.
Drawing shows right-hand piece, left-hand piece mirrored from right.
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:2
Licensed to Three Rivers Holdings LLC

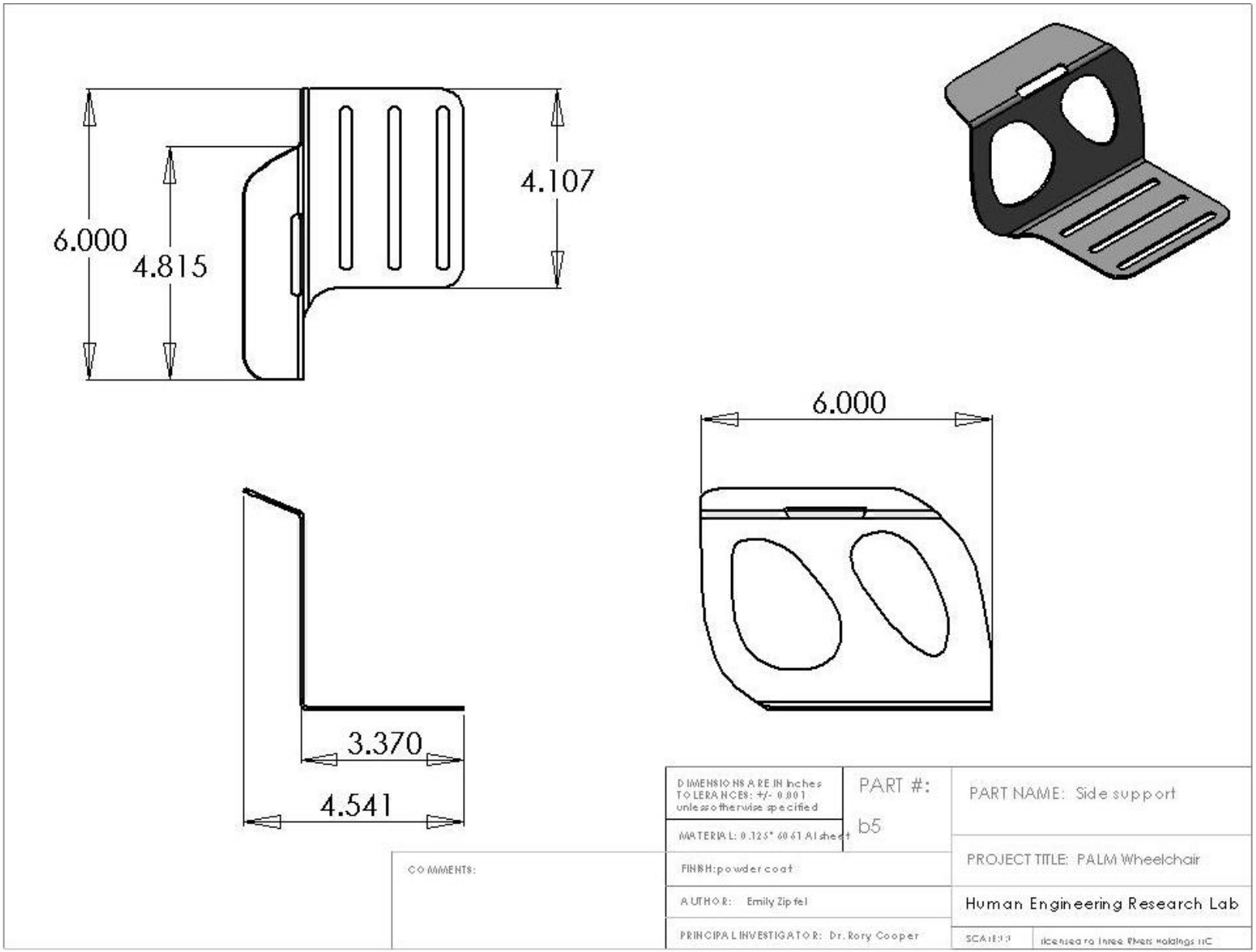


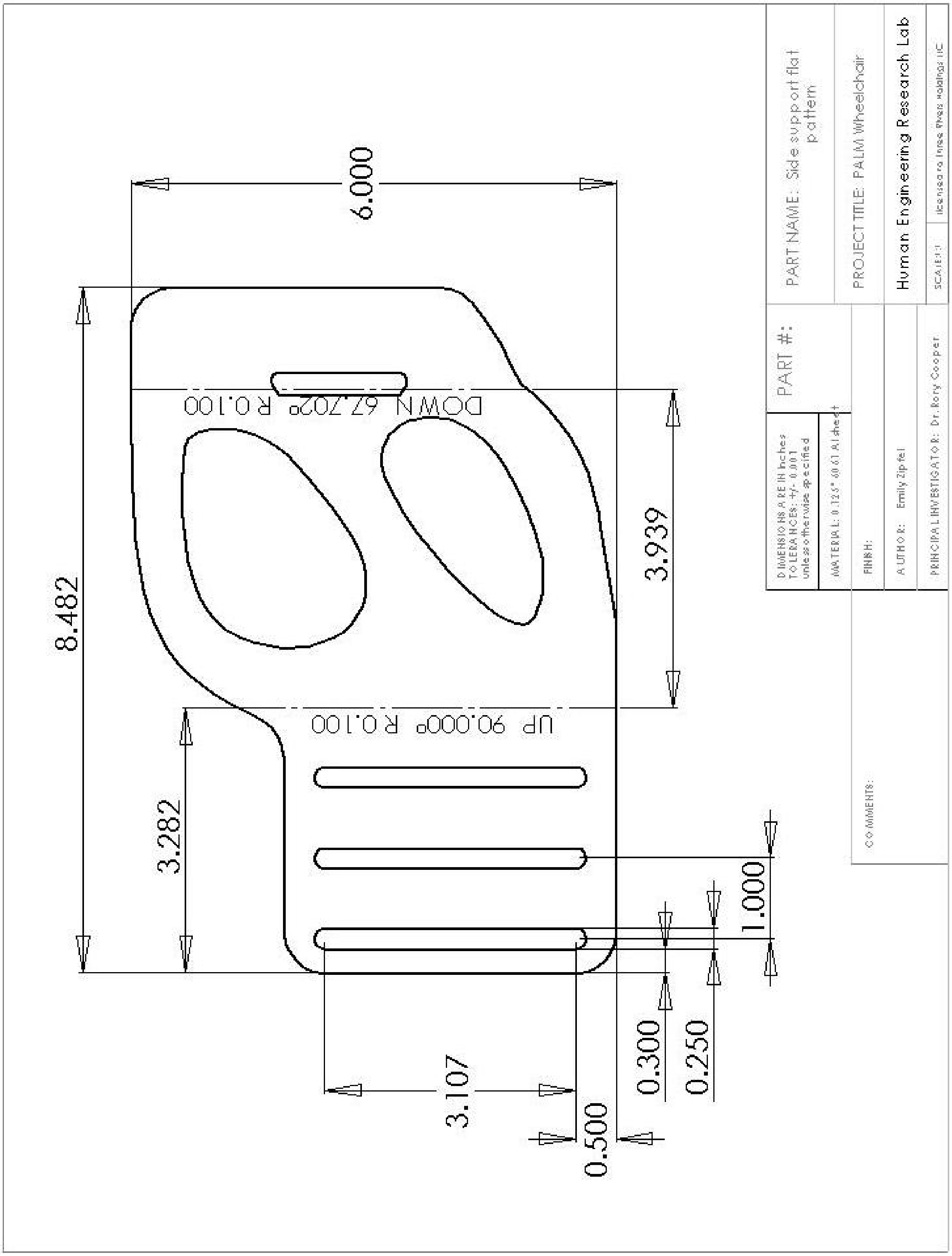
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: b2	PART NAME: front cross tube
MATERIAL: 6061 al		
COMMENTS: 0.75" OD 0.060 WT tube	FINISH: powder coat	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:12


0.275
9.250
7.000
1.000
1.500
2.500
1.000
2.000
1.000
10-32 thru hole
5.653
3.700
20.768
3.768
0.500
10.859
12.000
13.930
DIMENSIONS ARE IN inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
b3
PART NAME: seat bottom plate
MATERIAL: 6061 al
PROJECT TITLE: PALM Wheelchair
FINISH: powder coat
Human Engineering Research Lab
AUTHOR: Emily Zipfel
COMMENTS:
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1
University of Pittsburgh Rehab Engineering

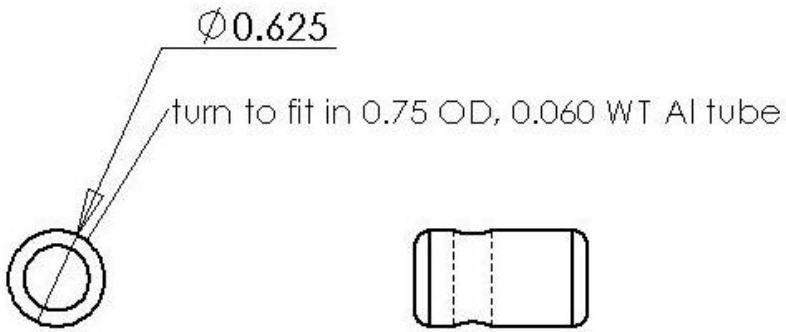


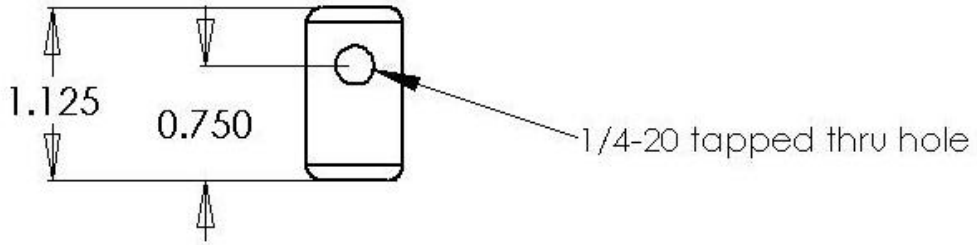
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: b4	PART NAME: seat pan tube
MATERIAL: 6061 al		
COMMENTS: 1" OD 0.060 WT tube	FINISH: powder coat	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:1 licensed to Three Rivers Holdings LLC


6.000
4.815
4.107
6.000
3.370
4.541
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
b5
MATERIAL: 0.125" 6061 Al sheet
FINISH: powder coat
COMMENTS:
AUTHOR: Emily Zipfel
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
PART NAME: Side support
PROJECT TITLE: PALM Wheelchair
Human Engineering Research Lab
SCALE: 1:1
licensed to Invacare Rehab Holdings LLC

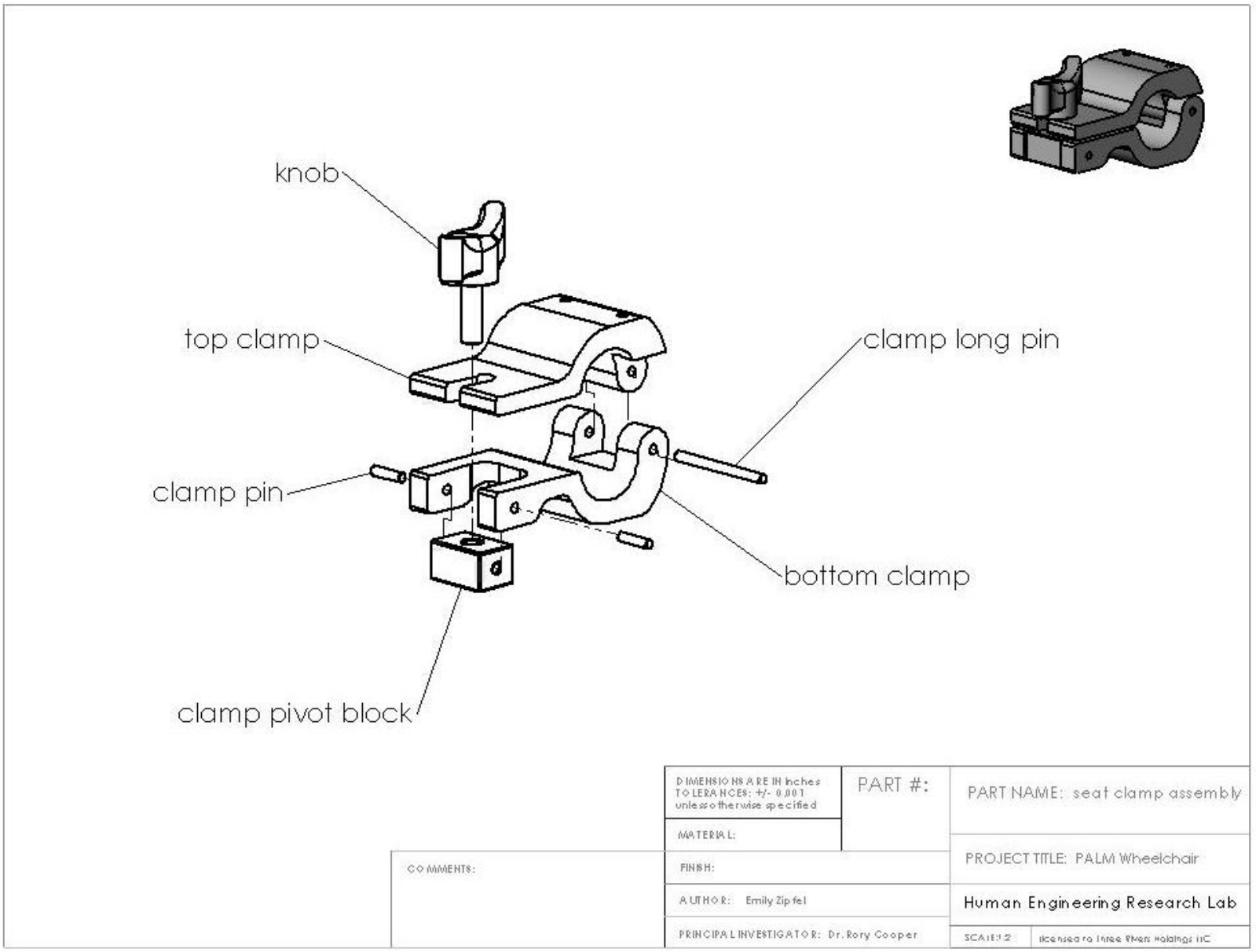


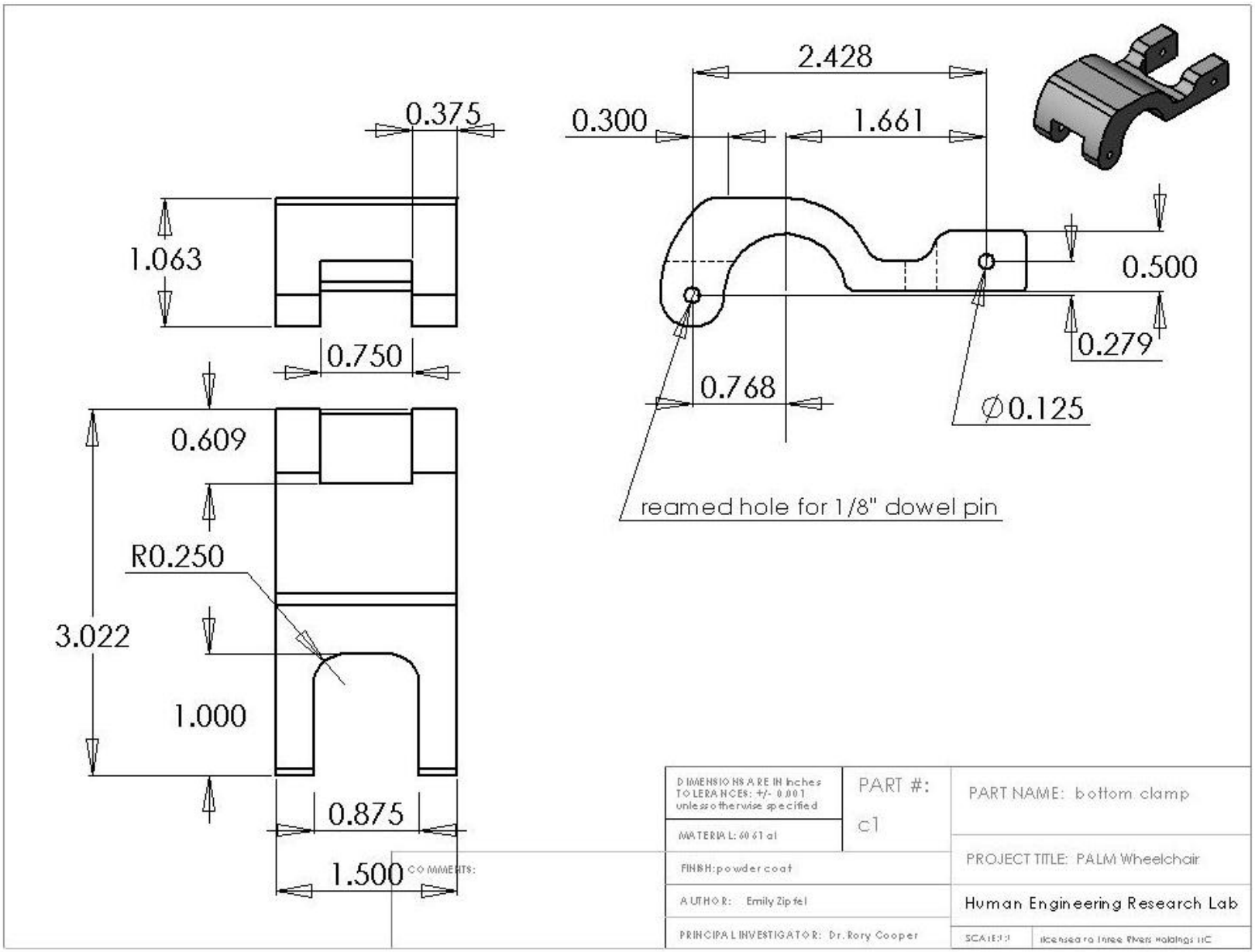
6.000
8.482
3.939
3.282
1.000
3.107
0.300
0.250
0.500
DOWN 67.702° R 0.100
UP 90.000° R 0.100
PART NAME: Side support flat pattern
PROJECT TITLE: PALM Wheelchair
Human Engineering Research Lab
PART #:
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified
MATERIAL: 0.125" 6061 Al sheet
FINISH:
AUTHOR: Emily Zipfel
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
COMMENTS:

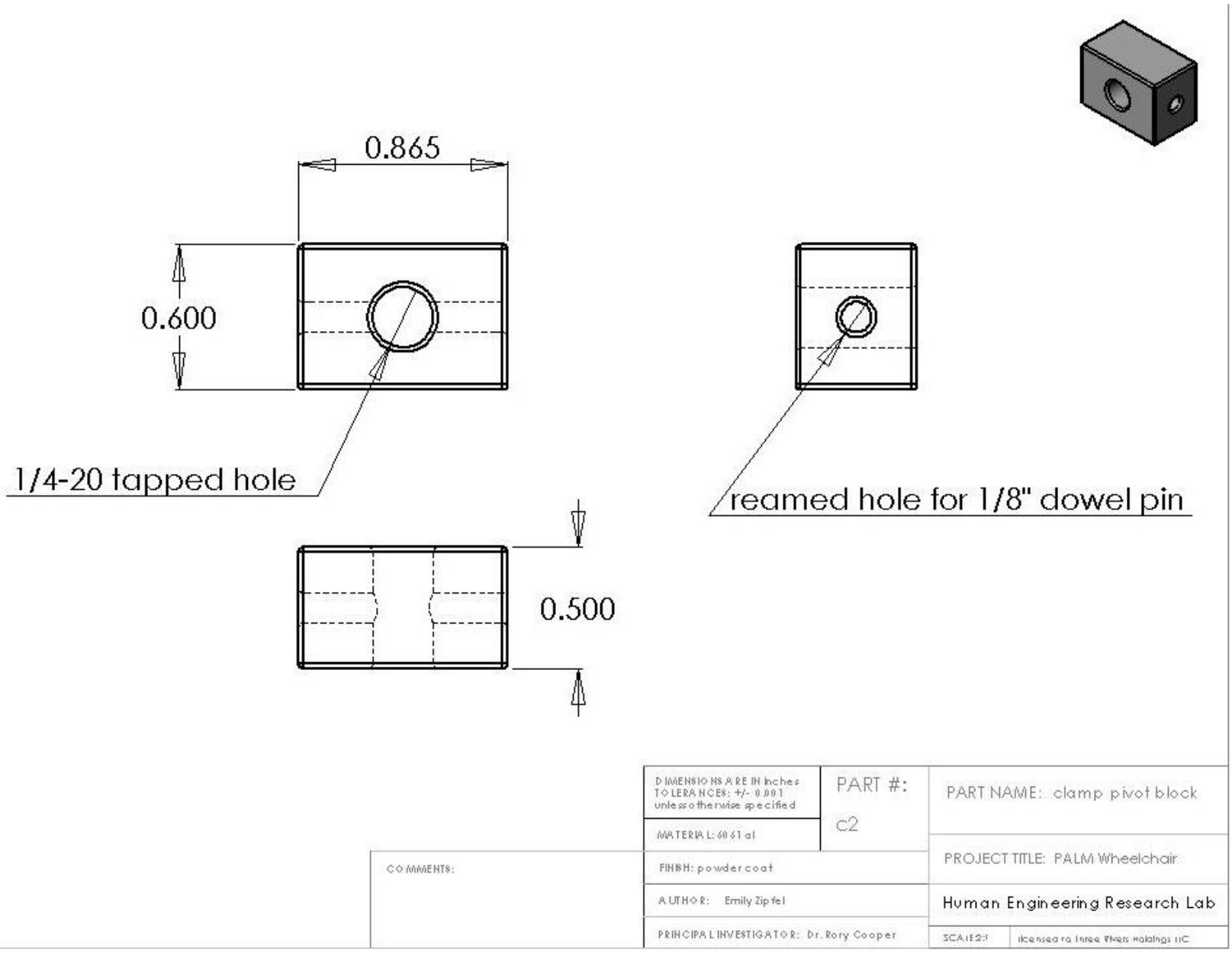


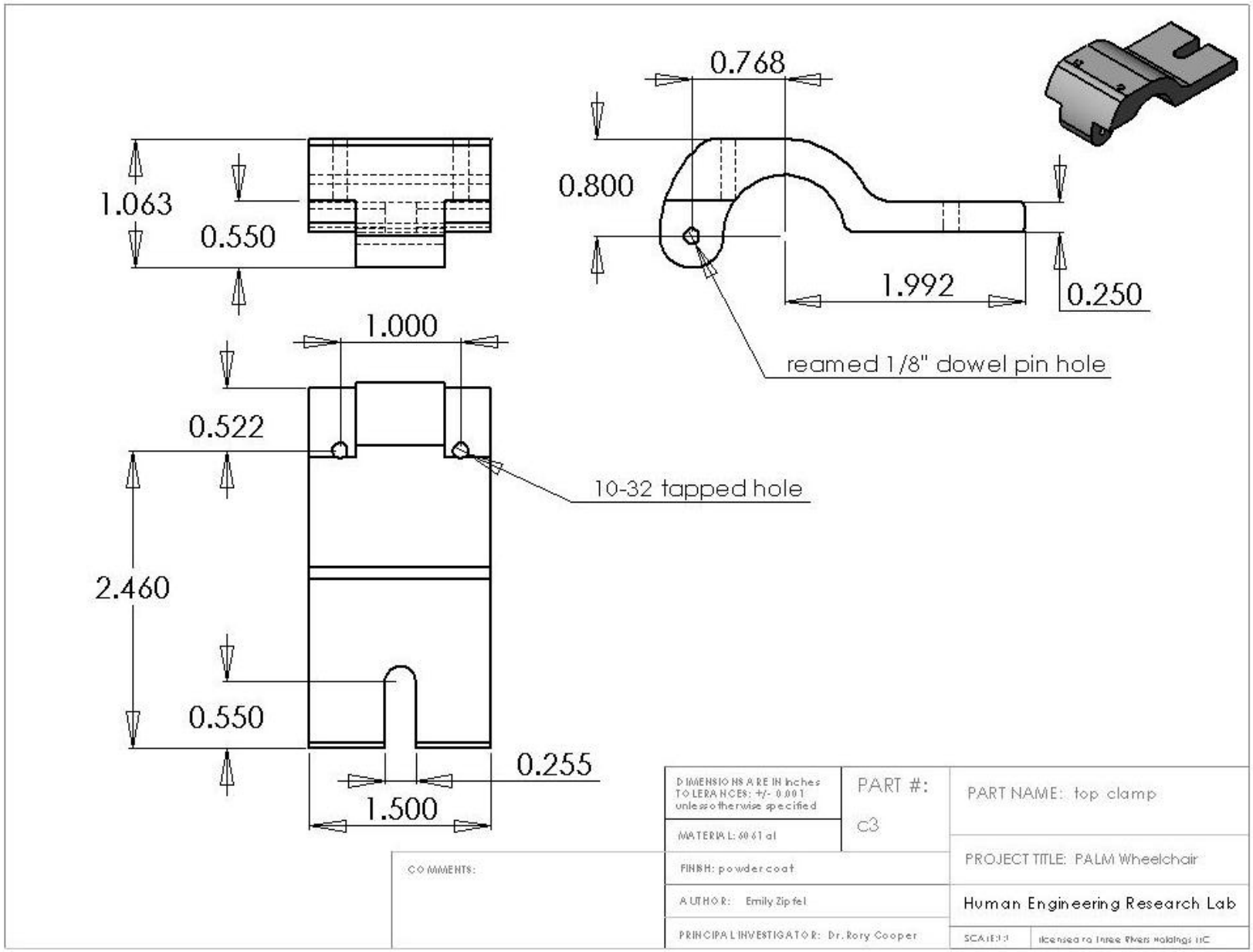


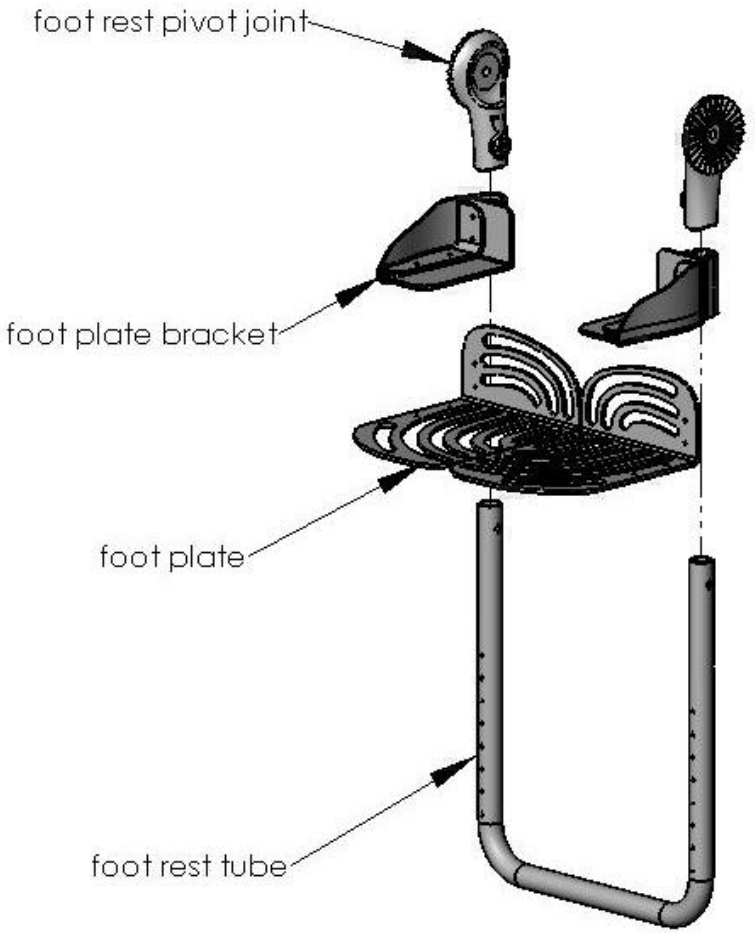
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: b6	PART NAME: 0.75" tube plug
MATERIAL: 6061 al		
COMMENTS:	FINISH:	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:1 licensed to Three Rivers Holdings LLC

