19 October 2016

Universal Exercise Unit - Spider Cage

BME 400 Design, Fall 2016

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Abstract

Cerebral palsy is a group of non-progressive, non-contagious motor conditions caused by a delay in physical development. The disease is usually acquired prenatally and caused by abnormal brain development in regions associated with movement such as the motor cortex and pyramidal tracts. There is no cure for cerebral palsy but treatment options include surgery, medication, and therapy. Matt Jahnke is the adult program director for United Cerebral Palsy (UCP) of Greater Dane County and he has tasked the team with creating a spider cage to aid in therapy. Spider cages are structures used in physical therapy to help motor impaired individuals gain strength, muscle control, balance, and independence. The team will fabricate a spider cage out of Telespar tubing based on a telescoping design that will contain a welded wire-mesh caging for harness attachment points. Coinciding with fabrication, software simulations will be completed to determine how sound the overall structure is and adjustments can be made to the design as needed. After the spider cage is completely fabricated, testing will be conducted with team members' weight to confirm the stability of the structure. Once fabricated and tested, UCP will be able to use the spider cage for therapy needs within its facility.

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1. Introduction

1.1. Client

Matt Jahnke is the adult program director for United Cerebral Palsy (UCP) of Greater Dane County. UCP provides supportive services for individuals with physical disabilities such as autism, down syndrome, epilepsy, and cerebral palsy [1]. Engineering students at the University of Wisconsin-Madison have worked on multiple projects for UCP over the past years to create adaptive equipment for the facility. In the fall of 2014 and spring of 2015, a biomedical engineering team worked with the client, Mr. Jahnke, to create a spider cage for therapy uses. The design was electronically modeled but never fabricated. Mr. Jahnke would like the spider cage to be redesigned and fabricated.

1.2. Problem Statement

A spider cage is a structure used by therapists to help treat muscular conditions and is typically used to treat children with cerebral palsy. The cage functions by resisting the patient's movements with the use of resistance bands connected to both the frame of the cage and a customized suit worn by the patient. The resistance to movement or displacement of weights allows for the development of gross motor movements and coordination skills. Spider cages are commercially available but can cost over $4,000. The client is looking for a design that is relatively inexpensive, uses previously purchased material, transportable via flatbed truck, able to fit through a doorway with dimensions of 82" by 42.5", and able to be assembled by employees of UCP.

1.3. Background

Cerebral palsy is a group of non-progressive, non-contagious motor conditions caused by a delay in physical development [2]. Almost 80% of cases are prenatal and arise from abnormal brain development of the fetus. Premature and low birth weight babies are most at risk for developing cerebral palsy and the disease affects 0.2 - 0.35% of all live births [2]. Perinatal and postnatal causes each account for 10% of cerebral palsy cases and are caused by infection and head trauma [3]. The disorder affects each individual differently and can cause complications in one limb, two limbs, or even the whole body. The two most common forms of cerebral palsy are ataxia, which is defined as a lack of motor control with voluntary movements, and spasticity, which is categorized as stiff or tight muscles and exaggerated reflexes [4]. Aside from interfering with physical movement of the body, cerebral palsy can also cause disturbances in sensation, perception, communication, and behavior. Currently there is no cure for the disorder but there are treatments options to help make the lives of those affected as independent and manageable as possible.

Forms of treatment for cerebral palsy include surgery, medication, and therapy. Surgery can be performed to release tight muscles and to correct anatomical abnormalities, leading to reduced pain. Medications are taken to control spasticity, seizures, and to again reduce pain. Physical therapy is another, less invasive, treatment option. The goal of therapy is to help individuals gain bodily function by helping them learn to control gross motor functions. Therapy equipment includes, but is not limited to, resistant bands, orthotics, and an exercise unit called a spider cage [4].

1.4. Project Motivation

The notion of spider cage therapy was first introduced in Poland by Norman Lozinski in 1994. The therapy is set up by attaching a set of elastic cords to a customized suit worn by the patient as well as attaching the cords to the cage of the structure (Figure 1). The cords may have varying stiffnesses depending on the needs of the patient and the specific exercises performed. The goal of spider cage therapy is to improve balance, gain muscle strength, and develop coordination [5]. Ideally, the therapy will help the patient learn/build skills to perform daily tasks and thus gain independence.

Figure 1: Spider Cage Therapy: Patient attached to cage via elastic cords and harness system [6].

UCP does not currently have a spider cage therapy unit within its facility but adding this structure would be beneficial to cerebral palsy treatment efforts. While commercially available spider cages are functional and provide a range of benefits, they are expensive and difficult to transport. Fabricating a relatively inexpensive and portable model that has the same level of functional ability as a commercial model is desirable to UCP.

2. Preliminary Designs

Each potential design was created with the use of Telespar tubing. This material was already purchased by the previous design team and will likely be used in the fabrication of the cage.

2.1. Panels Design

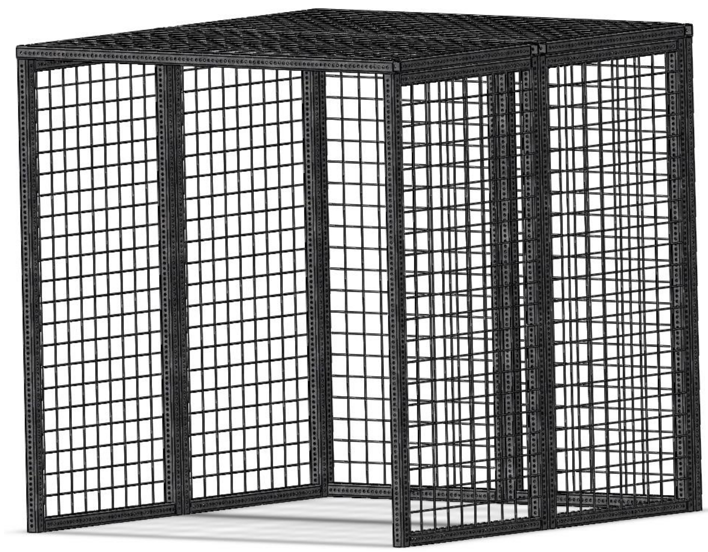

Figure 2: Three dimensional model of the panels design.

Modular panels are the focus of the first design. The design utilizes two rectangular panels on each of the sides and the top of the spider cage for a total of eight panels (Figure 2). Each of the panels are similar in size and configuration, each one would be about 3.5’ wide and about 7’ tall. Individual panels would have four framing members; two vertical and two horizontal members on the sides and top/bottom, respectively. The framing members would be either welded together or bracketed. Steel mesh with 3-4 square inch openings would be attached to the framing members to assist with lateral stabilization and for resistance band connections. The mesh would likely be welded to the framing members to eliminate the need for additional connection material that would add unnecessary weight relative to only welding. Welding individual sections of mesh to each panel's frame members is fairly practical for this design since each panel can be removed from the structure for repair or maintenance. The side and back panels would connect to one another with about 3-4 bolts spread out evenly between the top and bottom of the panels.

The panels design has