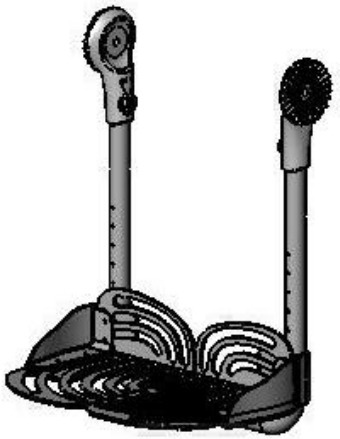

knob
top clamp
clamp long pin
clamp pin
bottom clamp
clamp pivot block
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
PART NAME: seat clamp assembly
MATERIAL:
COMMENTS:
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:2
licensed to Three Rivers Holdings LLC


2.428
0.375
0.300
1.661
1.063
0.500
0.279
0.750
0.768
∅0.125
reamed hole for 1/8" dowel pin
0.609
R0.250
3.022
1.000
0.875
1.500
COMMENTS:
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
c1
PART NAME: bottom clamp
MATERIAL: 6061 al
FINISH: powder coat
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1
licensed to Three Rivers Holdings LLC

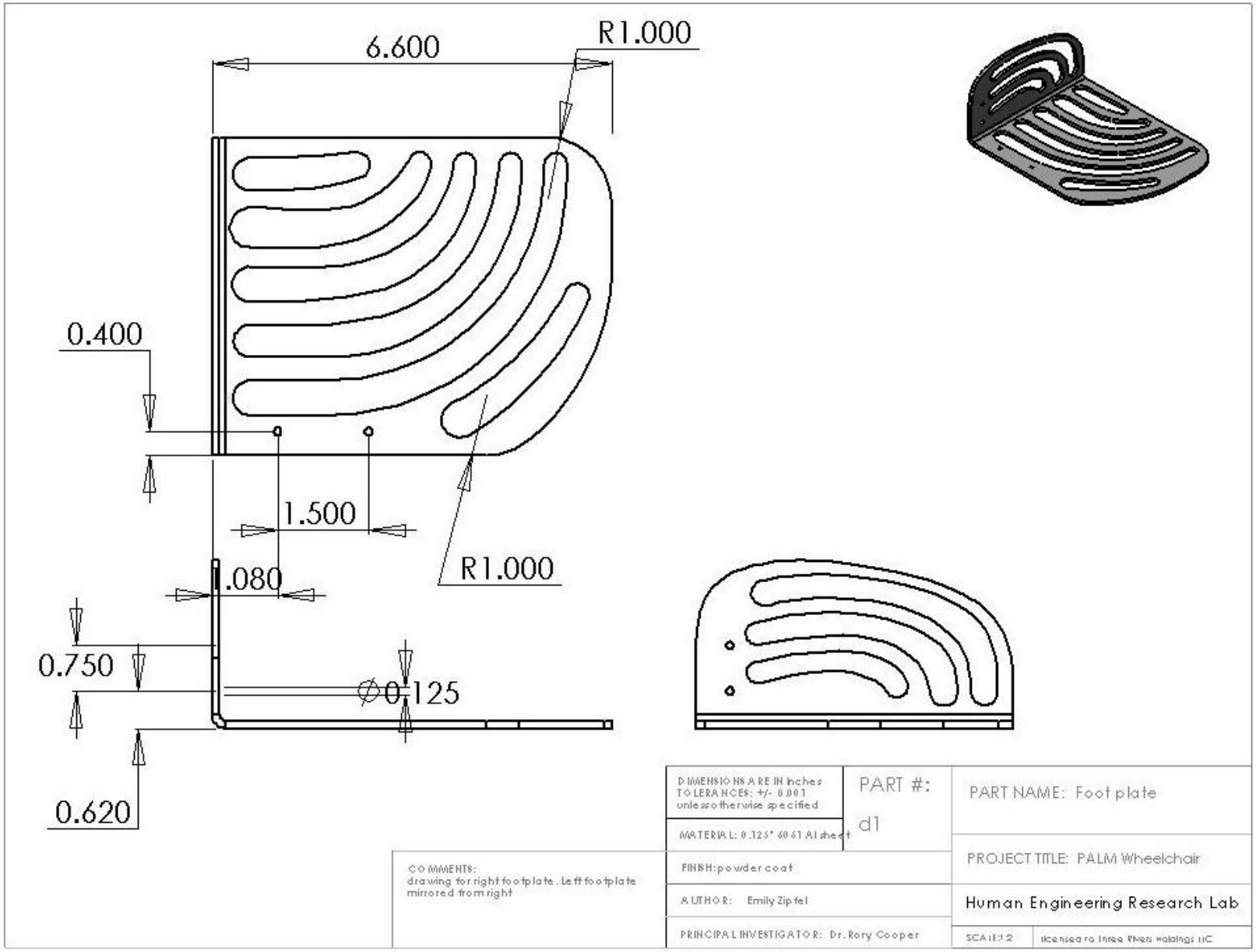

0.865
0.600
1/4-20 tapped hole
reamed hole for 1/8" dowel pin
0.500
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
c2
PART NAME: clamp pivot block
MATERIAL: 6061 al
COMMENTS:
FINISH: powder coat
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1
licensed to Three RMers Holdings LLC

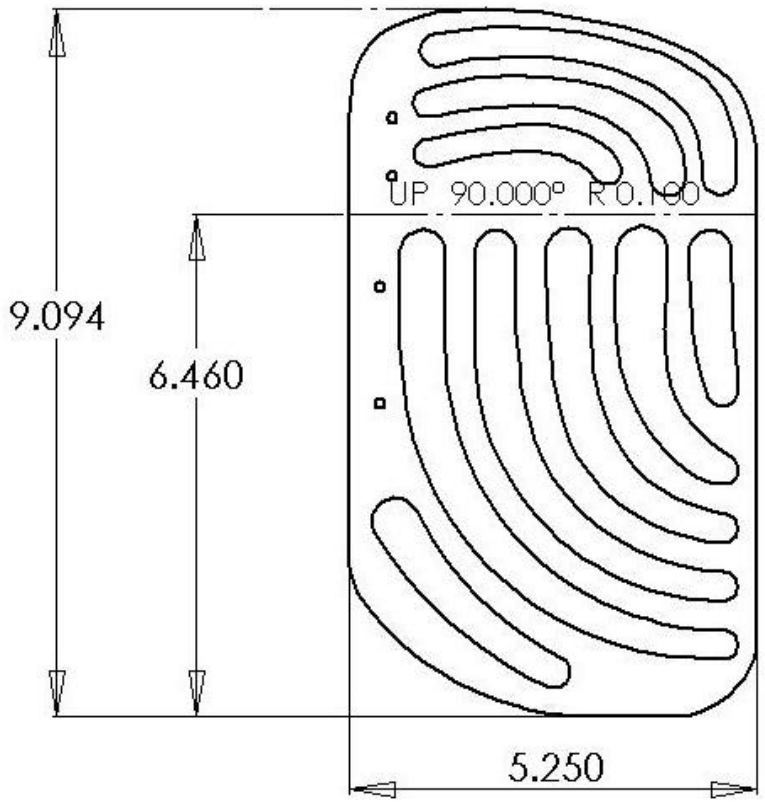

0.768
0.800
1.992
0.250
reamed 1/8" dowel pin hole
1.063
0.550
1.000
0.522
10-32 tapped hole
2.460
0.550
0.255
1.500
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
c3
PART NAME: top clamp
MATERIAL: 6061 al
COMMENTS:
FINISH: powder coat
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1
Licensed to Three Rivers Holdings LLC



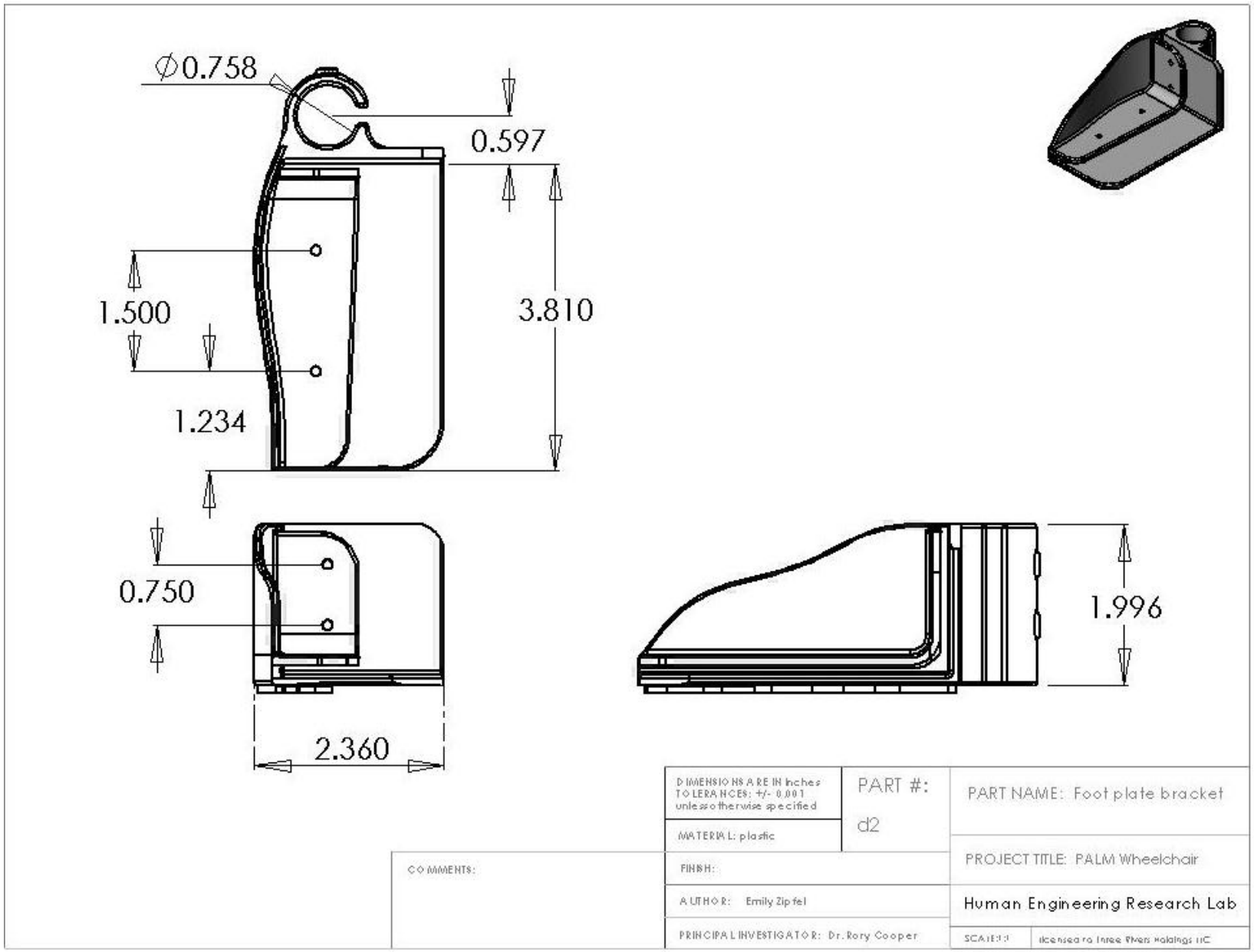


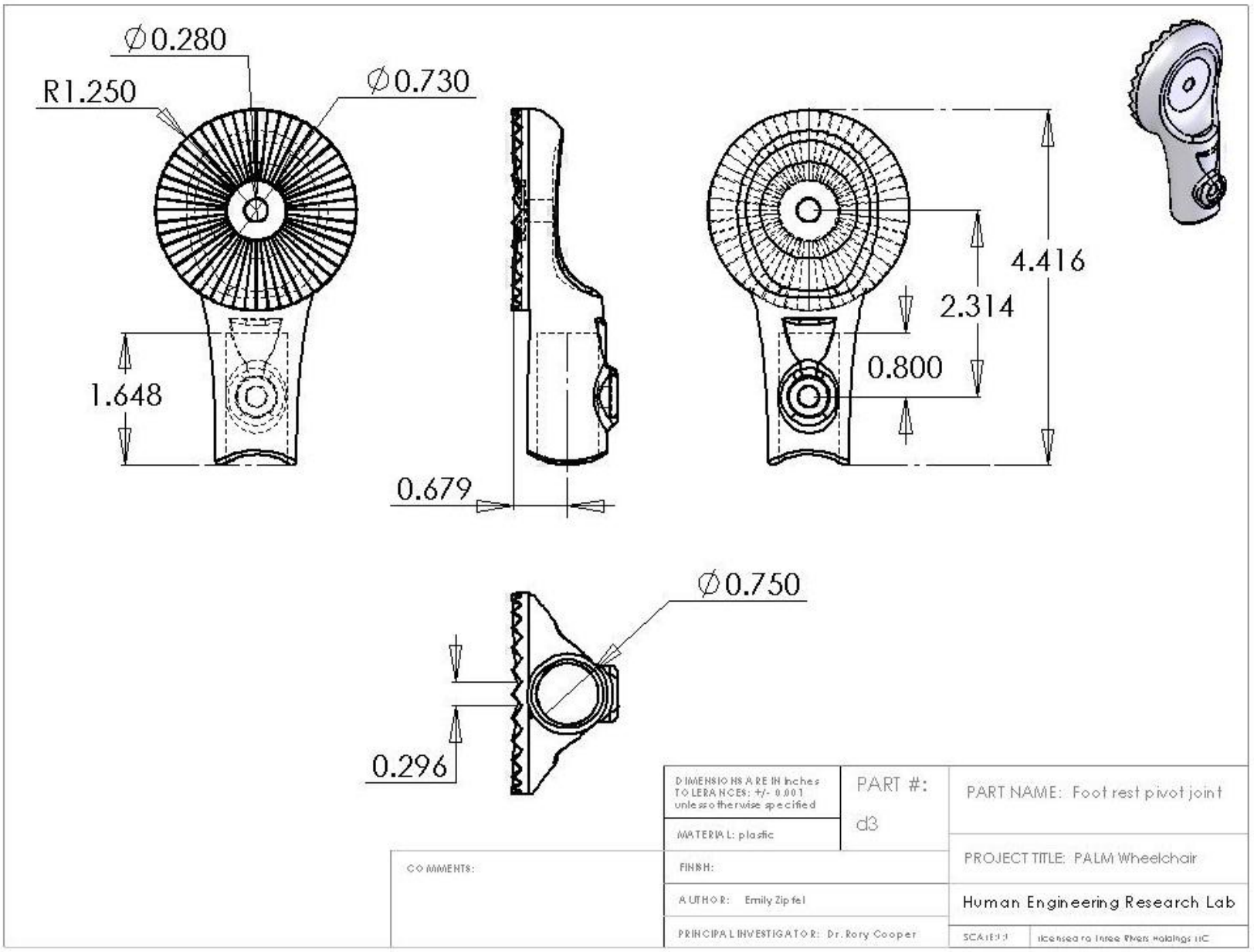
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #:	PART NAME: Footrest assembly
MATERIAL:		
COMMENTS: FINISH:		PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel		Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE: 1:10	licensed to Three Rivers Holdings LLC

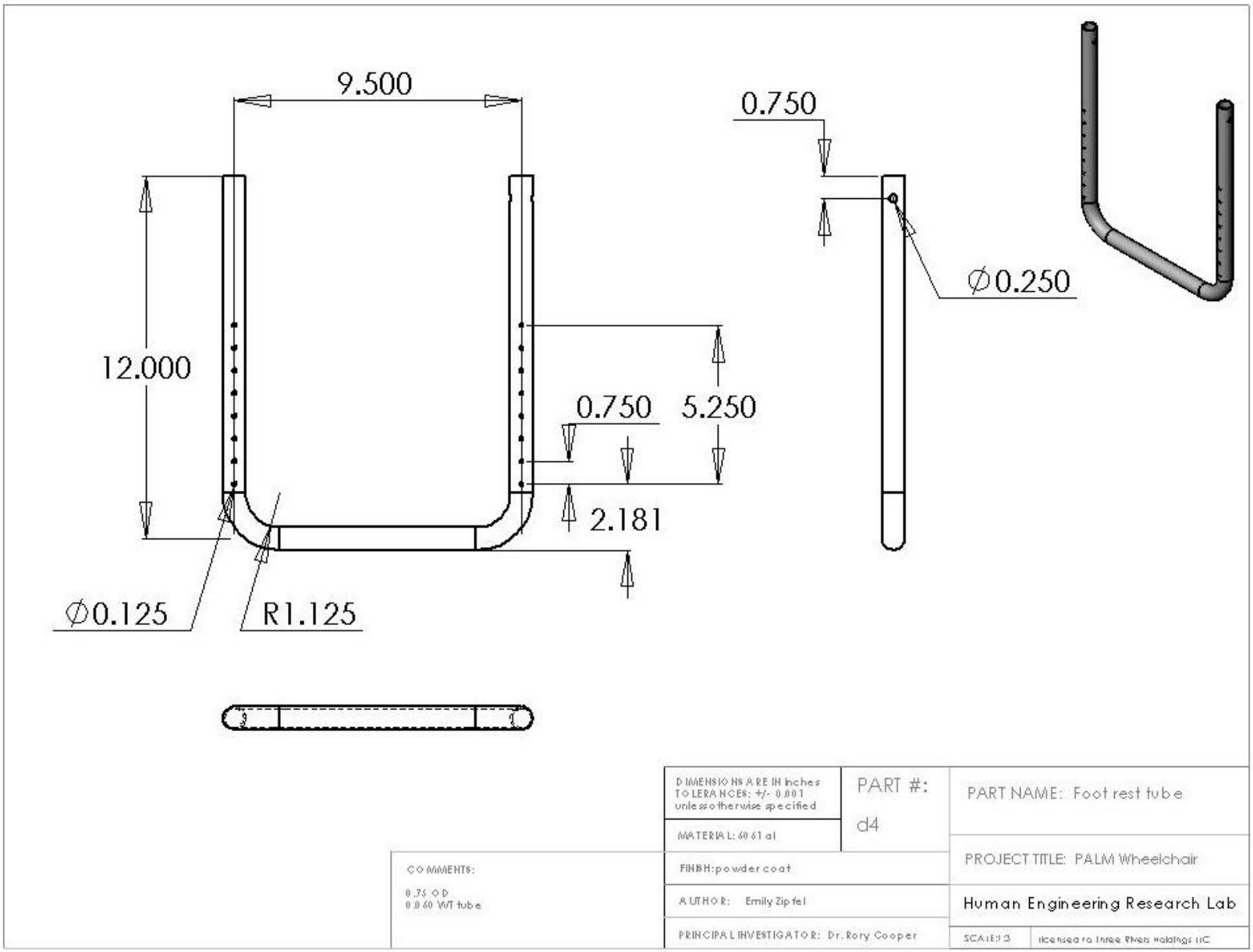

6.600
R1.000
0.400
1.500
.080
R1.000
0.750
⌀0.125
0.620
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
d1
PART NAME: Foot plate
MATERIAL: 0.125" 6061 Al sheet
PROJECT TITLE: PALM Wheelchair
COMMENTS:
drawing for right footplate. Left footplate
mirrored from right
FINISH: powder coat
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:2
licensed to Three Rivers Holdings LLC

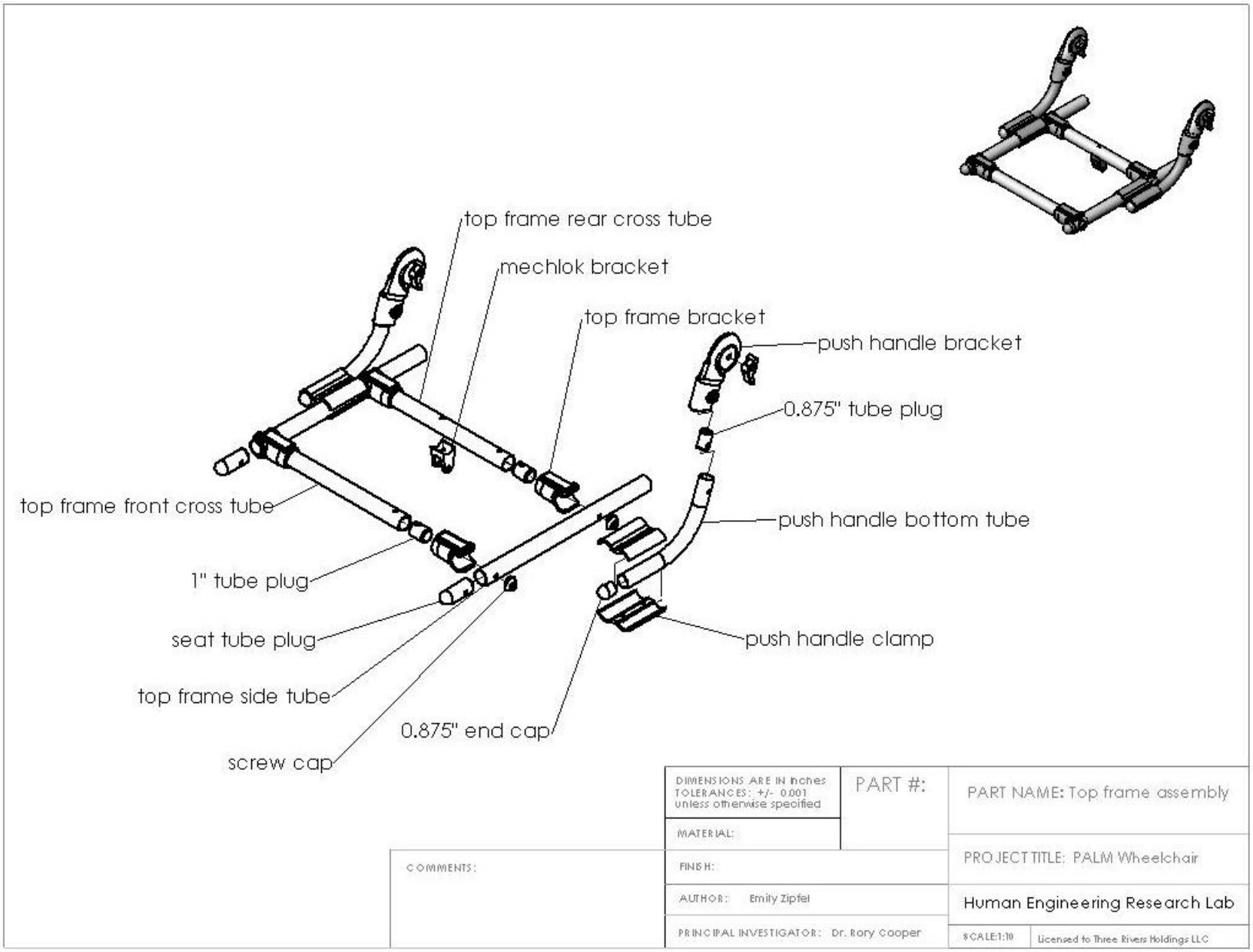


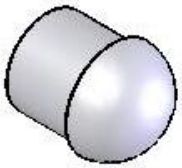
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #:	PART NAME: Foot plate flat pattern
MATERIAL: 0.125" 6061 Al sheet		
COMMENTS:	FINISH:	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE: 1:1 licensed to Three Rivers Holdings LLC

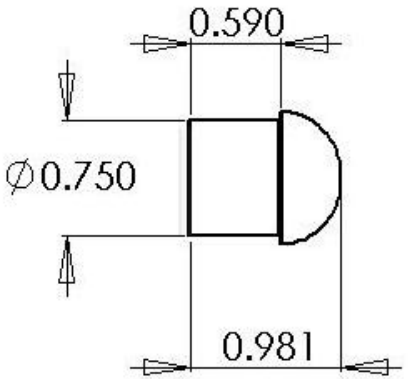

∅0.758
0.597
1.500
3.810
1.234
0.750
2.360
1.996
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
MATERIAL: plastic
PART #:
d2
PART NAME: Foot plate bracket
COMMENTS:
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1
licensed to Three Rivers Holdings LLC

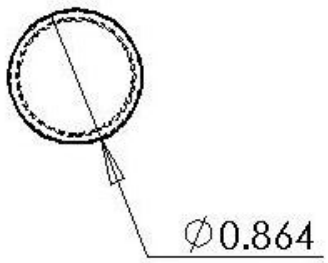

∅0.280
R1.250
∅0.730
1.648
0.679
4.416
2.314
0.800
∅0.750
0.296
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
d3
PART NAME: Foot rest pivot joint
MATERIAL: plastic
PROJECT TITLE: PALM Wheelchair
COMMENTS:
FINISH:
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1
licensed to Three Rivers Holdings LLC


9.500
12.000
0.750
5.250
2.181
∅0.125
R1.125
0.750
∅0.250
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
d4
PART NAME: Foot rest tube
MATERIAL: 6061 al
PROJECT TITLE: PALM Wheelchair
COMMENTS:
0.75 OD
0.060 WT tube
FINISH: powder coat
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 3
licensed to Three Rivers Holdings LLC

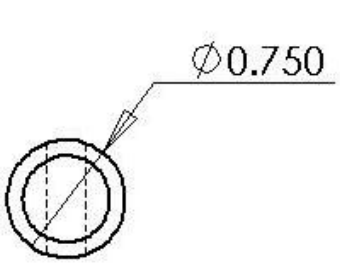

top frame rear cross tube
mechlok bracket
top frame bracket
push handle bracket
0.875" tube plug
top frame front cross tube
push handle bottom tube
1" tube plug
seat tube plug
push handle clamp
top frame side tube
0.875" end cap
screw cap
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
PART NAME: Top frame assembly
MATERIAL:
COMMENTS:
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:10
Licensed to Three Rivers Holdings LLC

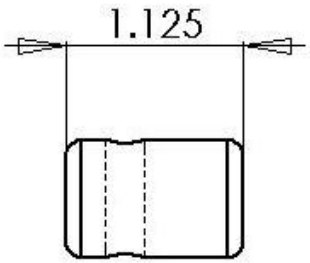


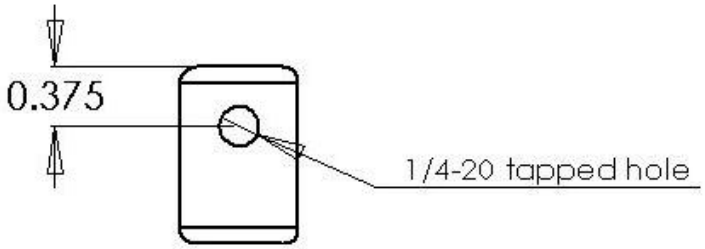




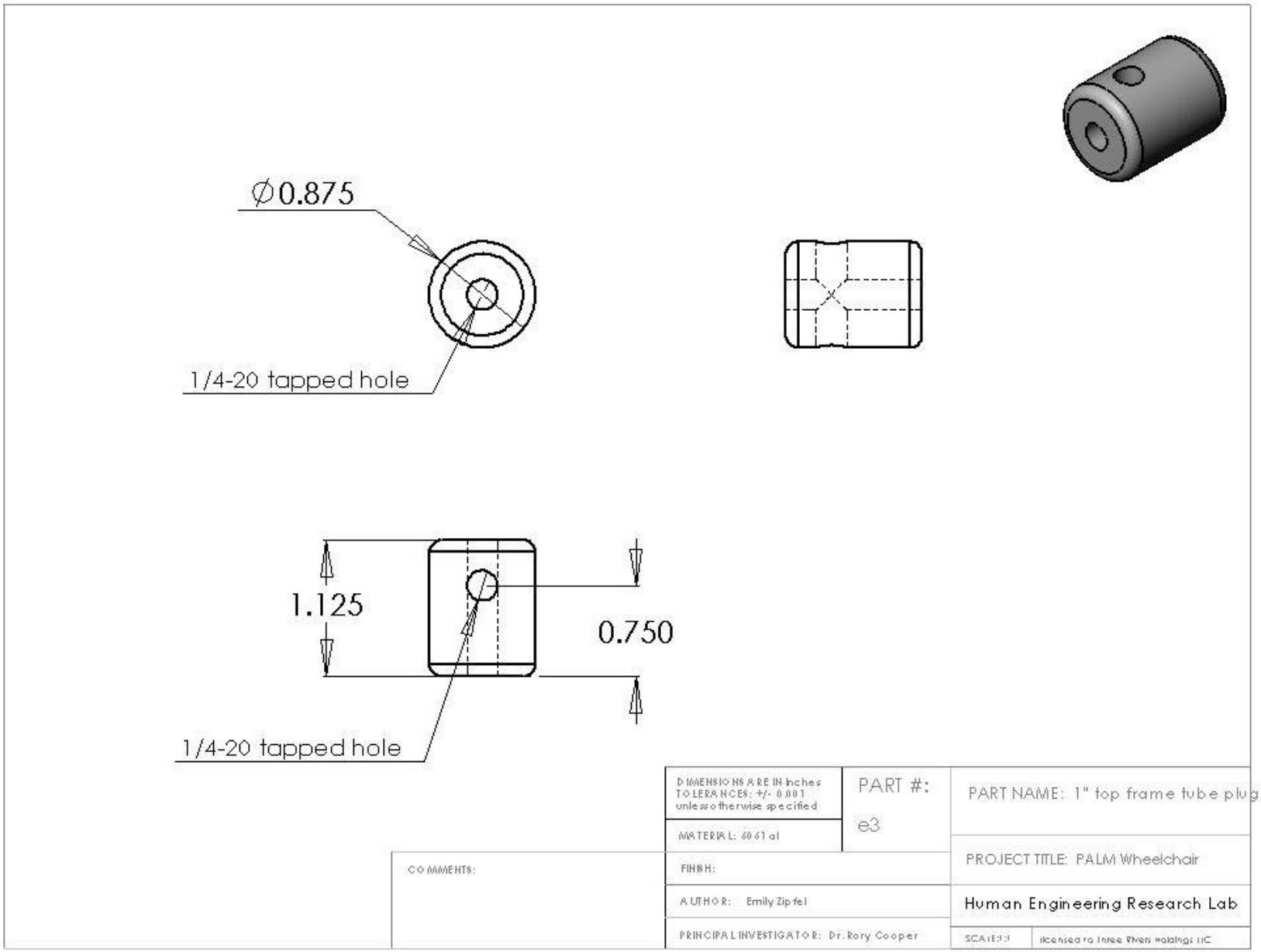
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: e1	PART NAME: 0.875" end cap
MATERIAL: SLA resin		
COMMENTS:	FINISH:	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE: 1:1 licensed to Three Rivers Holdings LLC

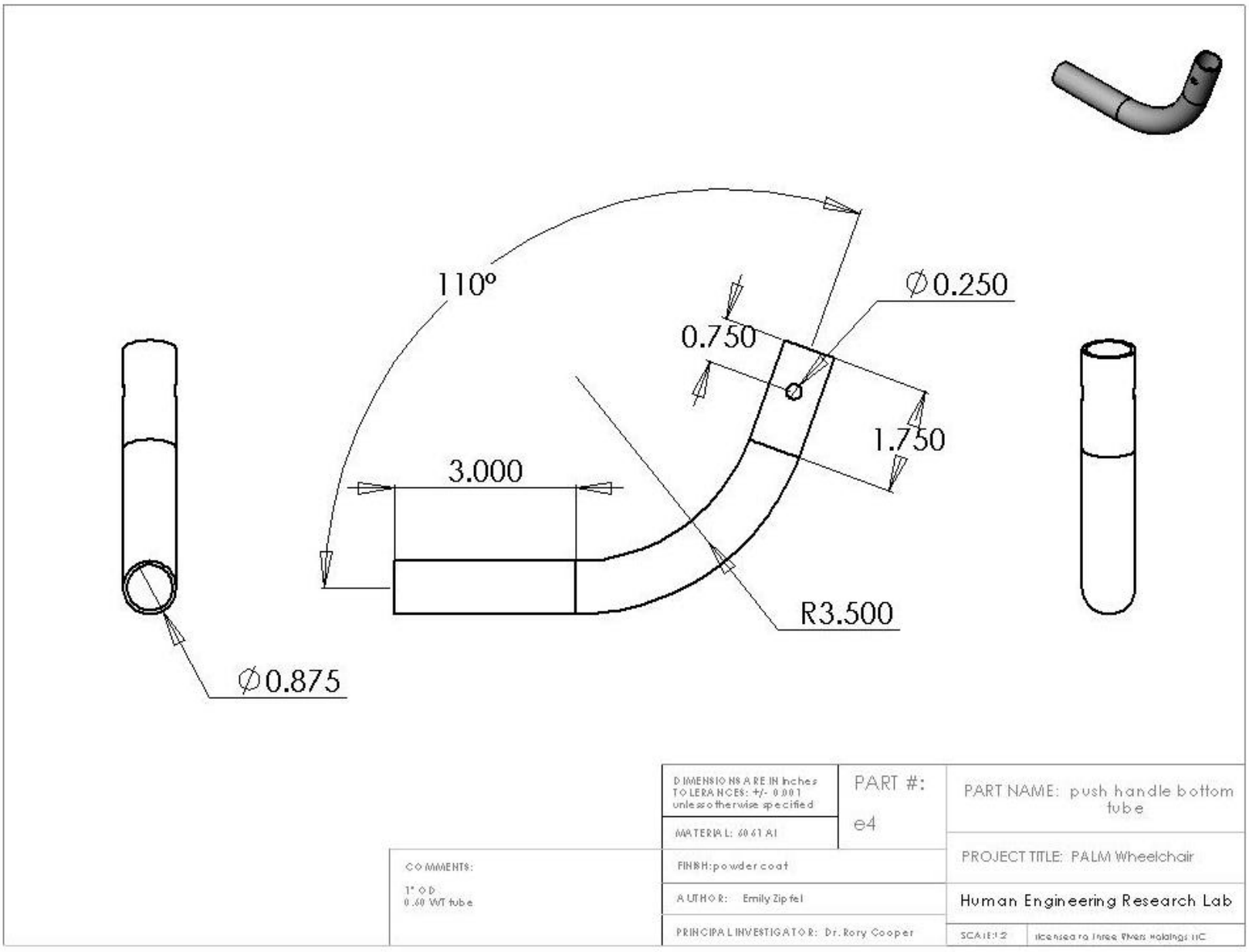


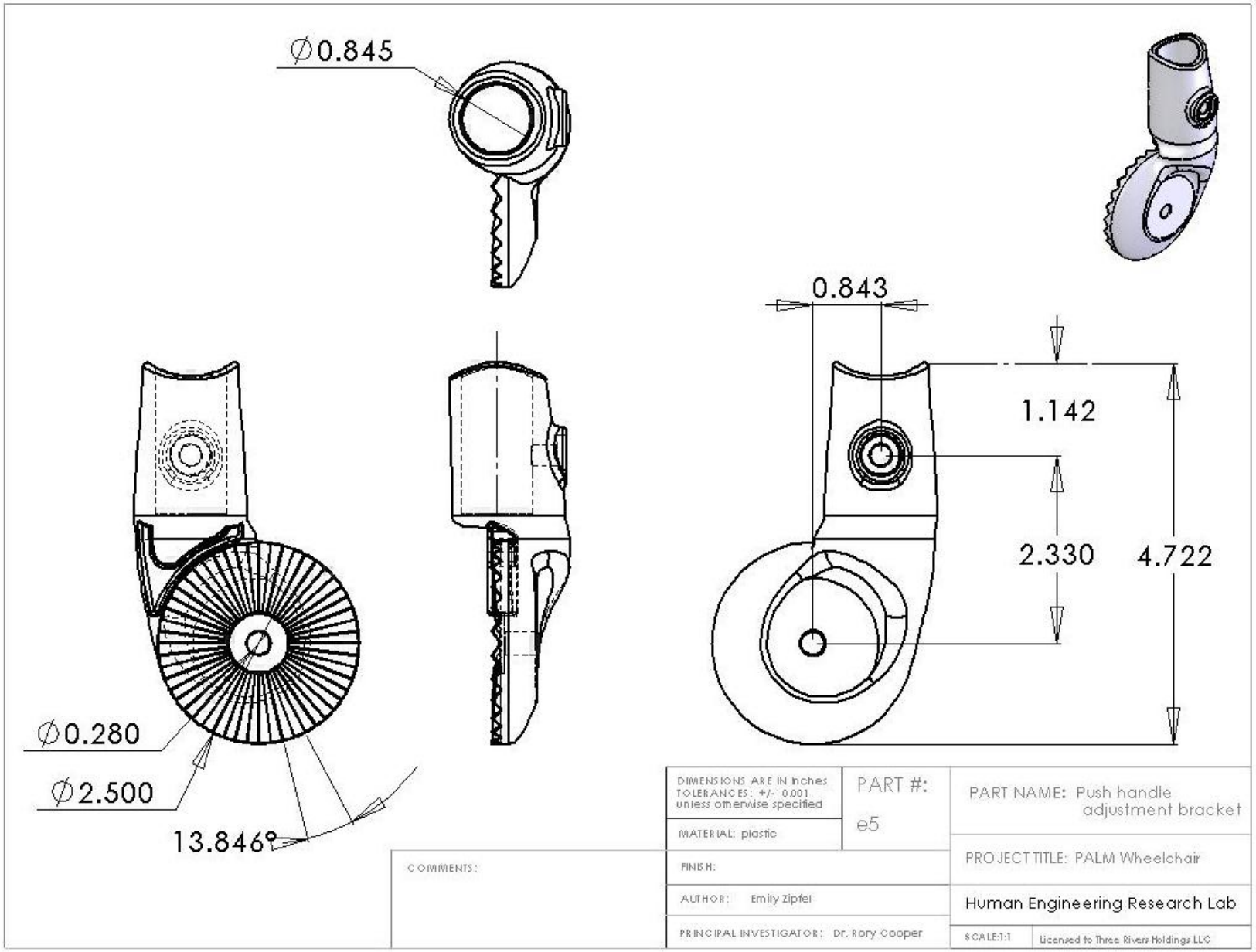


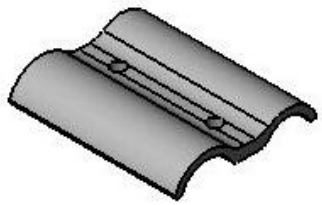


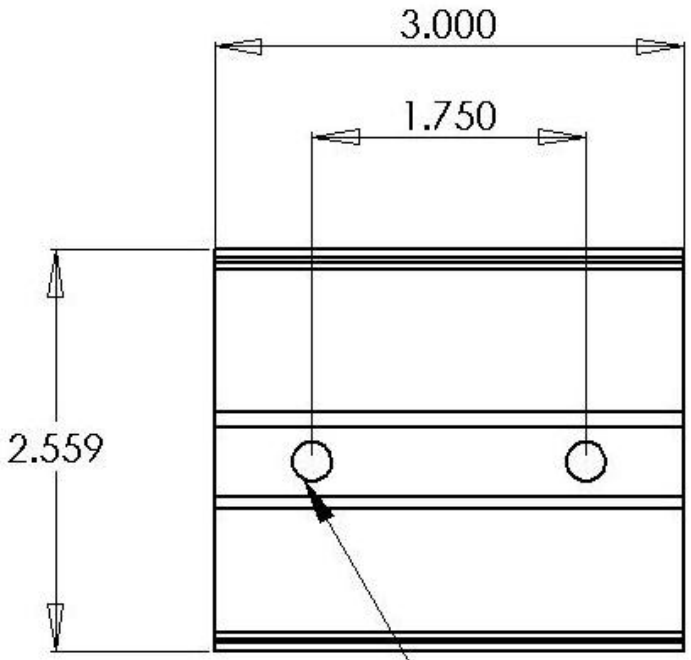
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: e2	PART NAME: 0.875 tube plug
MATERIAL: 6061 al		
COMMENTS: plug should fit in 0.875" OD 0.060 WT tube	FINISH:	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:1 Licensed to Three Rivers Holdings LLC

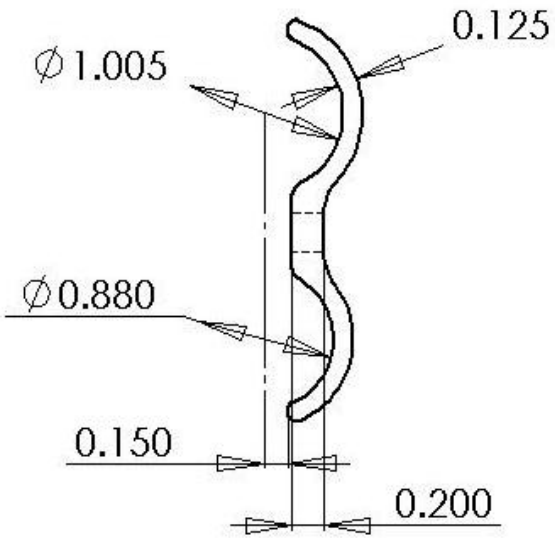

∅0.875
1/4-20 tapped hole
1.125
0.750
1/4-20 tapped hole
DIMENSIONS ARE IN inches
TOLERANCES: +/- 0.001
unless otherwise specified
MATERIAL: 6061 al
PART #:
e3
PART NAME: 1" top frame tube plug
COMMENTS:
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1
licensed to Three Rivers Holdings LLC


110°
Ø0.250
0.750
1.750
3.000
R3.500
Ø0.875
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
e4
PART NAME: push handle bottom tube
MATERIAL: 6061 Al
PROJECT TITLE: PALM Wheelchair
COMMENTS:
1" OD
0.60 WT tube
FINISH: powder coat
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:2
licensed to Three Rivers Holdings LLC

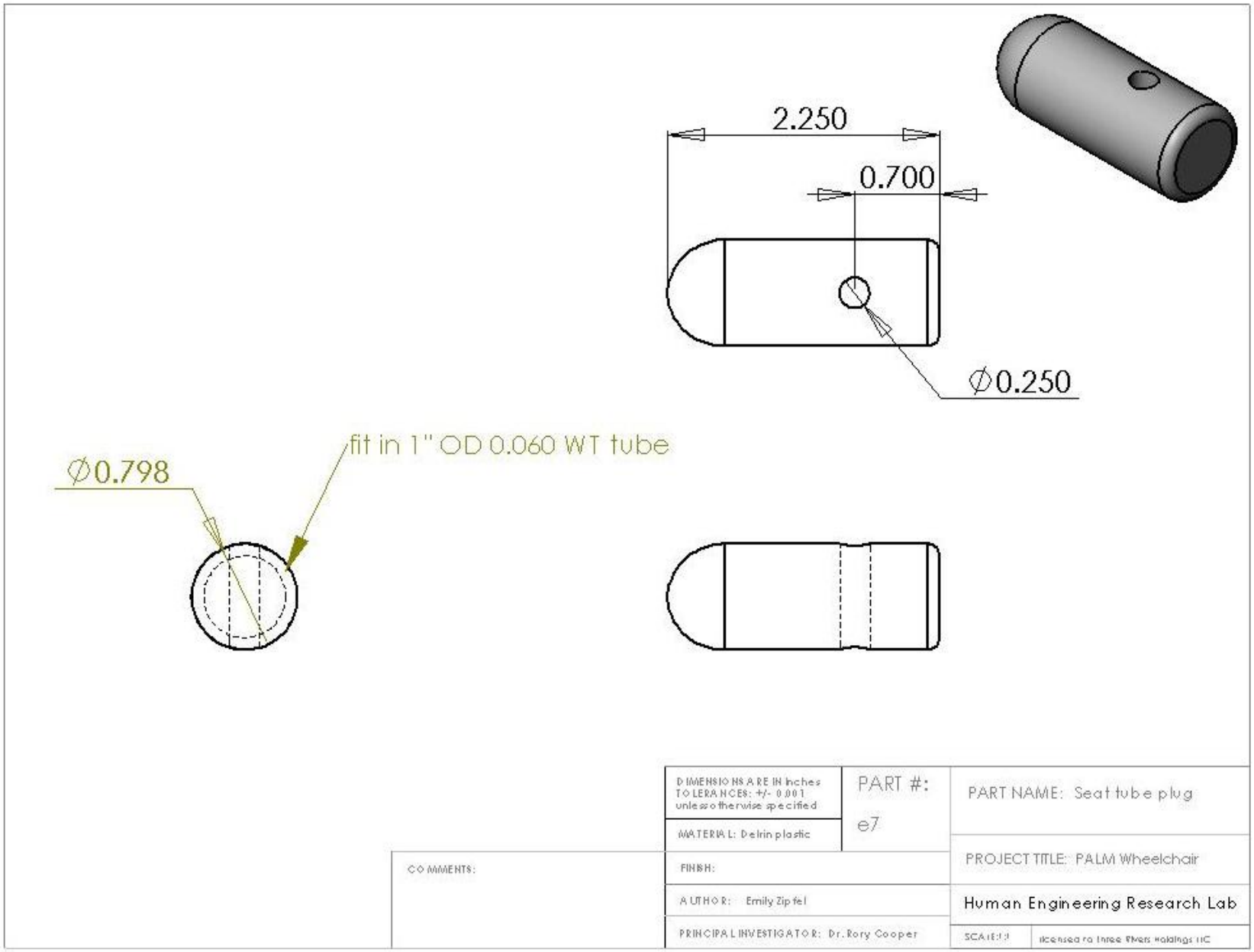

∅0.845
0.843
1.142
2.330
4.722
∅0.280
∅2.500
13.846°
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
e5
PART NAME: Push handle adjustment bracket
MATERIAL: plastic
PROJECT TITLE: PALM Wheelchair
COMMENTS:
FINISH:
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:1
Licensed to Three Rivers Holdings LLC

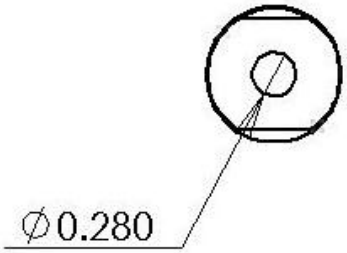


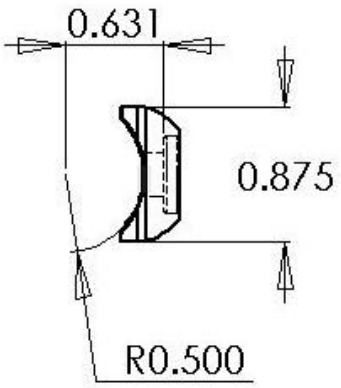


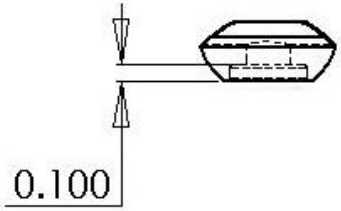


DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #:	PART NAME: Push handle clamp
MATERIAL: 6061 al	e6	
COMMENTS:	FINISH: powder coat	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE: 1:1 licensed to Three Rivers Holdings LLC

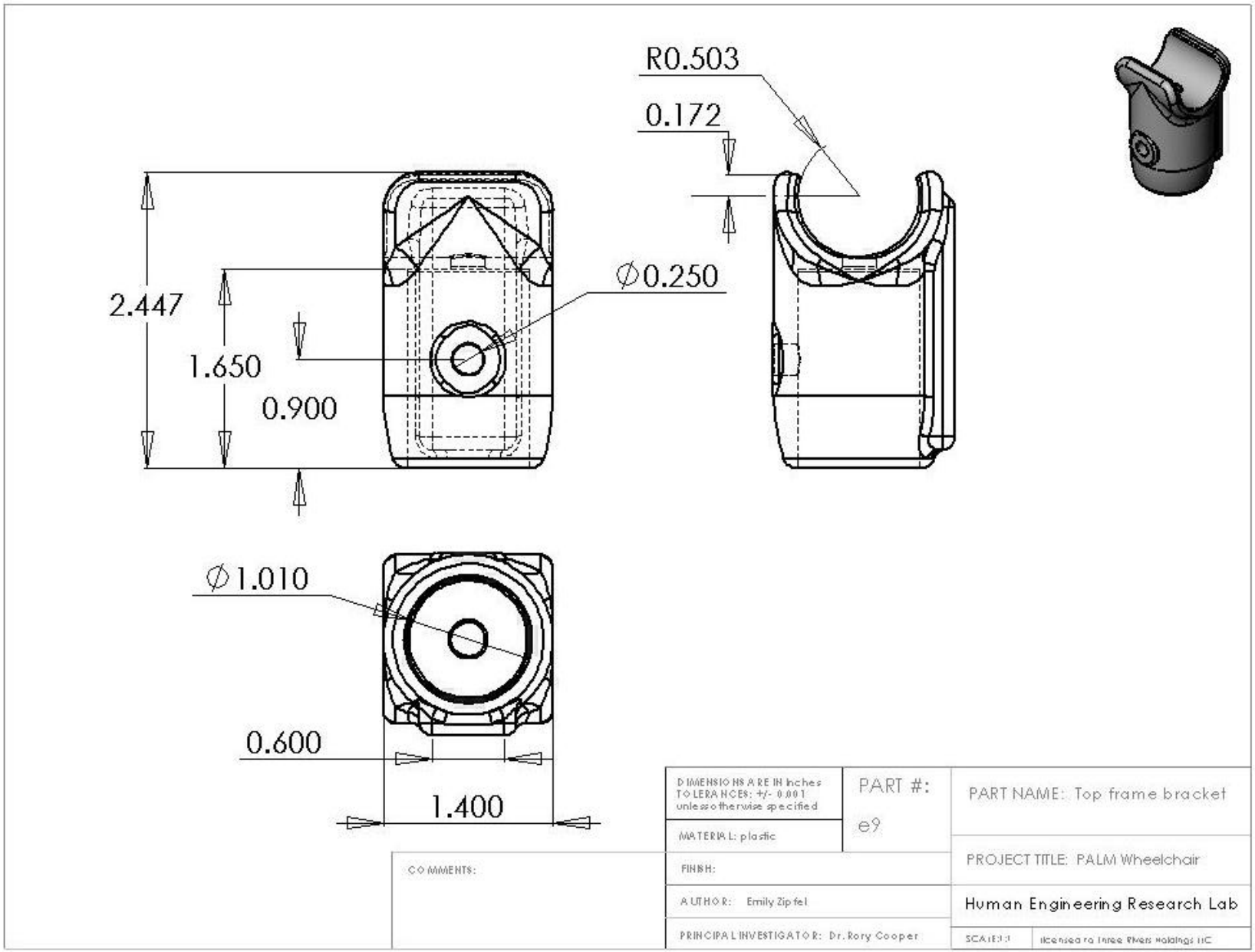

2.250
0.700
∅0.250
fit in 1" OD 0.060 WT tube
∅0.798
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
MATERIAL: Delrin plastic
PART #:
e7
PART NAME: Seat tube plug
COMMENTS:
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1
licensed to Three Rivers Holdings LLC

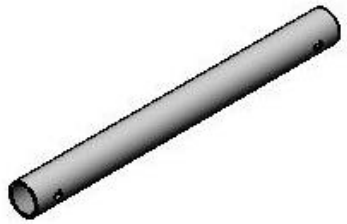


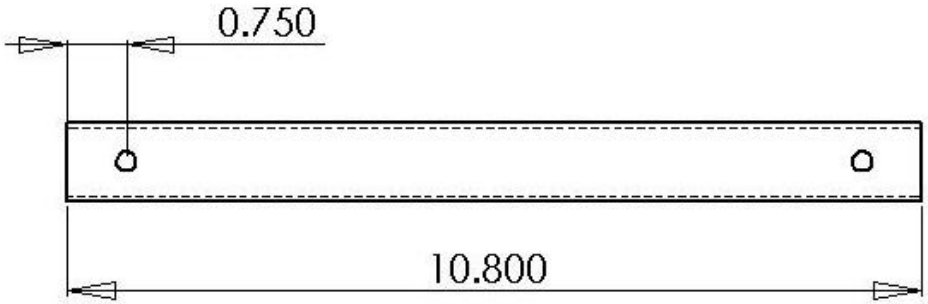


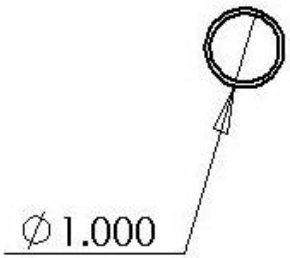


DIMENSIONS ARE IN inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: e8	PART NAME: screw cap
MATERIAL: sla resin		
COMMENTS:	FINISH:	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:1 licensed to Three Rivers Holdings LLC

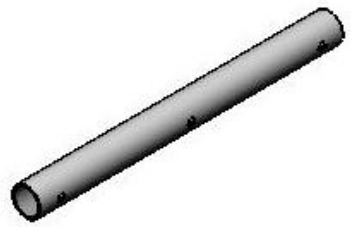

R0.503
0.172
∅0.250
2.447
1.650
0.900
∅1.010
0.600
1.400
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
MATERIAL: plastic
FINISH:
PART #:
e9
PART NAME: Top frame bracket
PROJECT TITLE: PALM Wheelchair
COMMENTS:
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:1
licensed to Three Rivers Holdings LLC

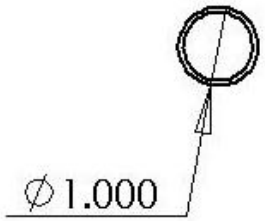


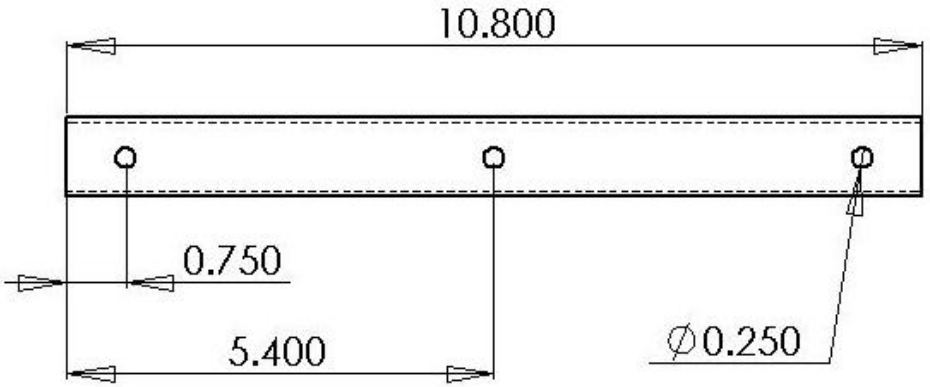




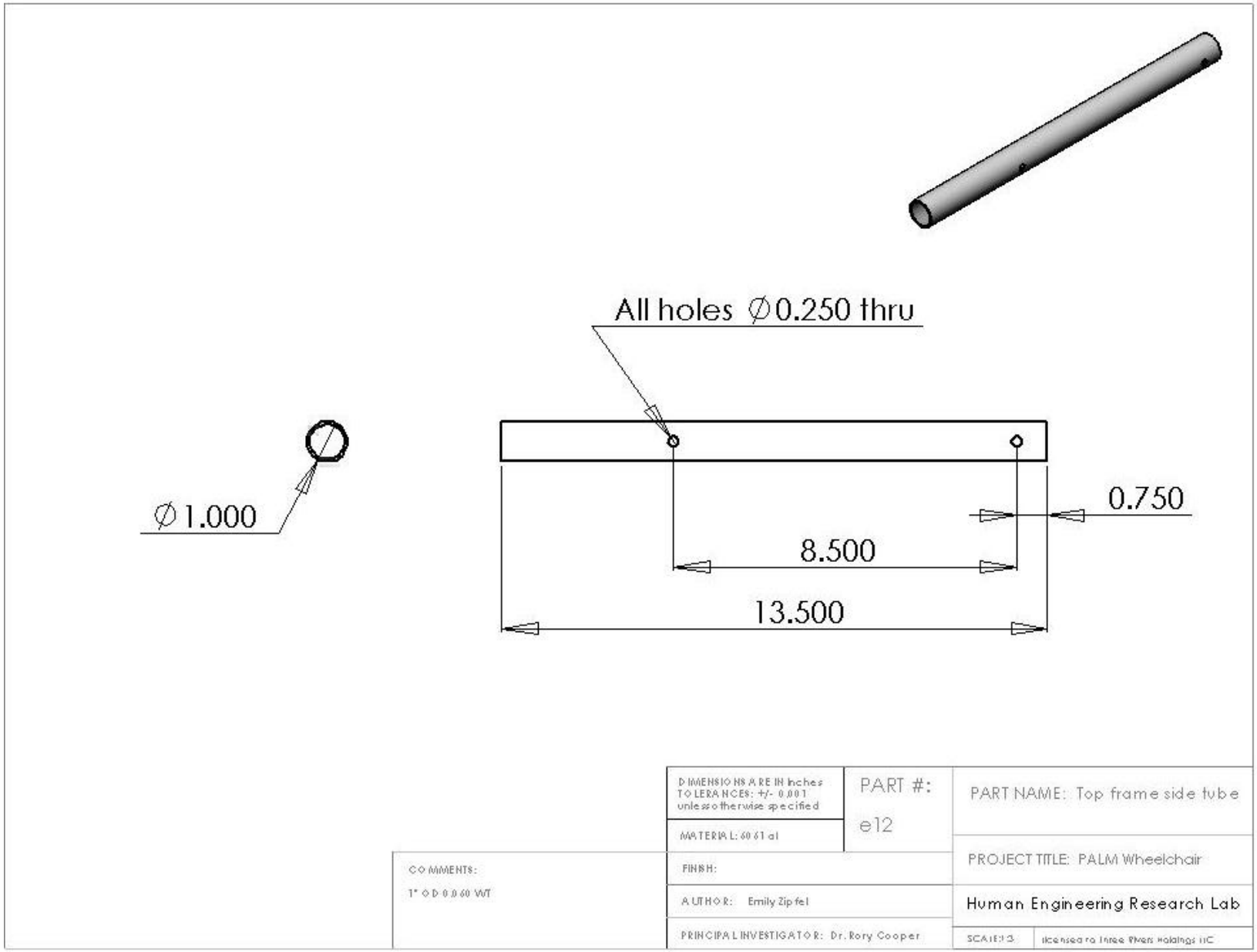
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: e10	PART NAME: top frame front cross tube
MATERIAL: 6061al		
COMMENTS: 1" OD 0.060 WT tube	FINISH: powder coat	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE: 1:2 licensed to Three Rivers Holdings LLC

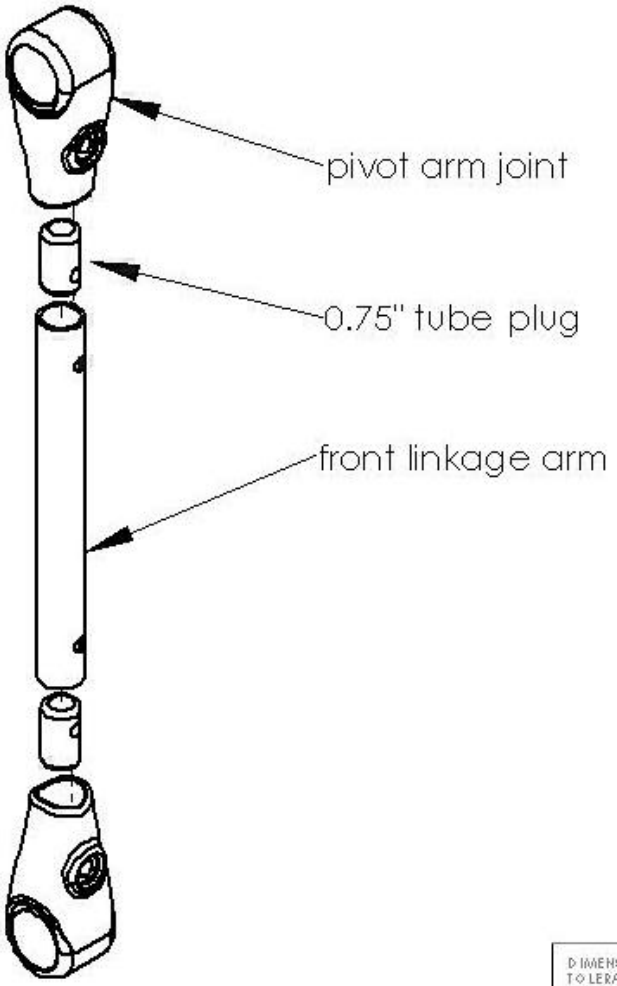




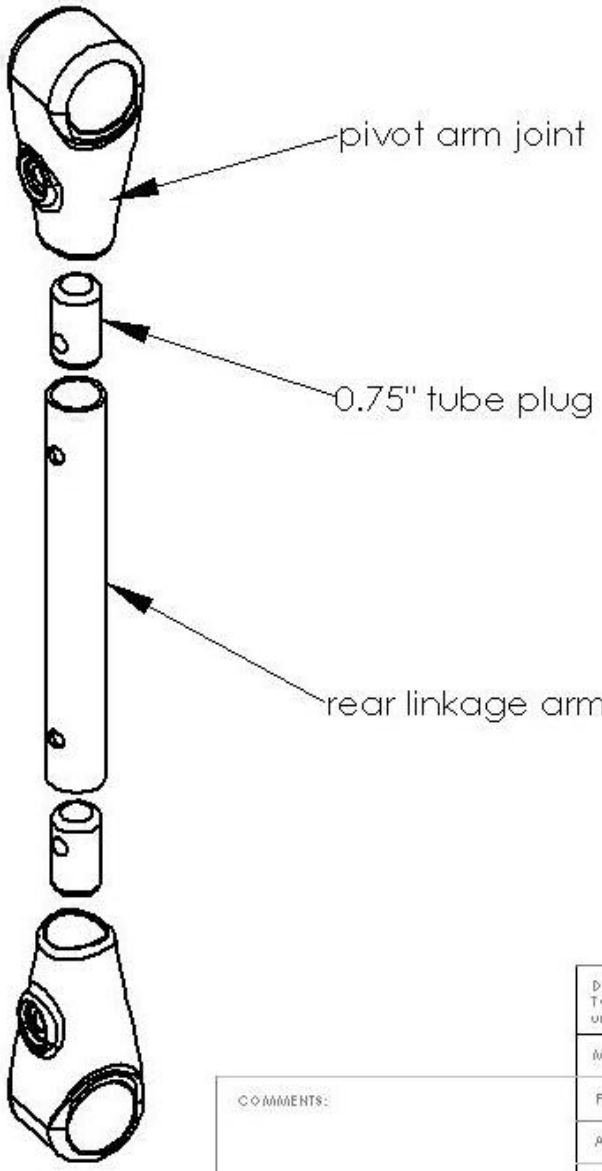


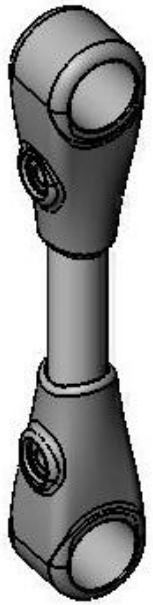
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: e11	PART NAME: top frame rear cross tube
MATERIAL: 6061 al		
COMMENTS: 1" OD 0.060 WT tube	FINISH: powder coat	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE: 1:2 — licensed to Three Rivers Holdings LLC


All holes ∅0.250 thru
∅1.000
0.750
8.500
13.500
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
e12
PART NAME: Top frame side tube
MATERIAL: 6061 al
COMMENTS:
1" OD 0.060 WT
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:3
Licensed to Three Rivers Holdings LLC

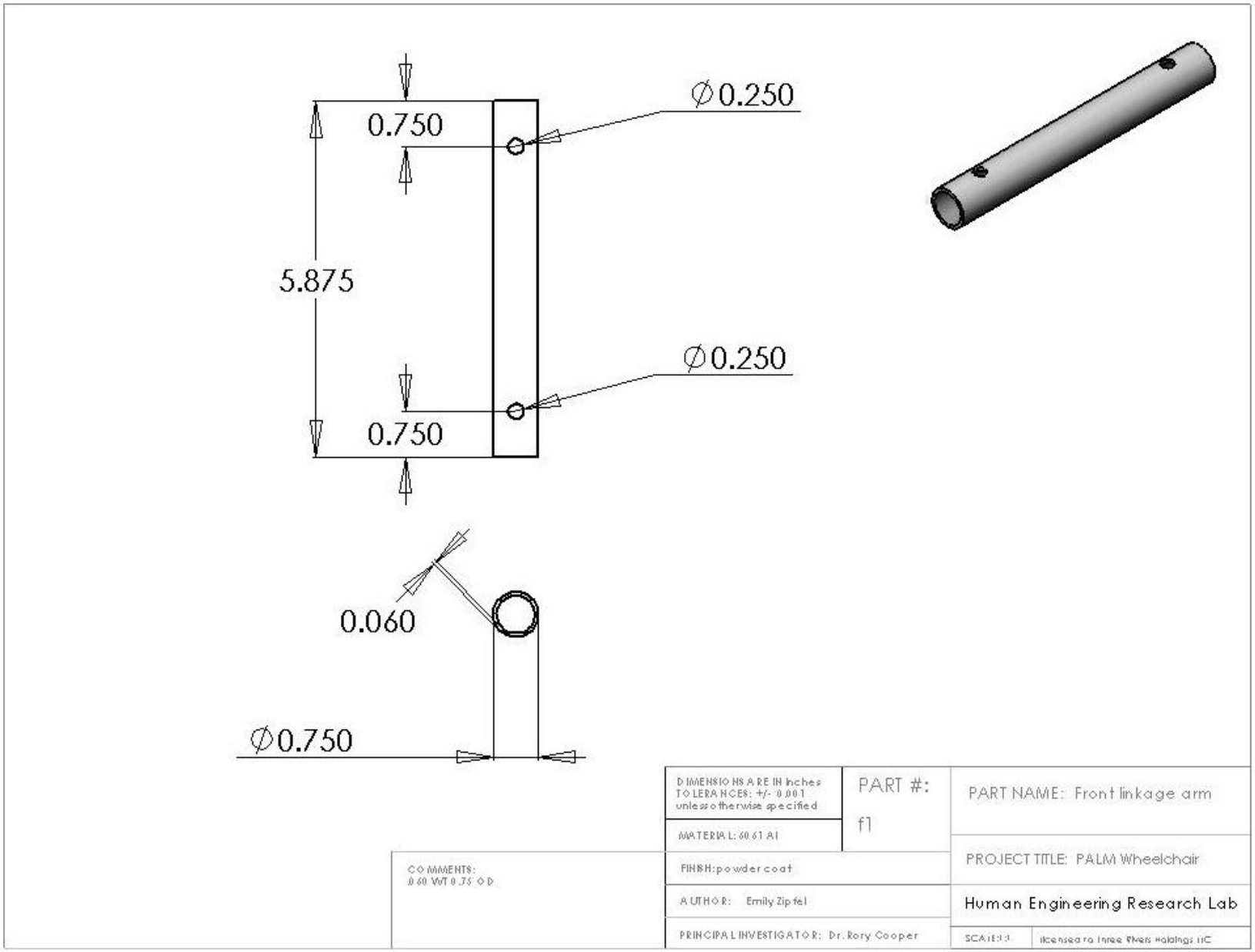


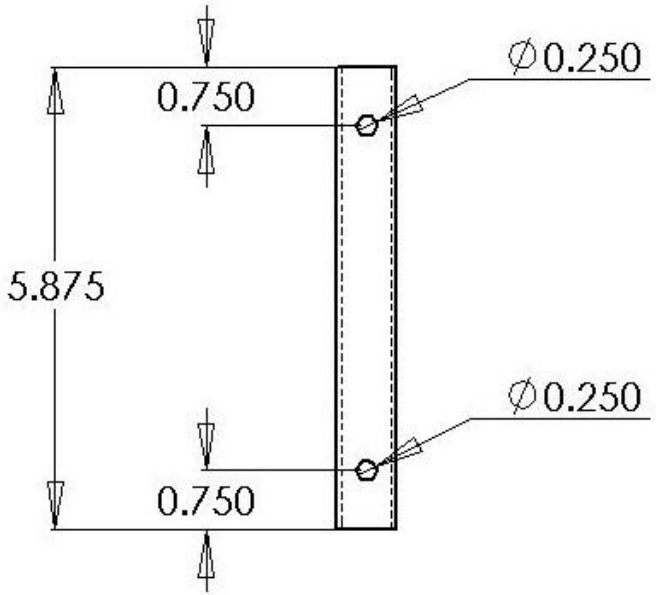
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #:	PART NAME: Front linkage arm assembly
MATERIAL:		
COMMENTS:	FINISH:	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE: 1:10 licensed to Three Rivers Holdings LLC

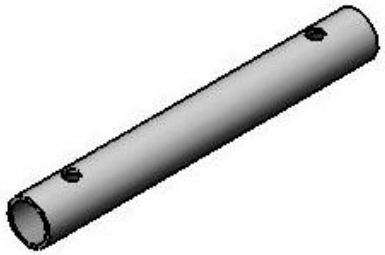


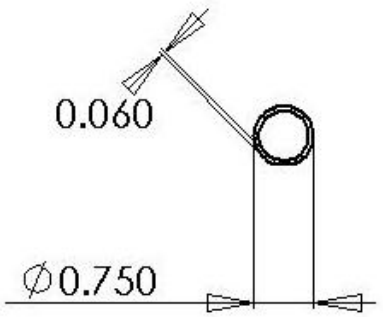


DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #:	PART NAME: Rear linkage arm assembly
MATERIAL:		
COMMENTS:	FINISH:	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:2

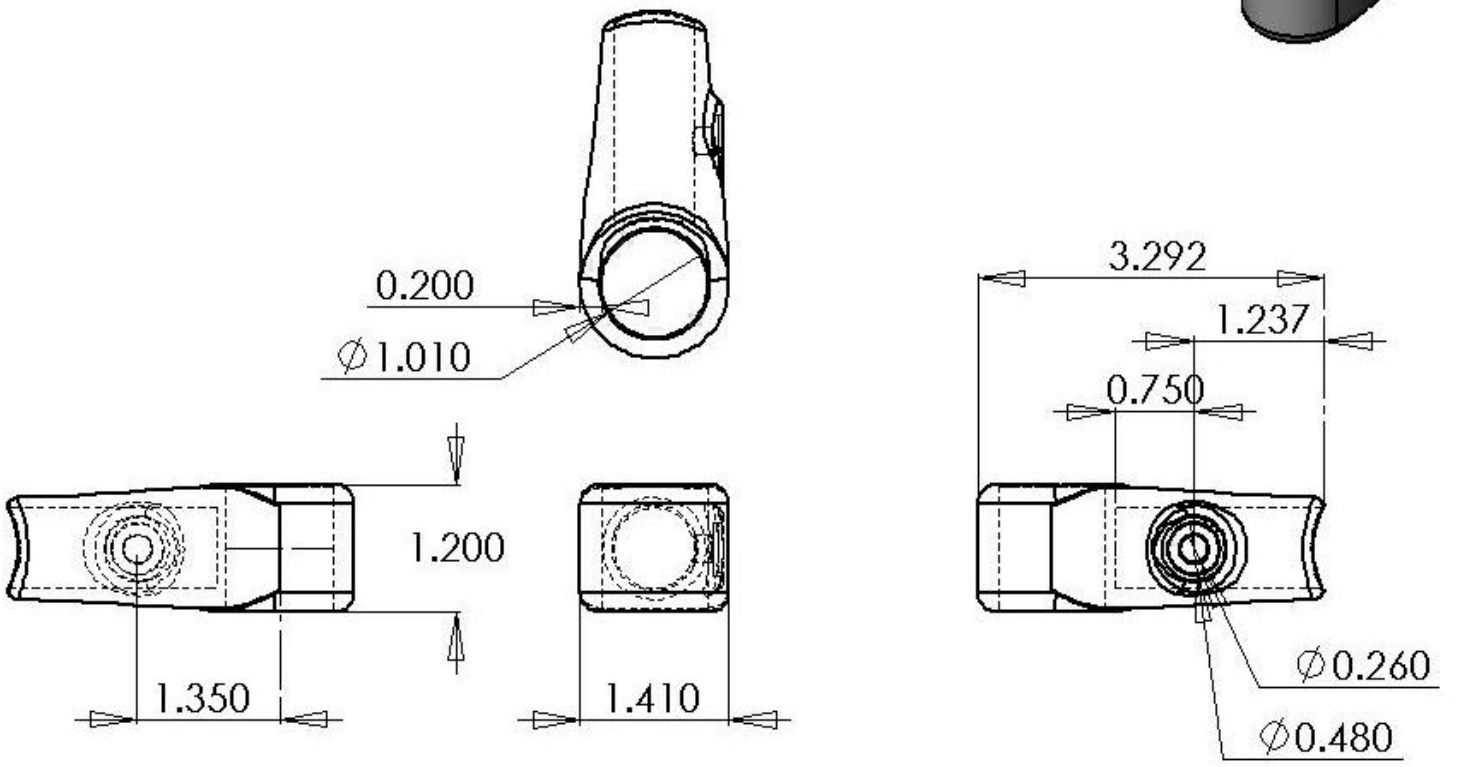

∅0.250
0.750
5.875
∅0.250
0.750
0.060
∅0.750
DIMENSIONS ARE IN inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
f1
PART NAME: Front linkage arm
MATERIAL: 6061 Al
COMMENTS:
0.60 WT 0.75 OD
FINISH: powder coat
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1
licensed to Three Rivers Holdings LLC



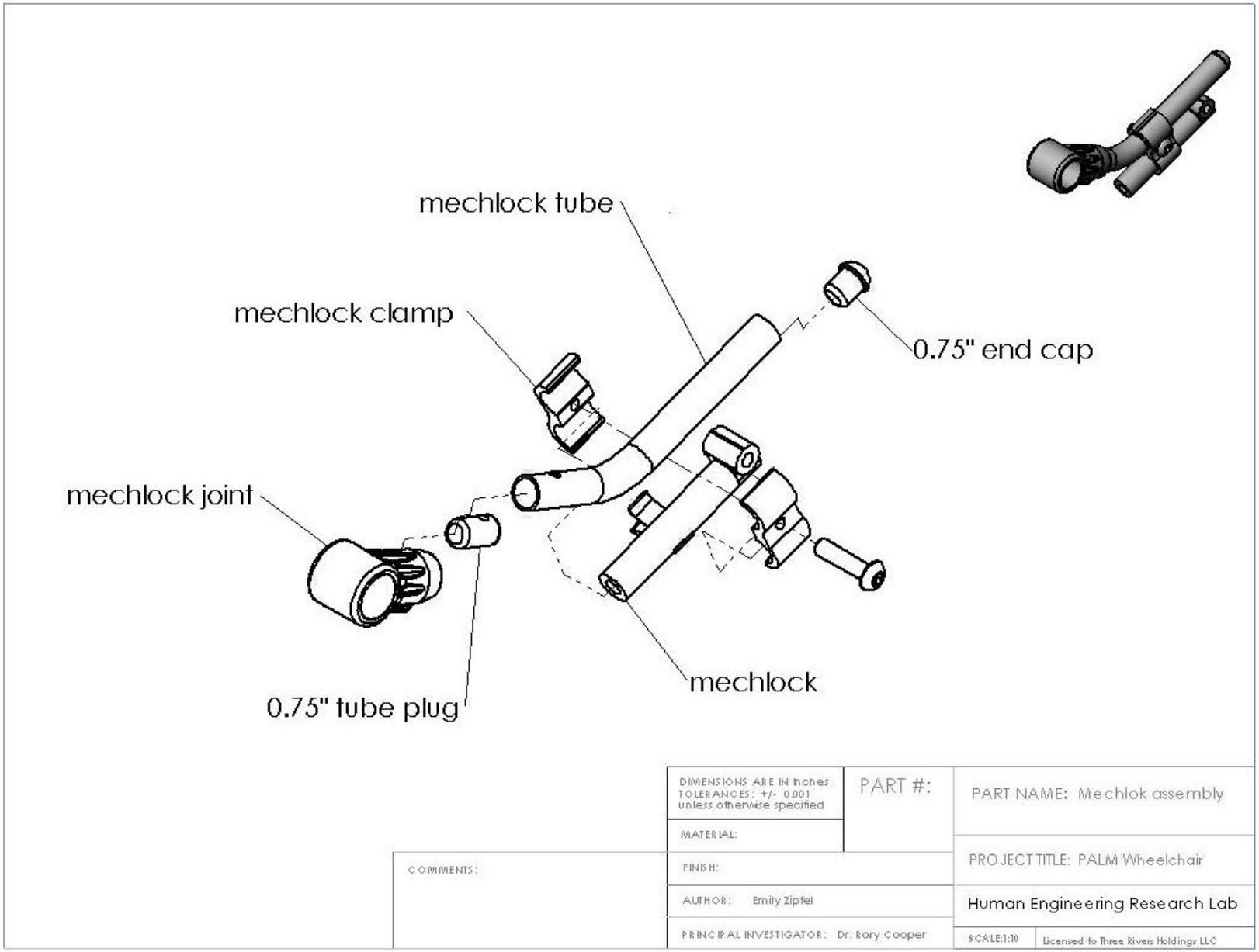


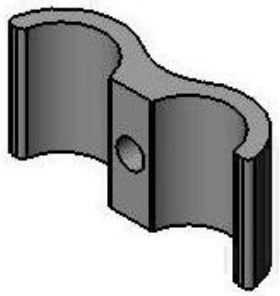


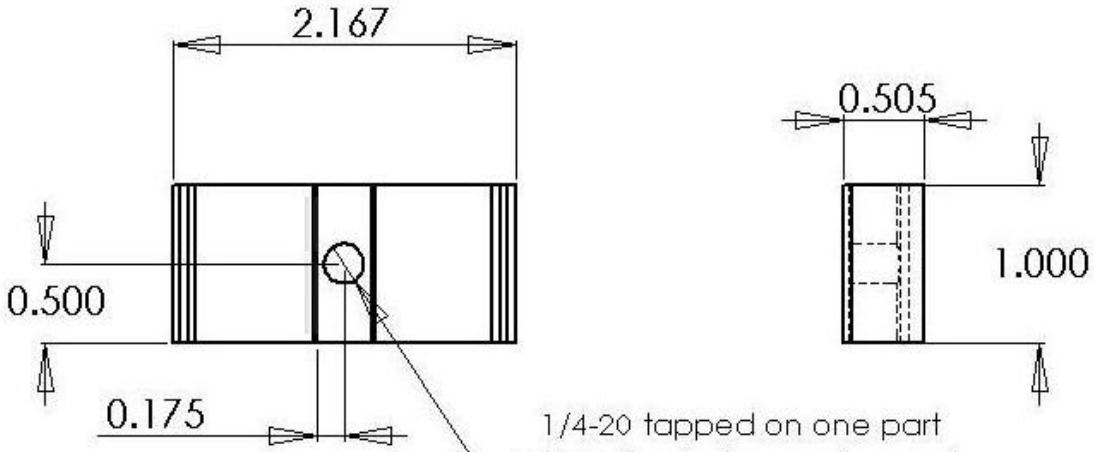
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #:	PART NAME: Rear linkage arm
MATERIAL: 6061 al	f2	
COMMENTS: 0.75 OD 0.060 WT tube	FINISH:	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE: 1:2 licensed to Three Rivers Holdings LLC

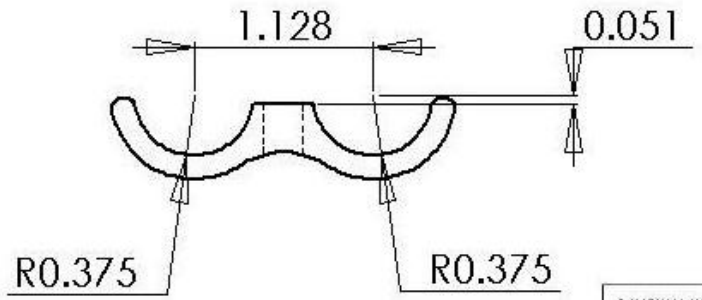


DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #:	PART NAME: Pivot arm joint
MATERIAL: plastic	f3	
COMMENTS:	FINISH:	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:1 licensed to Three Rivers Holdings LLC

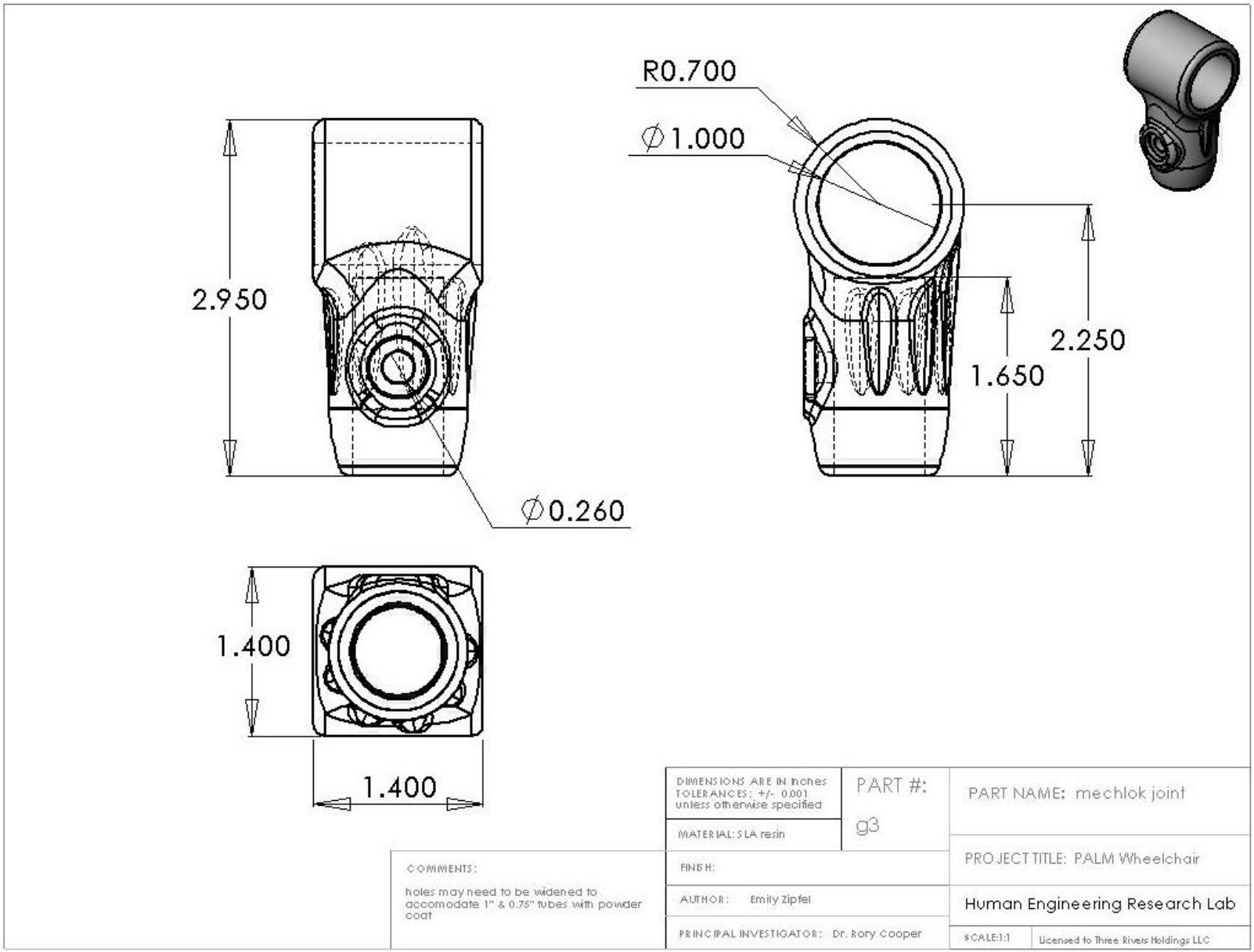

mechlock tube
mechlock clamp
0.75" end cap
mechlock joint
mechlock
0.75" tube plug
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
PART NAME: Mechlok assembly
MATERIAL:
COMMENTS:
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:10
Licensed to Three Rivers Holdings LLC

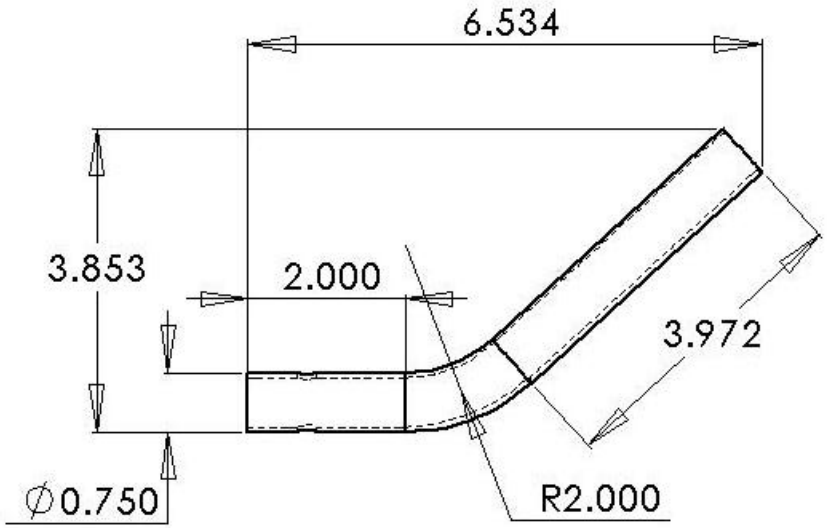


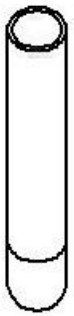


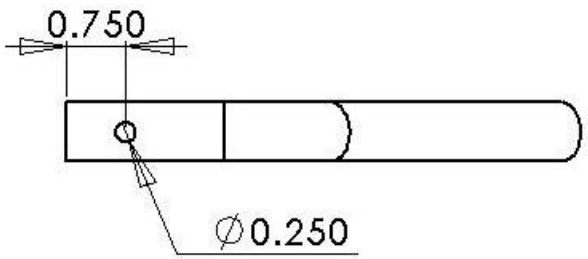


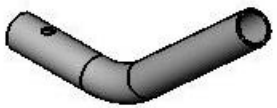
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: g2	PART NAME: mechlok clamp
MATERIAL: 6061 al		
COMMENTS: to make split clamp. one part 1/4-20 tapped other part, 1/4-20 through hole	FINISH: powder coat	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE: 1:1 licensed to Three Rivers Holdings LLC


R0.700
∅1.000
2.950
2.250
1.650
∅0.260
1.400
1.400
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
g3
PART NAME: mechlok joint
MATERIAL: SLA resin
PROJECT TITLE: PALM Wheelchair
COMMENTS:
holes may need to be widened to accomodate 1" & 0.75" tubes with powder coat
FINISH:
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:1
Licensed to Three Rivers Holdings LLC

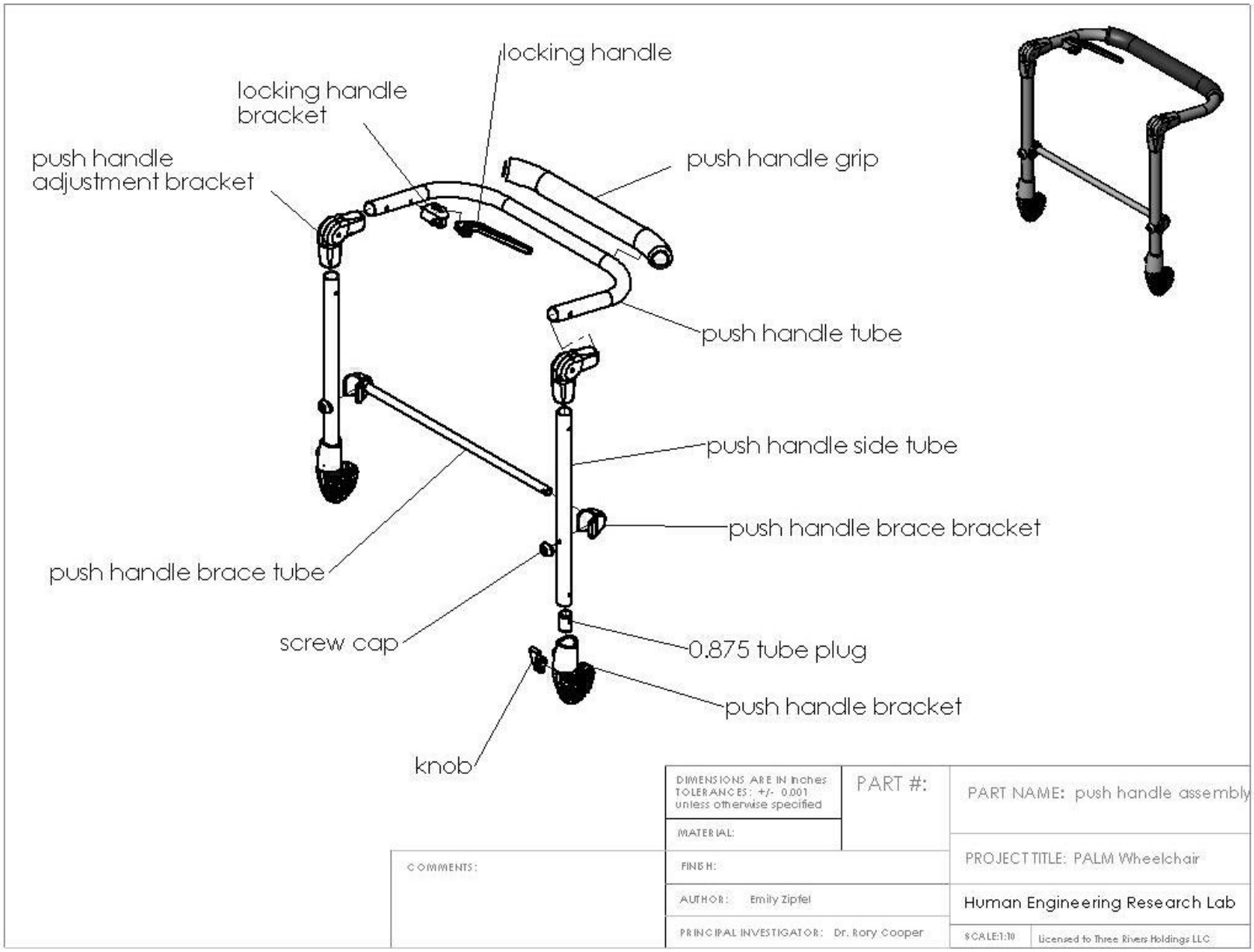


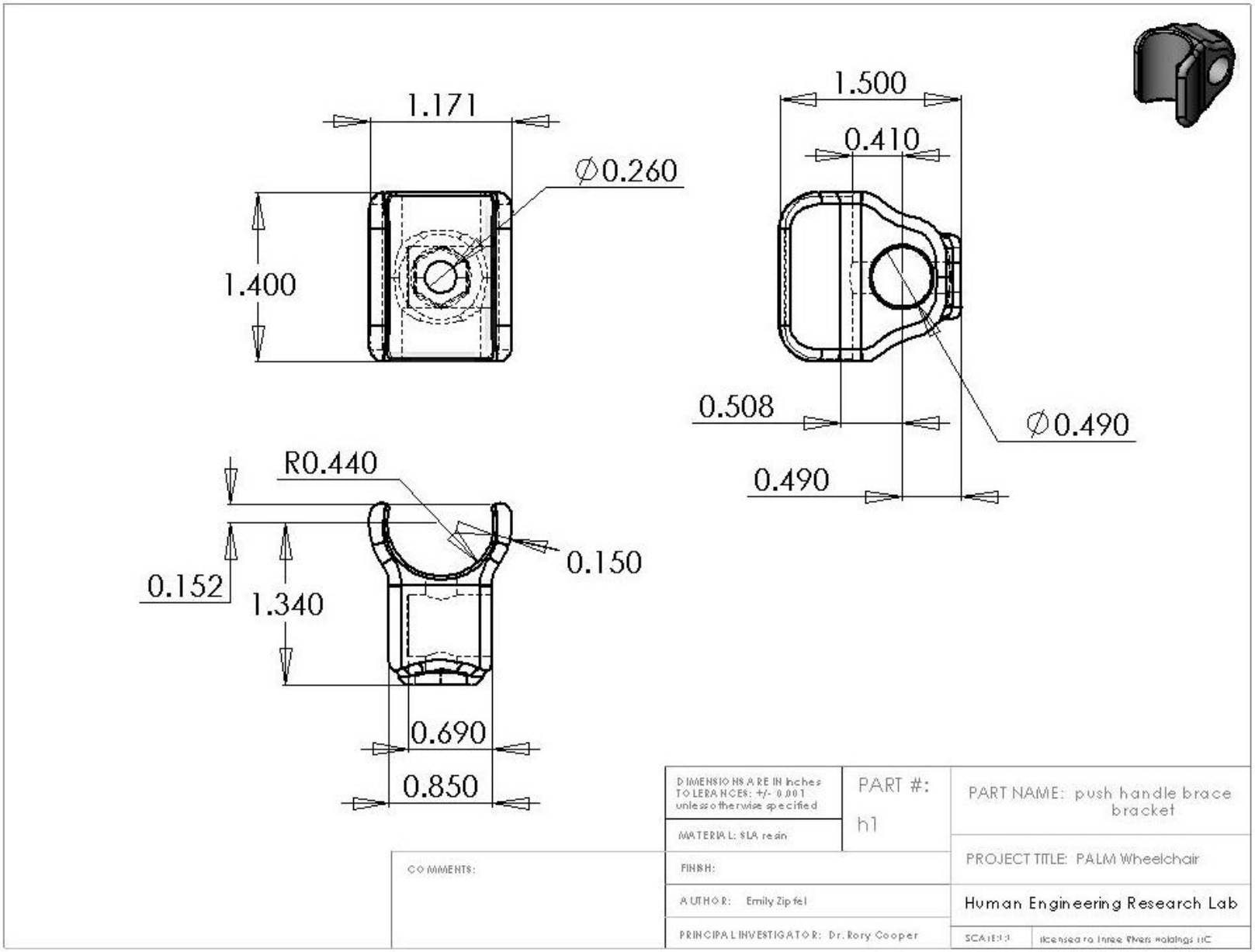


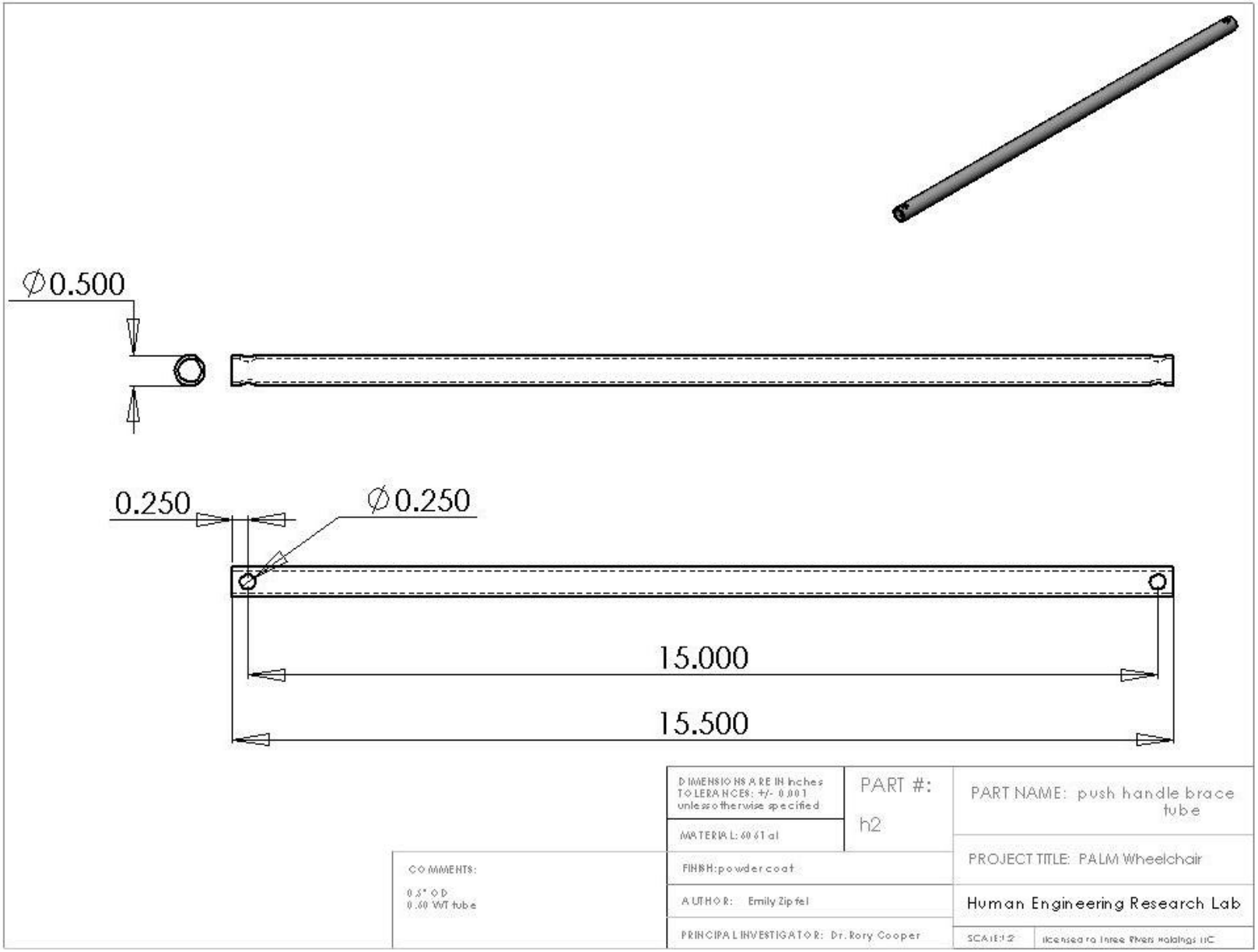


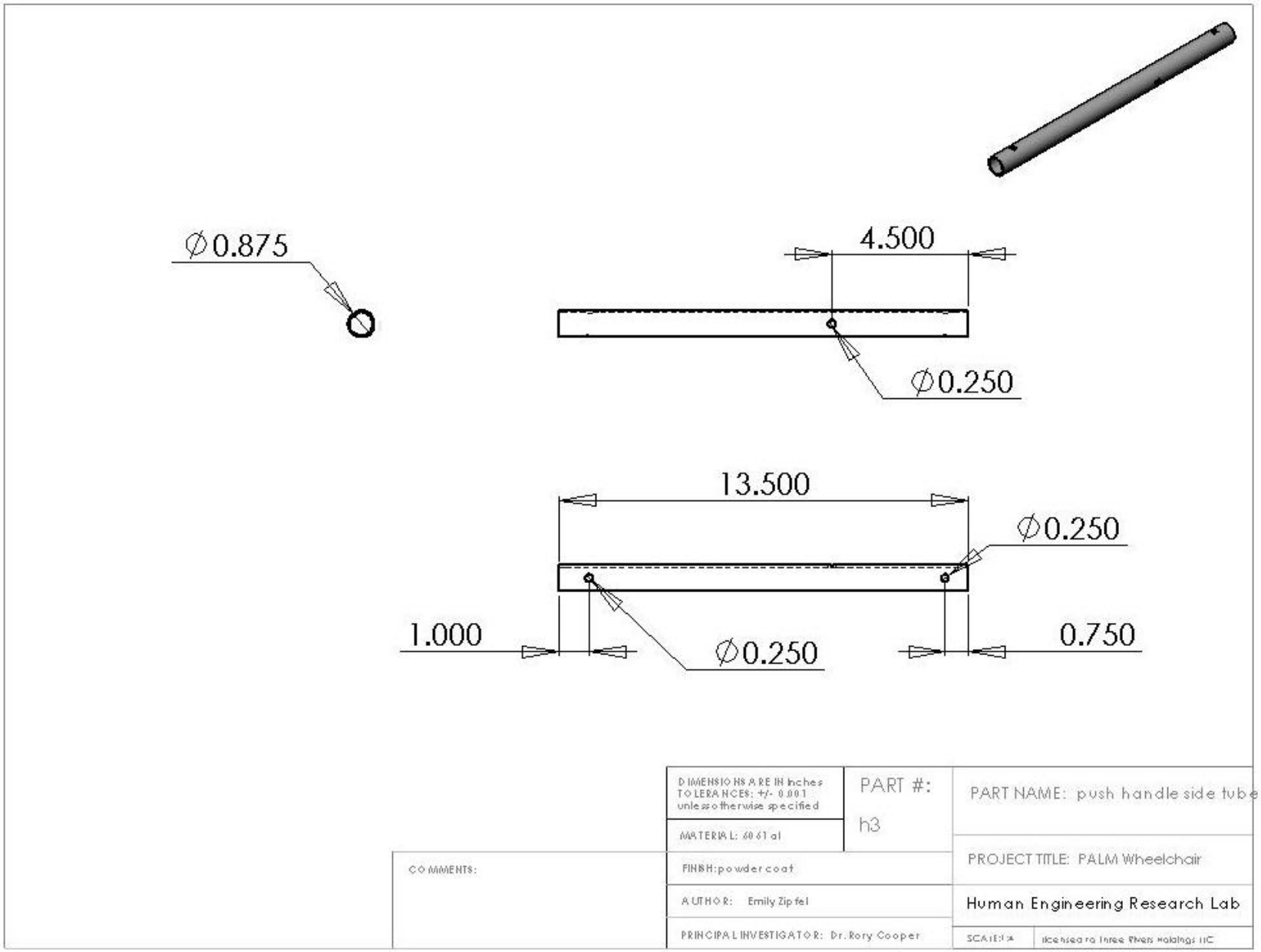


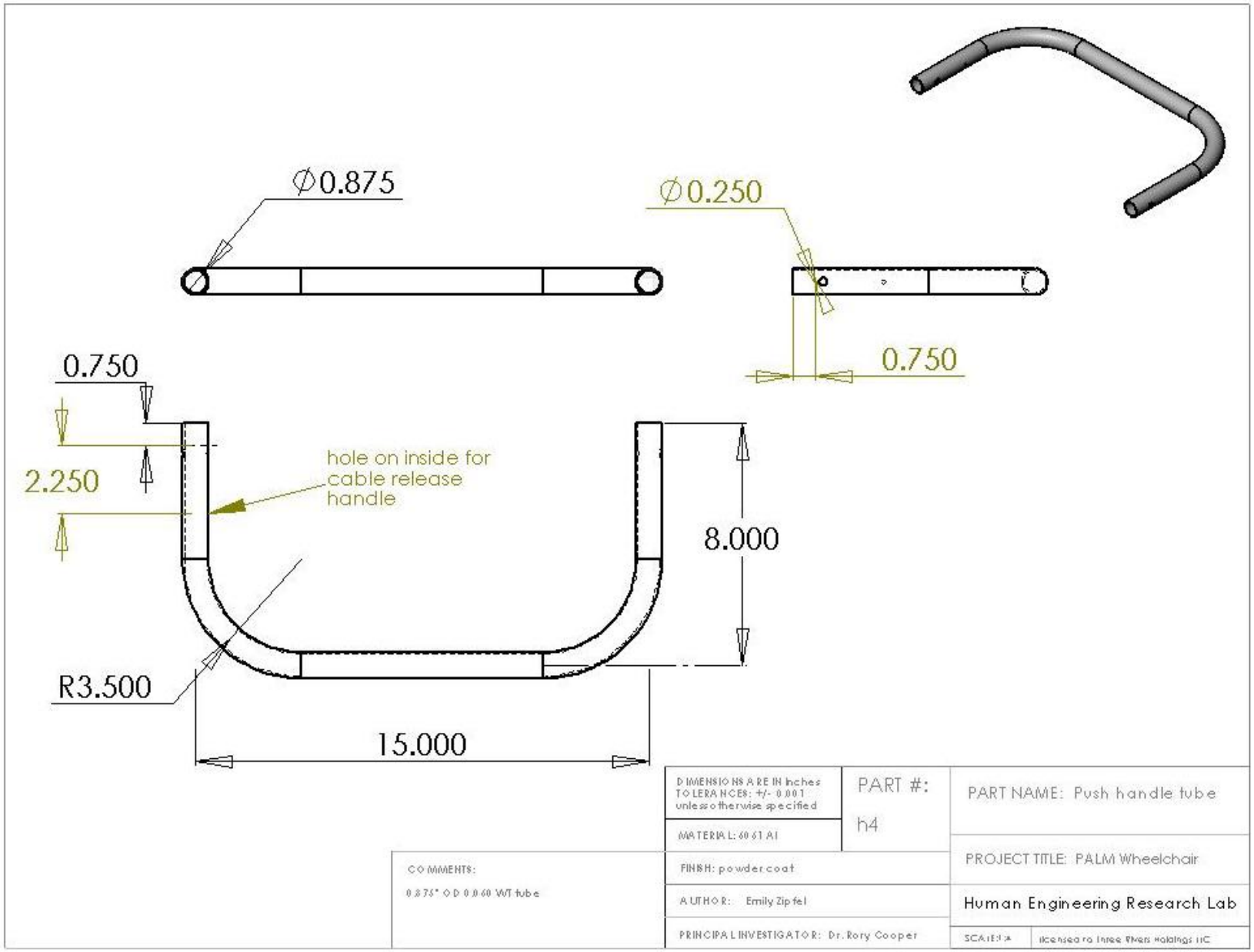
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: g4	PART NAME: mechlok tube
MATERIAL: 6061 al		
COMMENTS: 0.75" OD 0.060 WT	FINISH: powder coat	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:2

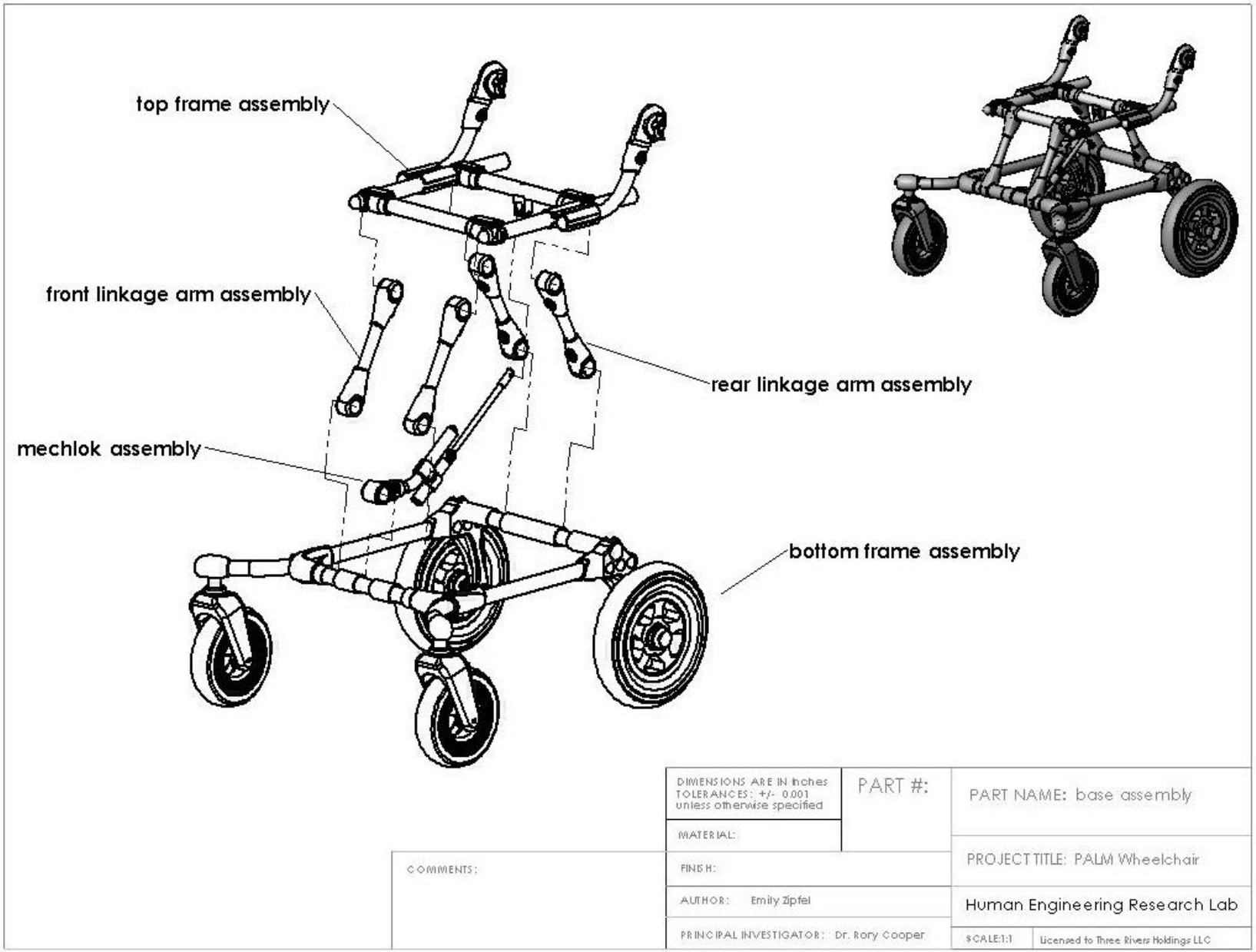

locking handle
locking handle bracket
push handle adjustment bracket
push handle grip
push handle tube
push handle side tube
push handle brace bracket
push handle brace tube
screw cap
0.875 tube plug
push handle bracket
knob
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
PART NAME: push handle assembly
MATERIAL:
COMMENTS:
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:10
Licensed to Three Rivers Holdings LLC

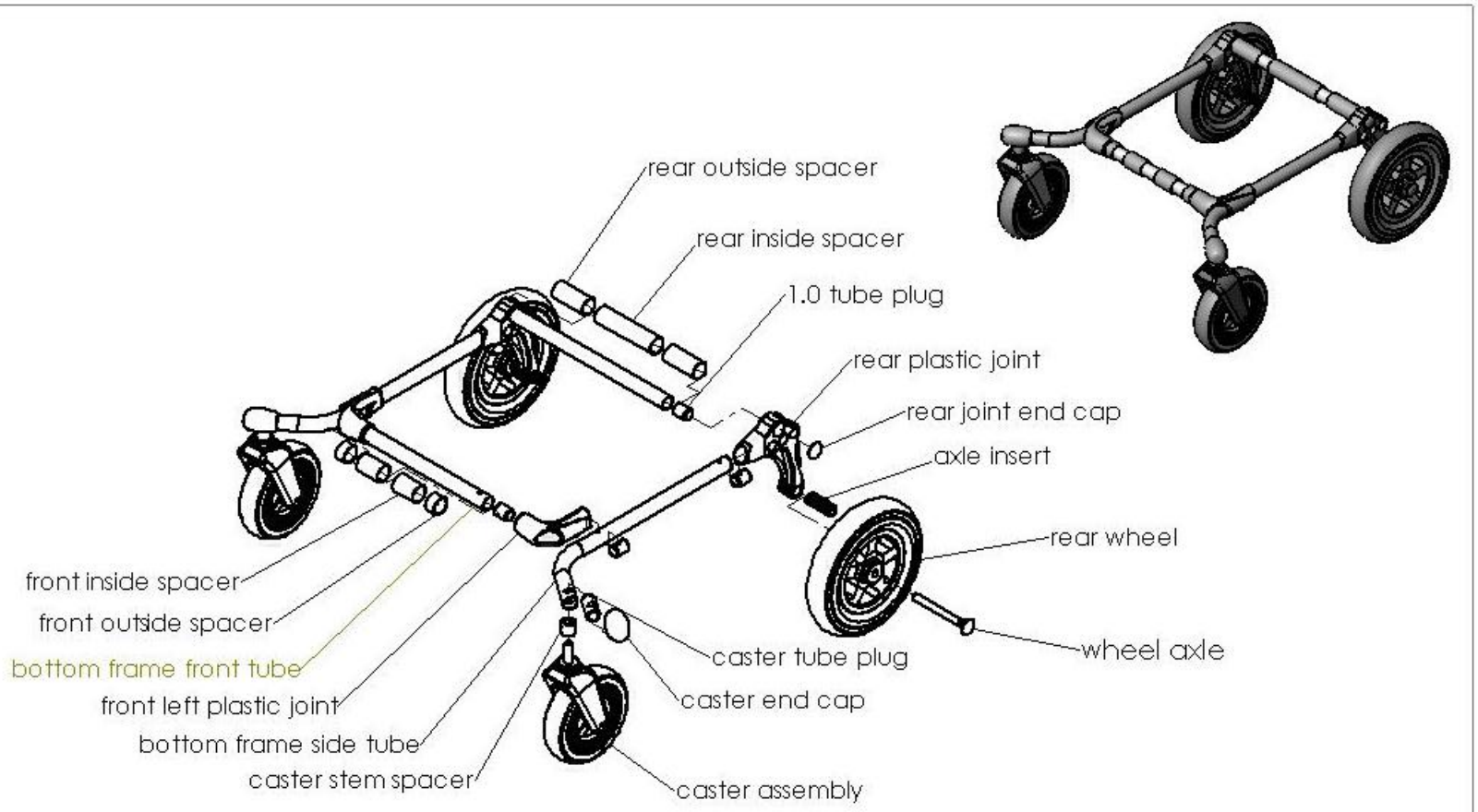

1.171
∅0.260
1.400
1.500
0.410
0.508
∅0.490
0.490
R0.440
0.150
0.152
1.340
0.690
0.850
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
h1
PART NAME: push handle brace bracket
MATERIAL: SLA resin
PROJECT TITLE: PALM Wheelchair
COMMENTS:
FINISH:
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:1
licensed to Three Rivers Holdings LLC


∅0.500
0.250
∅0.250
15.000
15.500
DIMENSIONS ARE IN inches
TOLERANCES: +/- 0.001
unless otherwise specified
MATERIAL: 6061 al
PART #:
h2
PART NAME: push handle brace tube
COMMENTS:
0.5" OD
0.60 WT tube
FINISH: powder coat
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:2
licensed to Three Rivers Holdings LLC

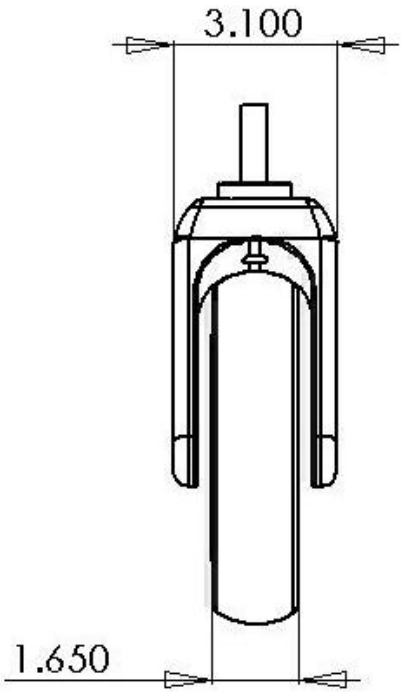

∅0.875
4.500
∅0.250
13.500
∅0.250
1.000
∅0.250
0.750
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
h3
PART NAME: push handle side tube
MATERIAL: 6061 al
COMMENTS:
FINISH: powder coat
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:4
licensed to Three Rivers Holdings LLC

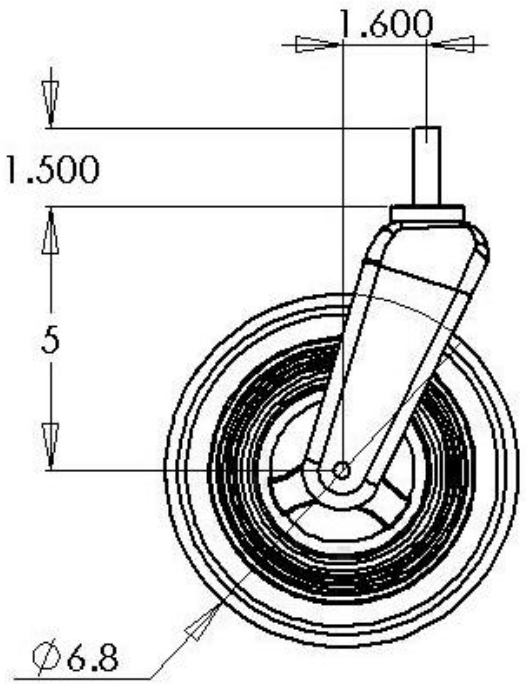

∅0.875
∅0.250
0.750
0.750
2.250
hole on inside for cable release handle
8.000
R3.500
15.000
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001 unless otherwise specified
PART #: h4
PART NAME: Push handle tube
MATERIAL: 6061 Al
PROJECT TITLE: PALM Wheelchair
COMMENTS:
0.875" OD 0.060 WT tube
FINISH: powder coat
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:2
licensed to Three Rivers Holdings LLC


top frame assembly
front linkage arm assembly
rear linkage arm assembly
mechlok assembly
bottom frame assembly
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
PART NAME: base assembly
MATERIAL:
COMMENTS:
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE:1:1
Licensed to Three Rivers Holdings LLC

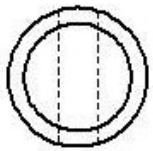


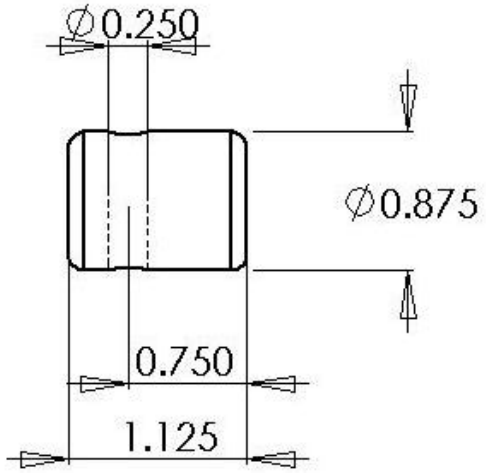
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #:	PART NAME: bottom frame assembly
MATERIAL:		
COMMENTS:	FINISH:	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:10 Licensed to Three Rivers Holdings LLC



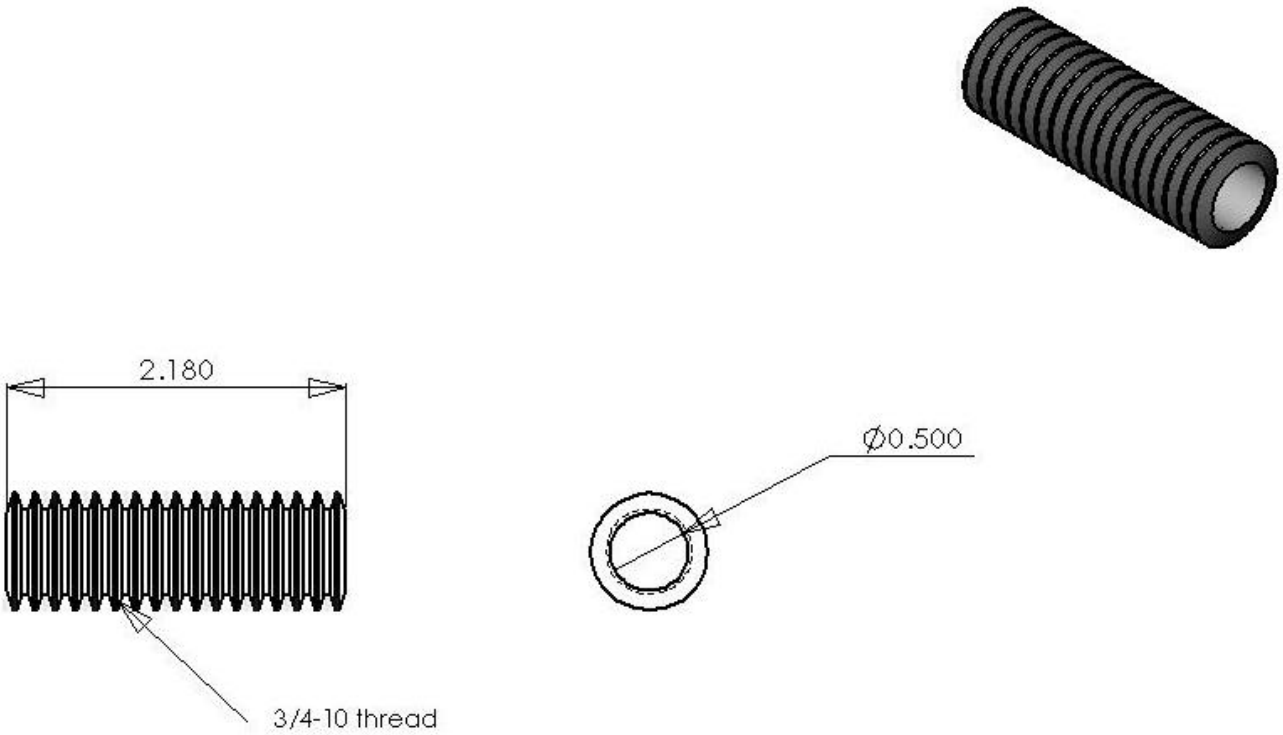


DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #:	PART NAME: caster assembly
MATERIAL:		
COMMENTS: 1.25" OD 0.035 Wt	FINISH:	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE: 2 licensed to Three Rivers Holdings LLC

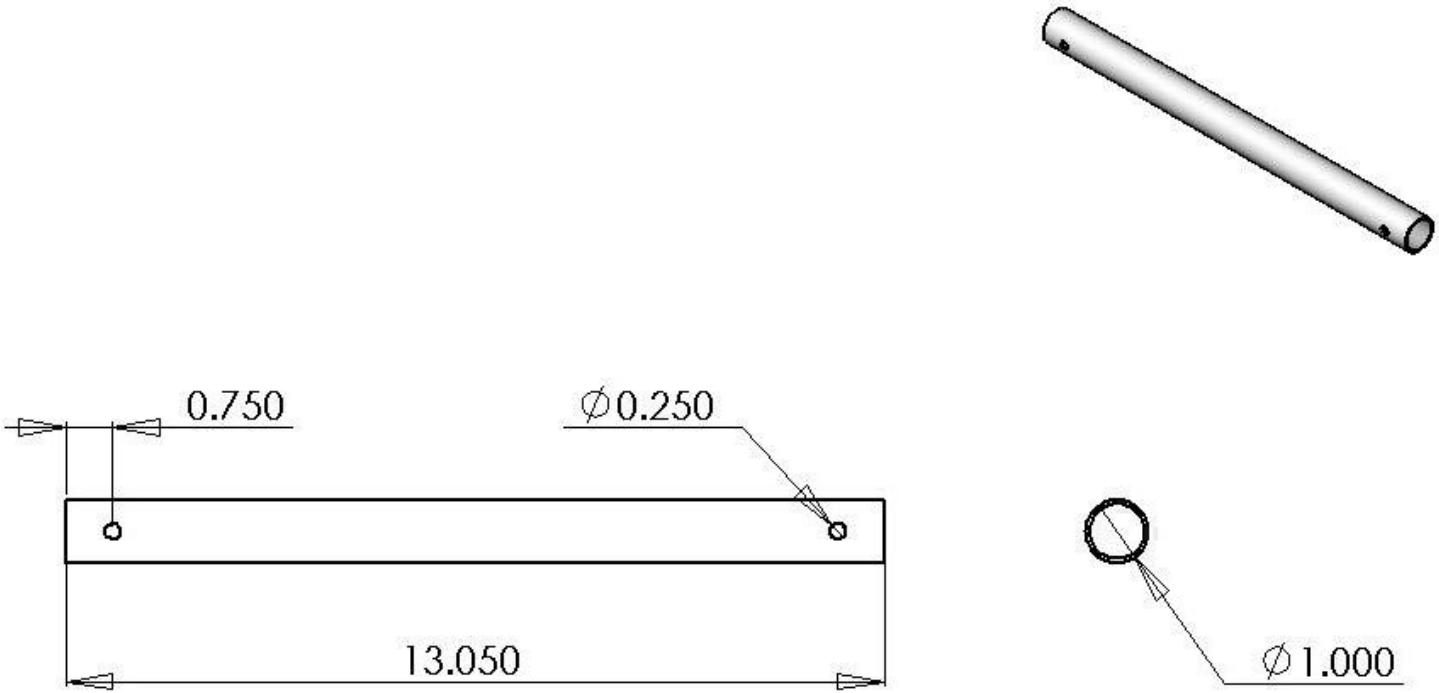




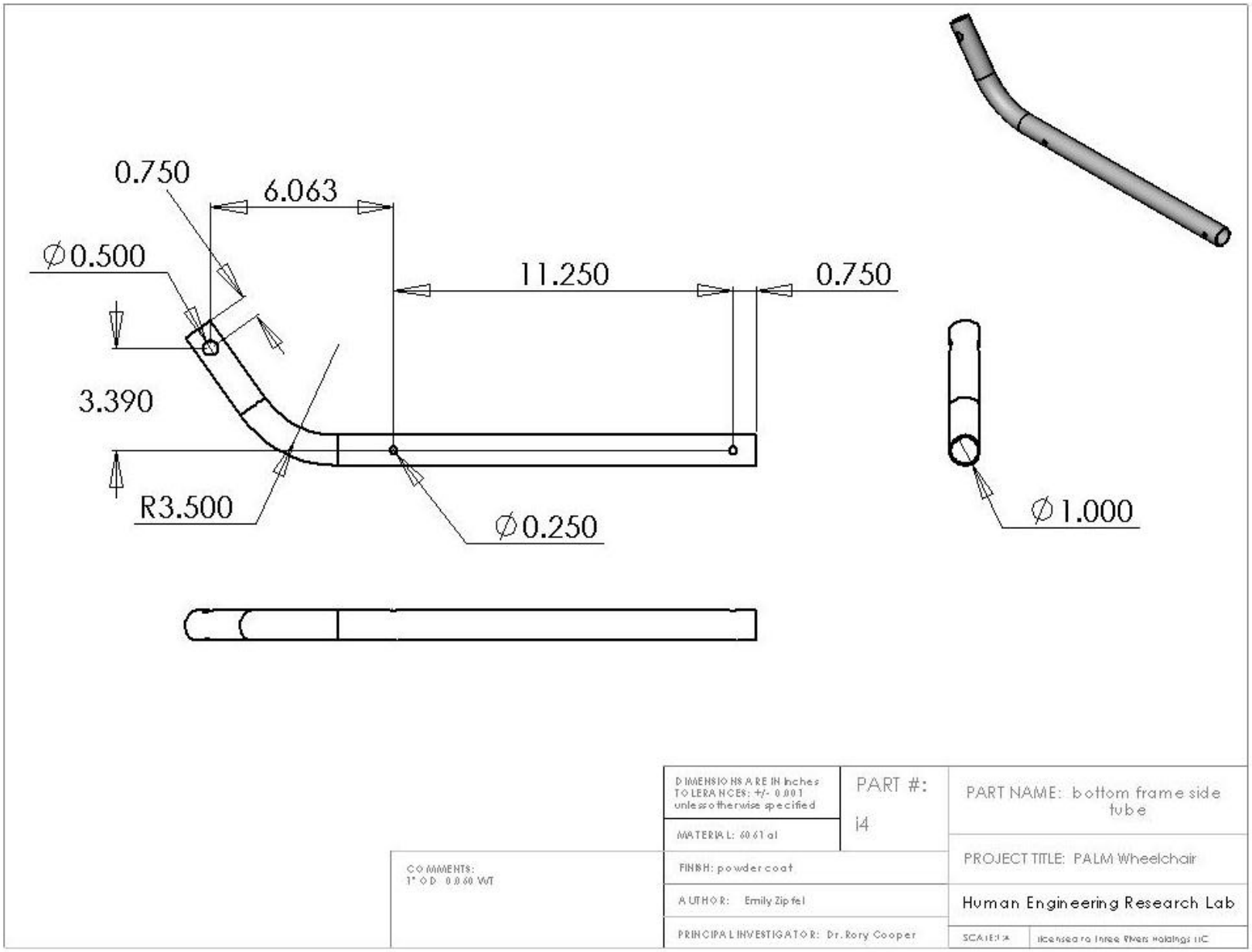
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified		PART #:	PART NAME: 1.0" tube plug
MATERIAL: 6061 Al		j1	
COMMENTS:	FINISH:		PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel		Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:1	licensed to Three Rivers Holdings LLC

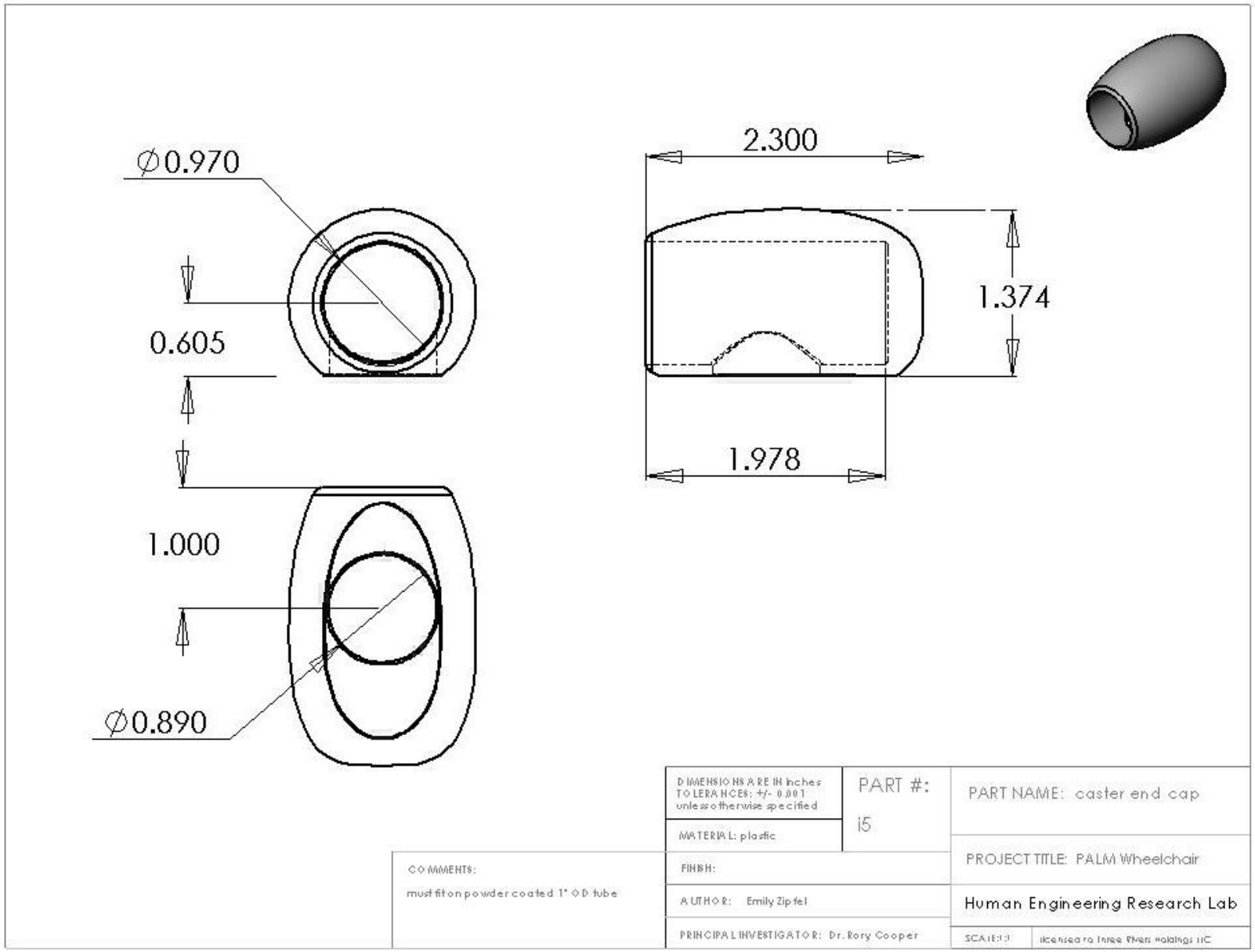


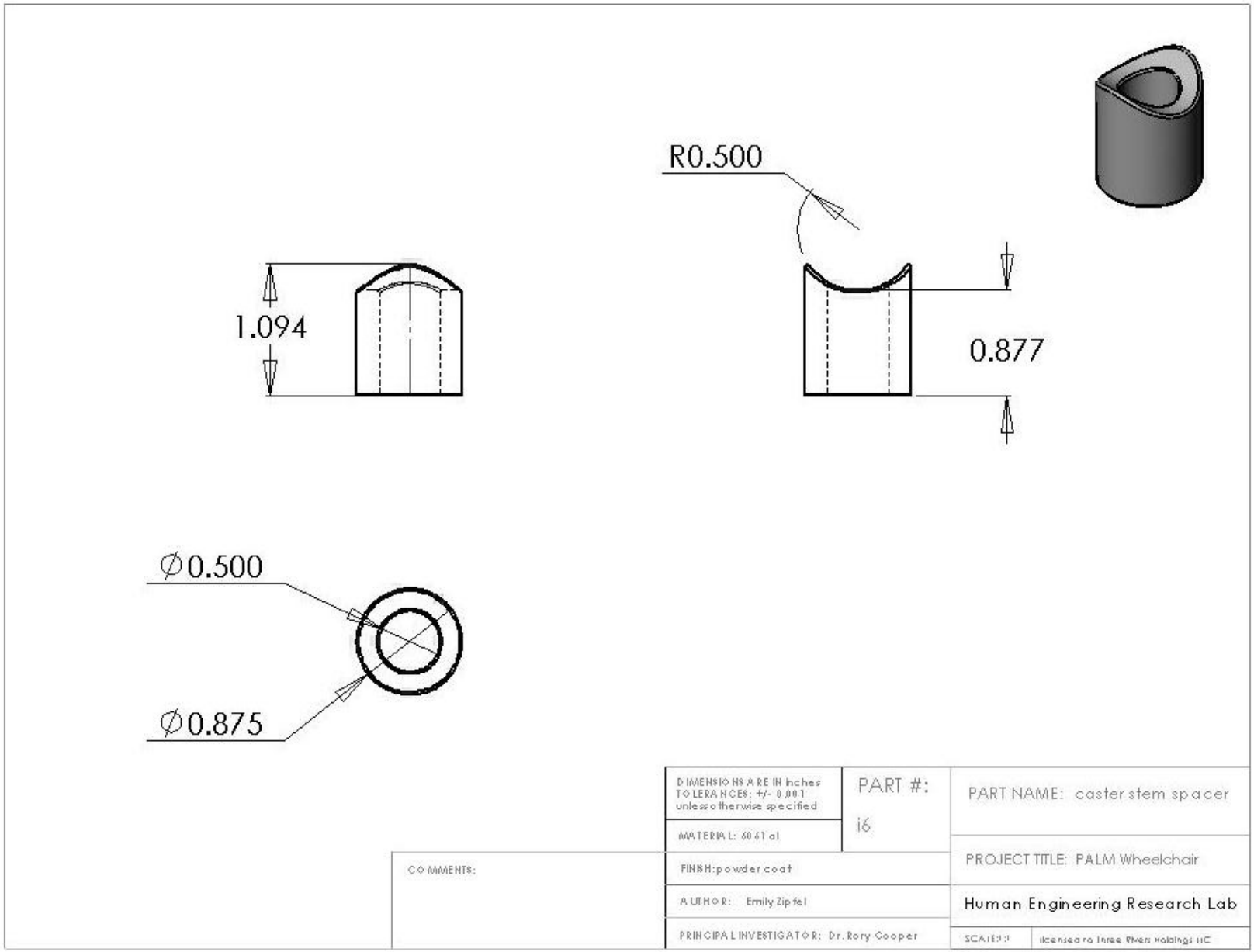
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: i2	PART NAME: Bottom Frame Axle Bolt
MATERIAL: Steel		
COMMENTS:	FINISH:	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE 2:1 licensed to Three Rivers Holdings LLC

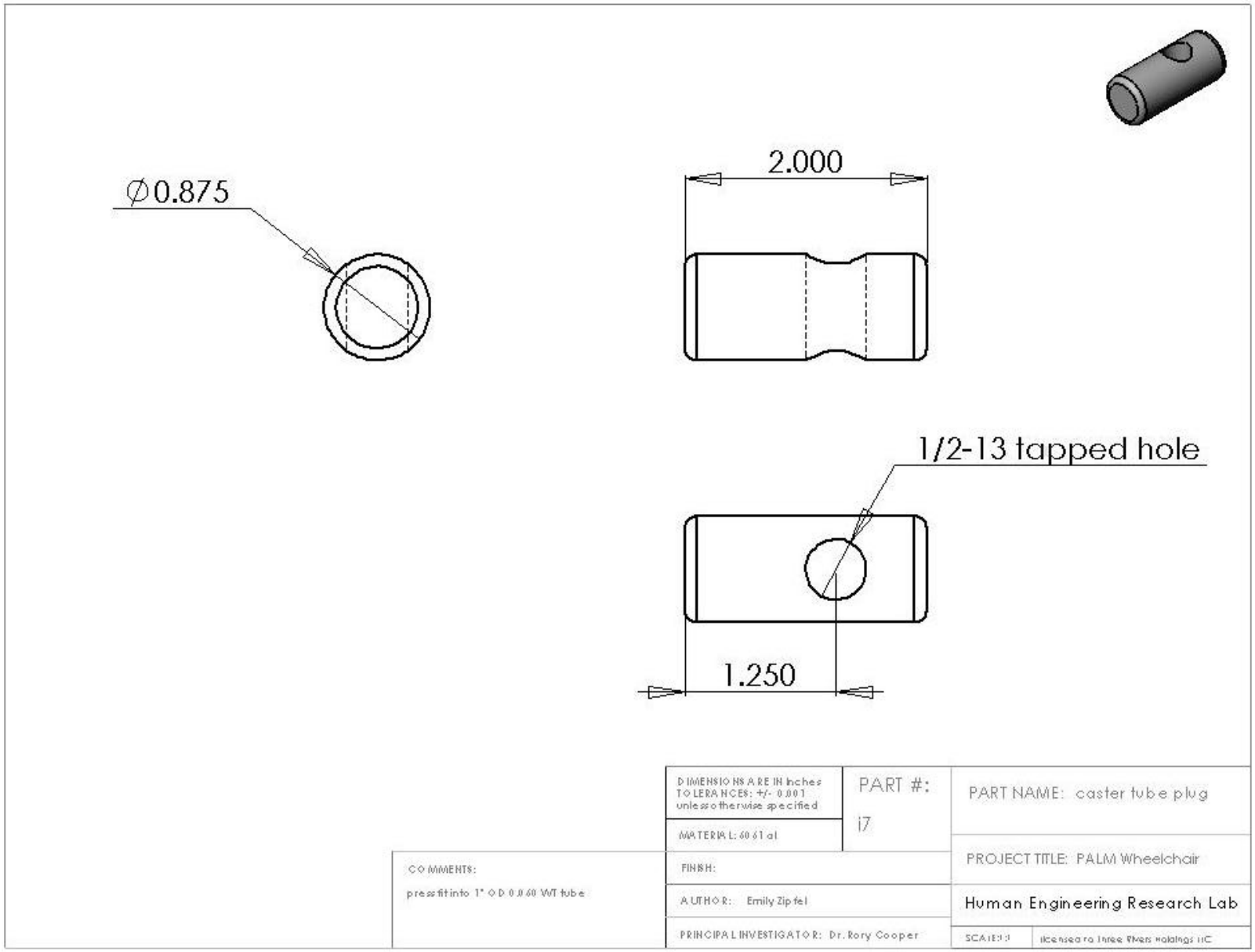


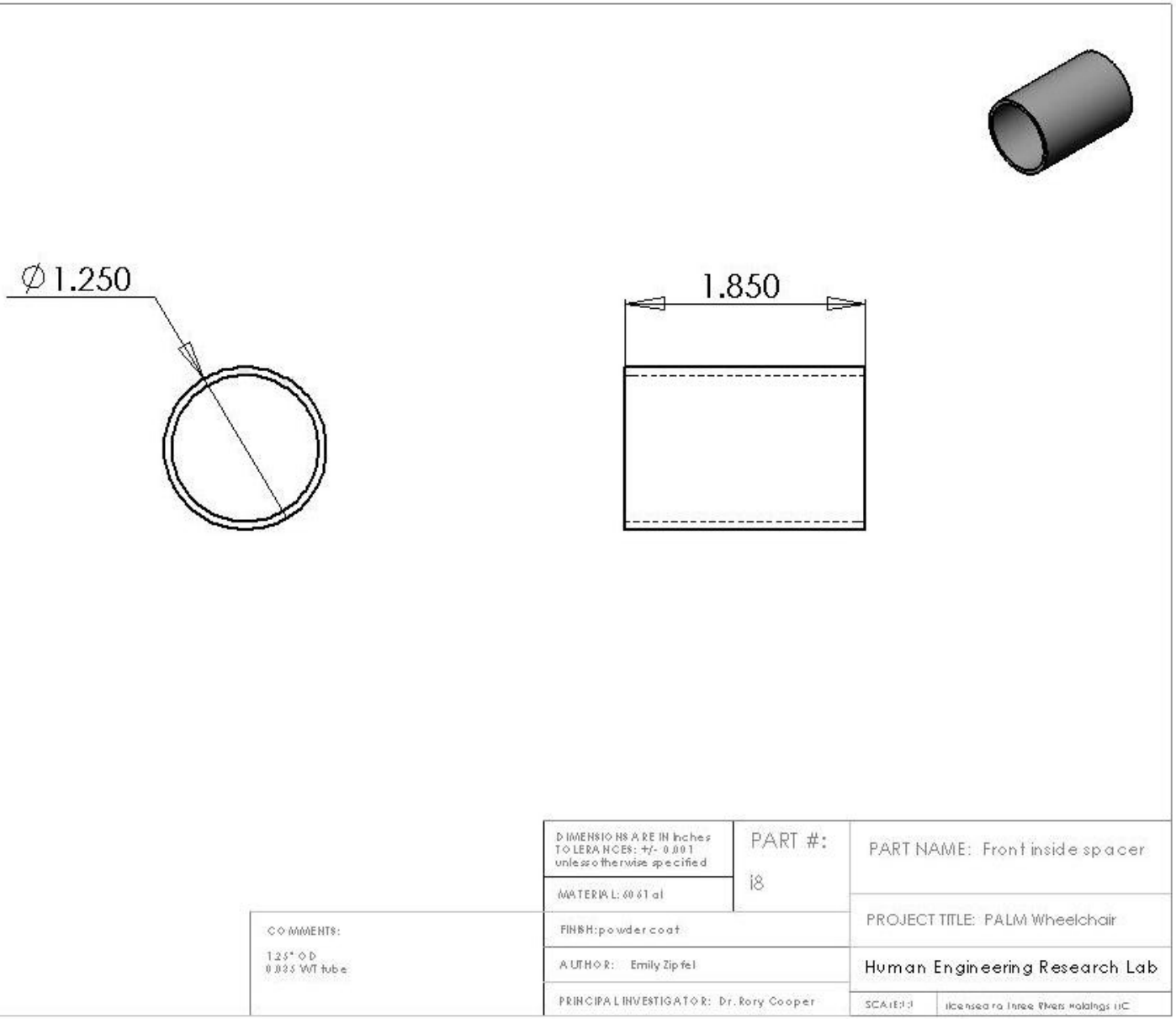
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: 13	PART NAME: bottom frame front tube
MATERIAL: 6061 al		
COMMENTS: 1.0 OD 0.060 WT tube	FINISH: powder coat	PROJECT TITLE: PALM Wheelchair
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE: 1:2.5 licensed to Three Rivers Holdings LLC

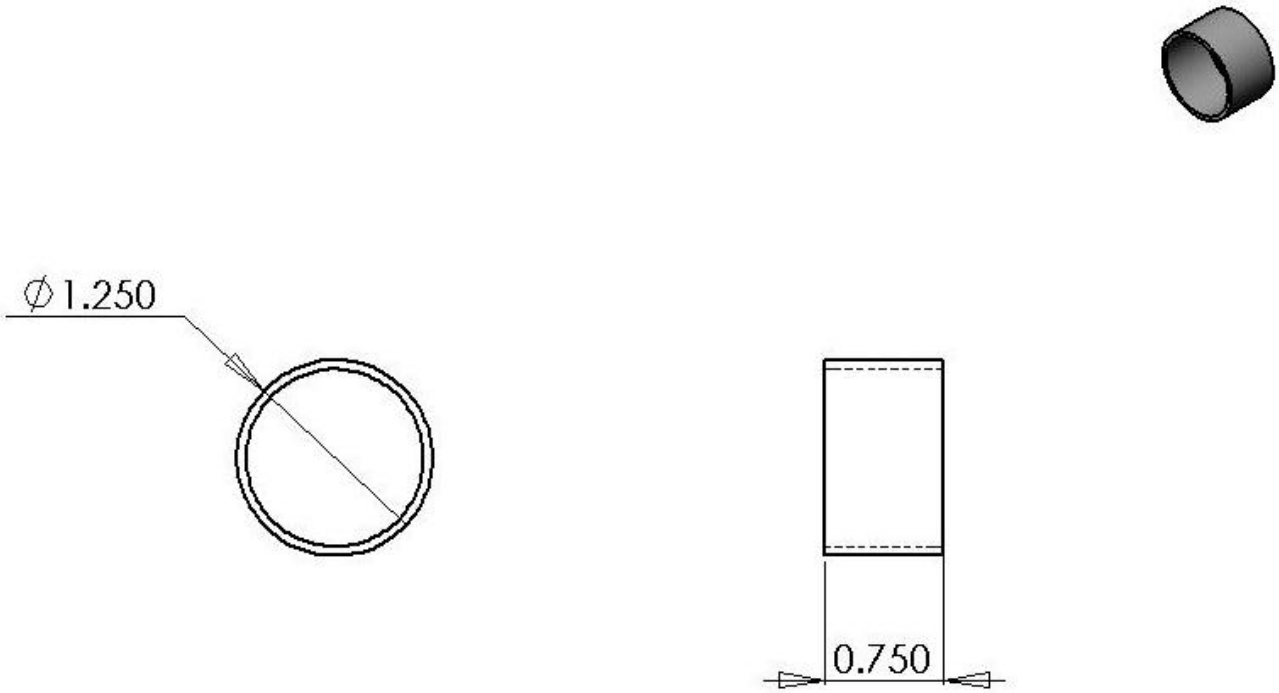

0.750
6.063
∅0.500
11.250
0.750
3.390
R3.500
∅0.250
∅1.000
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
i4
PART NAME: bottom frame side tube
MATERIAL: 6061 al
COMMENTS:
1" O.D. 0.060 WT
FINISH: powder coat
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:4
license to Three Rivers Holdings LLC


∅0.970
0.605
1.000
∅0.890
2.300
1.374
1.978
DIMENSIONS ARE IN inches
TOLERANCES: +/- 0.001
unless otherwise specified
MATERIAL: plastic
FINISH:
PART #:
i5
PART NAME: caster end cap
PROJECT TITLE: PALM Wheelchair
COMMENTS:
must fit on powder coated 1" OD tube
AUTHOR: Emily Zipfel
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
Human Engineering Research Lab
SCALE: 1:1
licensed to Three Rivers Holdings LLC

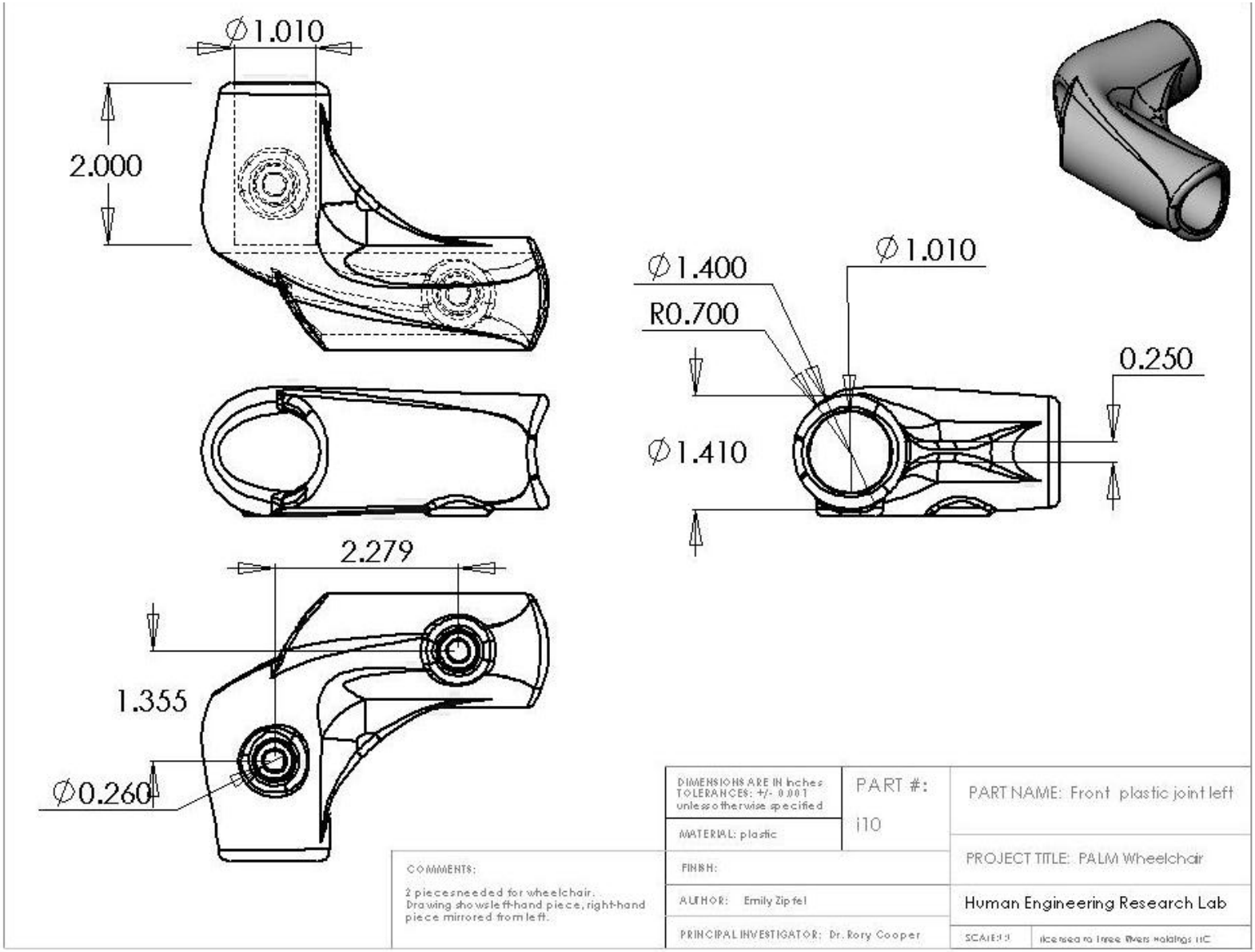

R0.500
1.094
0.877
∅0.500
∅0.875
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
MATERIAL: 6061 al
PART #:
i6
PART NAME: caster stem spacer
COMMENTS:
FINISH: powder coat
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1
licensed to Three Rivers Holdings LLC

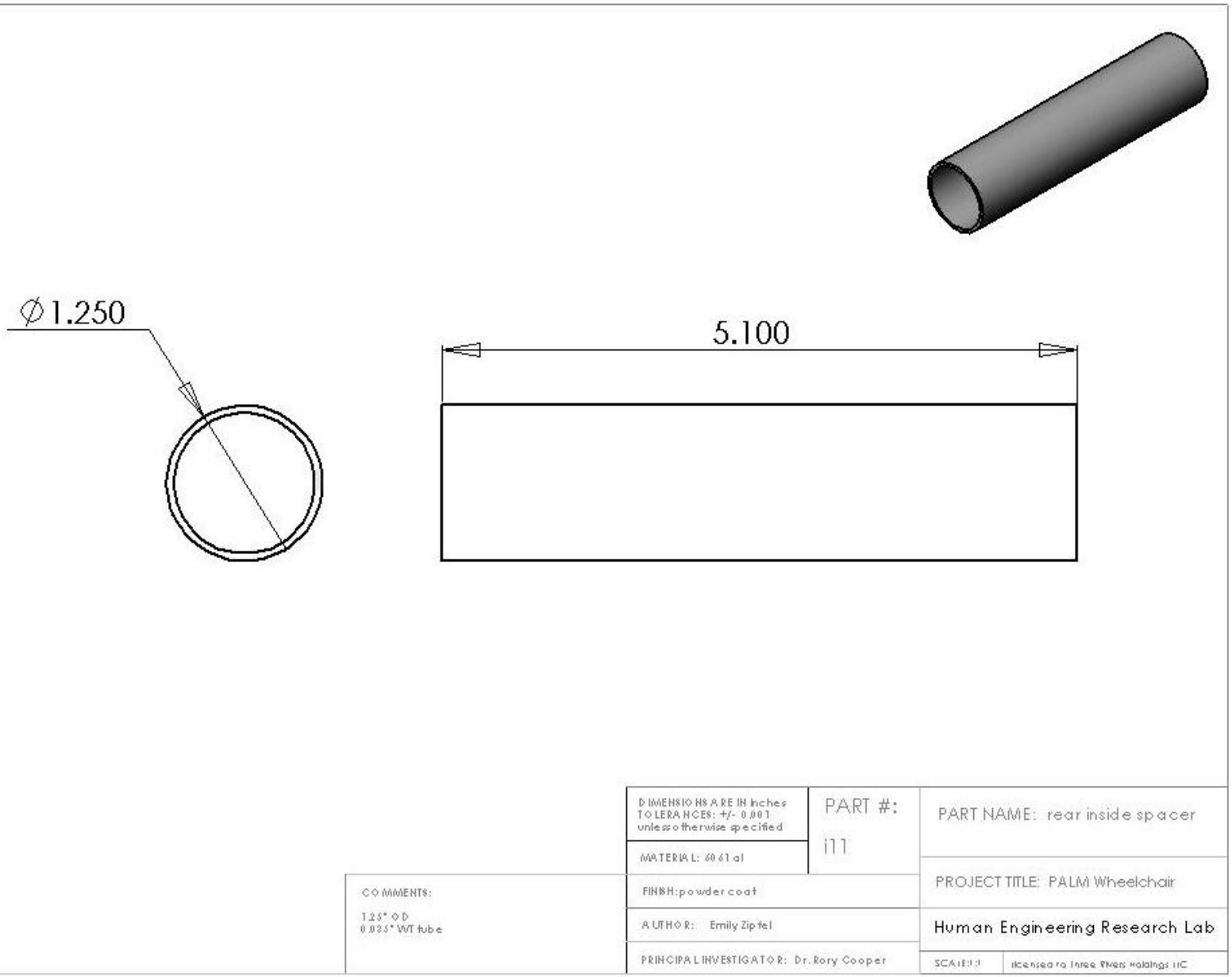

∅0.875
2.000
1/2-13 tapped hole
1.250
DIMENSIONS ARE IN inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
i7
PART NAME: caster tube plug
MATERIAL: 6061 al
COMMENTS:
press fit into 1" O D 0.060 WT tube
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1
licensed to Three Rivers Holdings LLC


∅1.250
1.850
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
i8
PART NAME: Front inside spacer
MATERIAL: 6061 al
COMMENTS:
1.25" OD
0.035 WT tube
FINISH: powder coat
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1
licensed to Three Rivers Holdings LLC

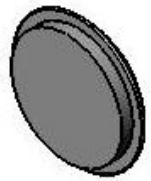


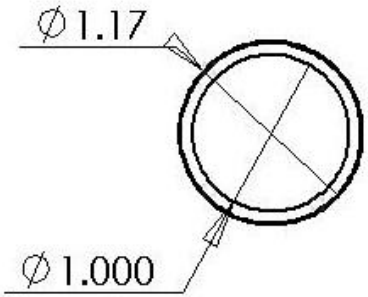
DIMENSIONS ARE IN inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: i9	PART NAME: Front outside spacer	
MATERIAL: 6061 al		PROJECT TITLE: PALM Wheelchair	
COMMENTS: 1.25" OD 0.035 WT	FINISH: powder coat	Human Engineering Research Lab	
	AUTHOR: Emily Zipfel		
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:1	licensed to Three Rivers Holdings LLC

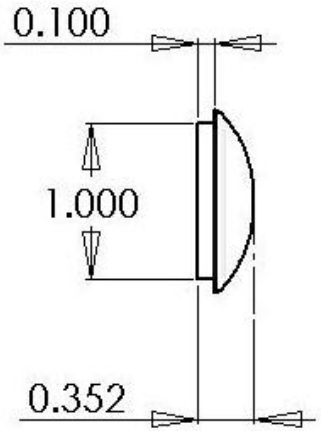

∅1.010
2.000
∅1.400
∅1.010
R0.700
0.250
∅1.410
2.279
1.355
∅0.260
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
i10
PART NAME: Front plastic joint left
MATERIAL: plastic
PROJECT TITLE: PALM Wheelchair
COMMENTS:
2 pieces needed for wheelchair.
Drawing shows left-hand piece, right-hand piece mirrored from left.
FINISH:
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1
licensed to Three Rivers Holdings LLC



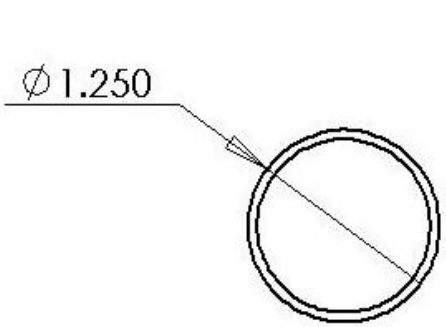
DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #:	PART NAME: rear inside spacer	
MATERIAL: 6061 al	i11		
COMMENTS: 1.25" OD 0.035" WT tube	FINISH: powder coat	PROJECT TITLE: PALM Wheelchair	
	AUTHOR: Emily Zipfel	Human Engineering Research Lab	
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:1	licensed to Three Rivers Holdings LLC

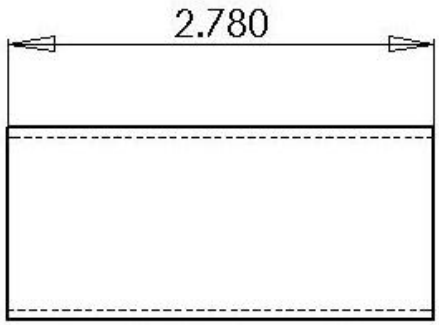






DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: i12	PART NAME: rear joint end cap	
MATERIAL: SLA resin		PROJECT TITLE: PALM Wheelchair	
COMMENTS: press fit into hole on rear plastic joint	FINISH:		
	AUTHOR: Emily Zipfel	Human Engineering Research Lab	
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:1	licensed to Three Rivers Holdings LLC

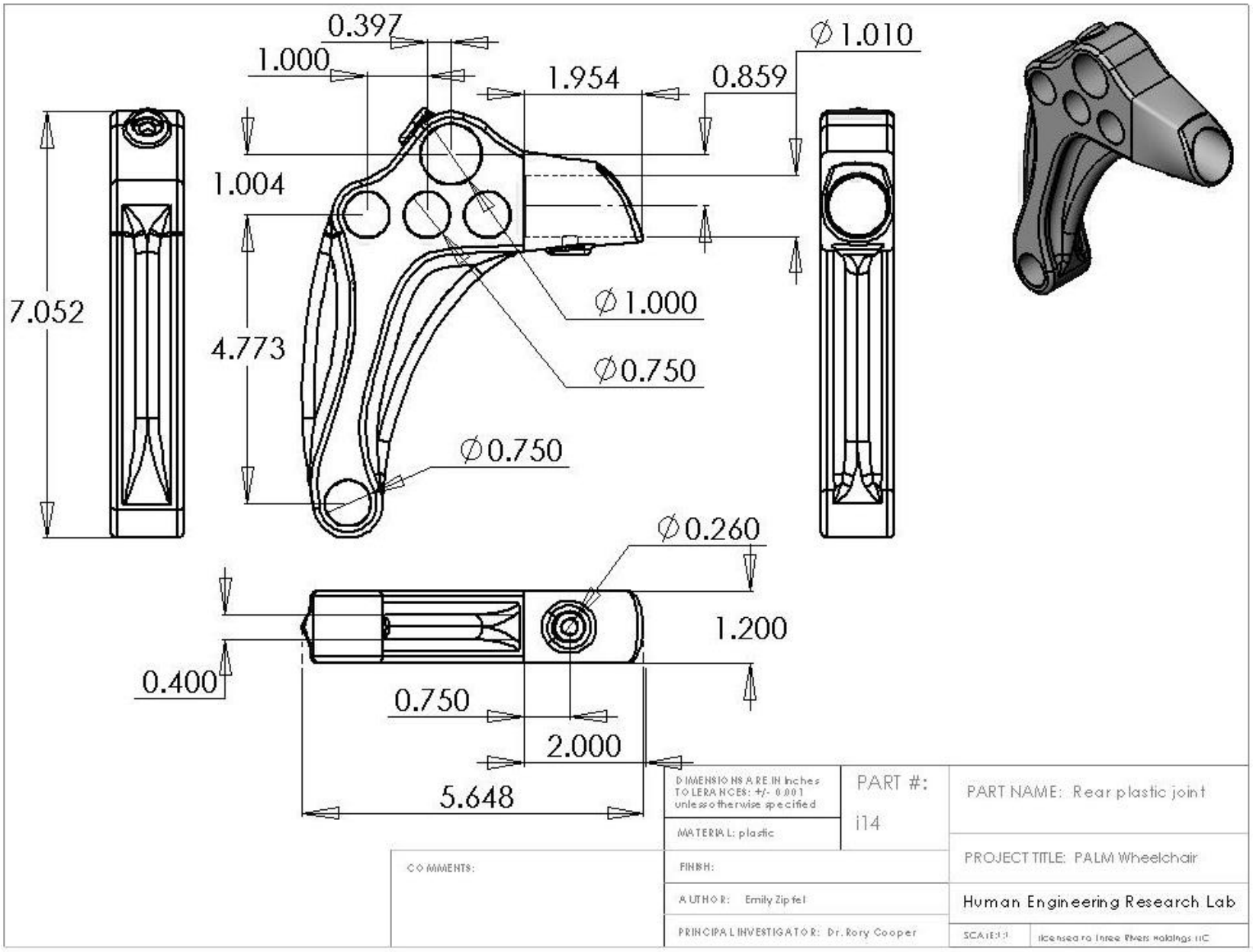


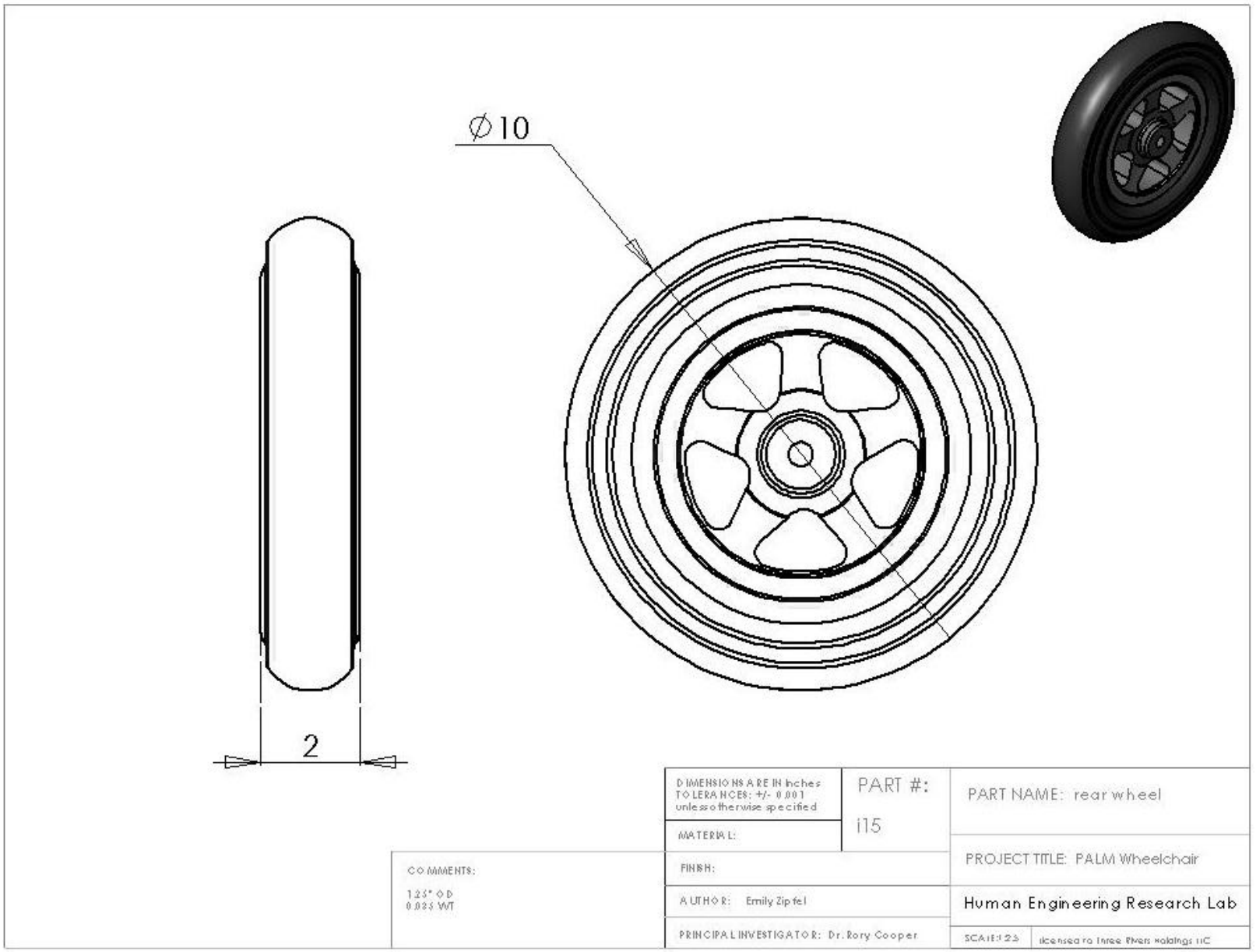


DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: i13	PART NAME: rear outside spacer
MATERIAL: 6061 al		
FINISH: powder coat		PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel		Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE:1:1	licensed to Three Rivers Holdings LLC

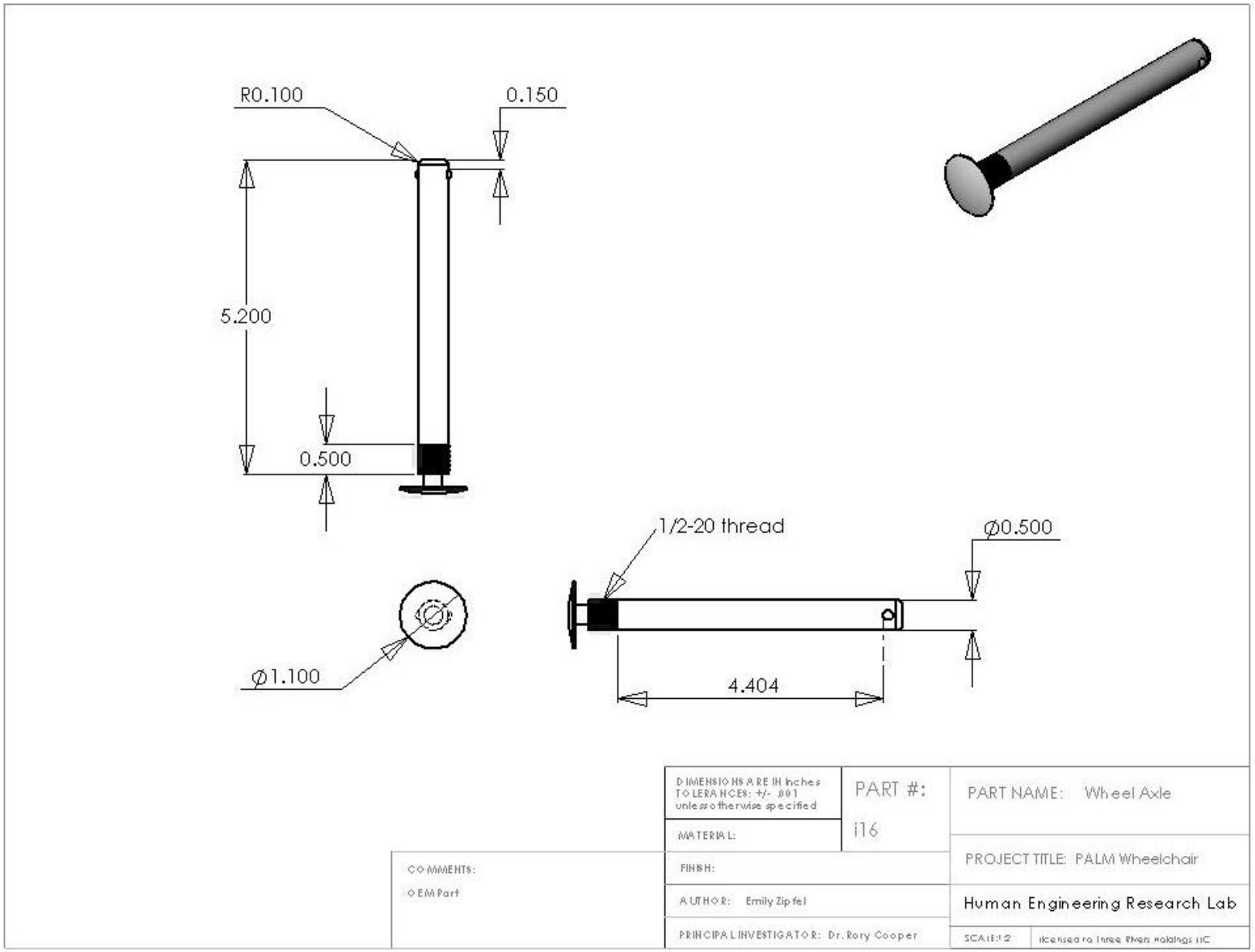
COMMENTS:

1.25" OD
0.035 WT


0.397
1.000
1.954
0.859
∅1.010
1.004
7.052
4.773
∅1.000
∅0.750
∅0.750
∅0.260
1.200
0.400
0.750
2.000
5.648
DIMENSIONS ARE IN Inches
TOLERANCES: +/- 0.001
unless otherwise specified
PART #:
i14
PART NAME: Rear plastic joint
MATERIAL: plastic
COMMENTS:
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1
licensed to Three Rivers Holdings LLC



DIMENSIONS ARE IN Inches TOLERANCES: +/- 0.001 unless otherwise specified	PART #: i15	PART NAME: rear wheel
MATERIAL:		PROJECT TITLE: PALM Wheelchair
COMMENTS: 1.25" OD 0.035 WT	FINISH:	
	AUTHOR: Emily Zipfel	Human Engineering Research Lab
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE: 1:2.5 licensed to Three Rivers Holdings LLC


R0.100
0.150
5.200
0.500
Ø1.100
1/2-20 thread
Ø0.500
4.404
DIMENSIONS ARE IN Inches
TOLERANCES: +/- .001
unless otherwise specified
PART #:
i16
PART NAME: Wheel Axle
MATERIAL:
COMMENTS:
◇EM Part
FINISH:
PROJECT TITLE: PALM Wheelchair
AUTHOR: Emily Zipfel
Human Engineering Research Lab
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:2
licensed to Three Rivers Holdings LLC

REFERENCES

1. Zipfel E, Cooper RA, Pearlman J, Cooper R, McCartney M. New design and development of a manual wheelchair for India. Journal of disability and rehabilitation 2007;29(11):949-962.
2. Pearlman JL, Cooper RA, Zipfel E, Cooper R, McCartney M. Towards the development of an effective technology transfer model of wheelchairs to developing countries. Journal of Disability and Rehabilitation: Assistive Technology January 2006;1(1&2):103-110.
3. Ekman S, Sanderson S. Mobility design for body and mind. 2004 May 17, 2004; Banff, Alberta, Canada.
4. Batavia M, Batavia AI, Friedman R. Changing chairs: anticipating problems in prescribing wheelchairs. Disabil Rehabil 2001;23(12):539-48.
5. Bruseberg A, McDonagh-Philip D. New product development by eliciting user experience and aspirations. International Journal of Human-Computer Studies 2001;55:435-452.
6. Nielsen J. Usability engineering. San Diego: AP Professional; 1993. 362 p.
7. Norman D. The design of everyday things. New York: Basic books: Perseus; 2002. 272 p.
8. Ryan S, Rigby P, From W. Understanding the product needs of consumers of assistive devices. Canadian journal of rehabilitation 1996;9(2):129-135.
9. Post MWM, van Asbeck FWA, van Dijk AJ, Schrijvers AJP. Services for spinal cord injured: availability and satisfaction. Spinal Cord 1997;35(2):109-115.
10. Scherer MJ. Outcomes of assistive technology use on quality of life. Disabil Rehabil 1996;18(9):439-448.
11. Wenger DL, Kaye HS, LaPlante MP. Disabilities among children. US Department of Education, National Institute on Disability and Rehabilitation Research; 1996 March.
12. Segedy A. Hope for mobility. Rehab Manag 2000;13(5):12-4.
13. Disability, poverty and development. UK Department for International Development; 2000 February.
14. World Bank, World Development Indicators Database. <http://go.worldbank.org/1SF48T40L0>. Accessed July 17, 2007
15. Mulcahey MJ. Unique management needs of pediatric spinal cord injury patients: rehabilitation. J Spinal Cord Med 1997;20(1):25-30.
16. Cox DI. Not your parent's wheelchair. Rehab Manag 2004;17(7):26-7, 39.
17. Kermoian R. Locomotor experience facilitates psychological functioning: implications for assistive mobility for young children. In: Gray D, Quatrano L, Lieberman M,

editors. Designing and using assistive technology: the human perspective. Baltimore: Brookes; 1998. p 251-268.
18. Raine A, Reynolds C, Venables PH, Mednick SA. Stimulation seeking and intelligence: a prospective longitudinal study. J Pers Soc Psychol 2002;82(4):663-74.
19. Wright-Ott C, Escobar R, Leslie S. Encouraging exploration. Rehab Manag 2002.
20. Samaniego IA. A sore spot in pediatrics: risk factors for pressure ulcers. Pediatr Nurs 2003;29(4):278-82.
21. Krey CH, Calhoun CL. Utilizing research in wheelchair and seating selection and configuration for children with injury/dysfunction of the spinal cord. J Spinal Cord Med 2004;27 Suppl 1:S29-37.
22. Cooper RA. A perspective on the ultralight wheelchair revolution. Technology and Disability 1996;5:383-392.
23. Ward D. Prescriptive seating for wheeled mobility. Kansas City: HealthWealth International; 1994. 213 p.
24. Lange ML. Evaluating the options. The pros and cons of dependent mobility systems. Rehab Manag 2002;15(1):20, 22-3.
25. Fisher K, Ricardo G. Maximizing mobility. Rehab Manag 2000.
26. Daus C. Back to basics. Rehab Manag 2000.
27. Weary G, Gleicher F, Marsh KL. Control motivation and social cognition. NY: Springer-Verlag; 1993. 344 p.
28. Msall ME, Tremont MR. Measuring functional status in children with genetic impairments. Am J Med Genet 1999;89(2):62-74.
29. Cook A, Howery K, Gu J, Meng M. Robot-enhanced discovery and exploration for very young children with disabilities. Technology and Disability 2000;13(1):1-8.
30. Engstrom B. Ergonomic seating, a true challenge: wheelchair seating and mobility priniciples. Sweden: Posturalis books; 2002. 249 p.
31. Dube A, Mitchell E. Accidental strangulation from vest restraints. Journal of the American Medical Association 1986;256(1919):2725-2726.
32. Promoting airway safety when prescribing harnesses for wheelchairs and other seating devices: guidelines for prescribers. Victorian harness safety industry working group supported by department of human services <http://www.scopevic.org.au/Guidelines%20for%20Seating%20Prescribers.pdf>. Accessed July 8, 2007.
33. Paley K, Walker JL, Cromwell F, Enlow C. Transportation of children with special seating needs. South Med J 1993;86(12):1339-41.
34. Karg P, Bertocci GE, van Roosmalen L, Hobson D, Furui T. Wheelchair transportation safety. In: Cooper R, Ohnabe H, Hobson D, editors. An introduction to rehabilitation engineering. London: Taylor and Francis Group; 2007. p 187-209.
35. Mulholland C. A child's first seating system. Rehab Manag 2003;16(2):30.
36. Cooper RA. Wheelchairs: A Guide to Selection and Configuration. NY: Demos Medical Publishers; 1998. 380 p.
37. Liptak GS, Accardo PJ. Health and social outcomes of children with cerebral palsy. J Pediatr 2004;145(2 Suppl):S36-41.

38. Snyder R, Schneider L, Owings C, Reynolds H, Golomb D, Schork M. 1977 July 17, 2007. Anthropometry of infants, children, and youths to age 18 for product safety design. The highway safety research institute, The University of Michigan <http://www.itl.nist.gov/iaui/ovrt/projects/anthrokids/>. Accessed 2007 July 17, 2007.
39. American National Standard for Wheelchairs. 1998.
40. Cooper RA, Boninger ML, Rentschler A. Evaluation of selected ultralight manual wheelchairs using ANSI/RESNA standards. Arch Phys Med Rehabil 1999;80(4):462-7.
41. Fitzgerald SG, Cooper RA, Boninger ML, Rentschler AJ. Comparison of fatigue life for 3 types of manual wheelchairs. Arch Phys Med Rehabil 2001;82(10):1484-8.
42. Kaminski BA, Cooper RA, Hoover A, Cooper R, Ding D. Application of a commercial datalogger to electric powered and manual wheelchairs of children. 2004; Orlando Florida.
43. Hanington B. Methods in the making: a perspective on the state of human research in design. Design Issues 2003;19(4):9-18.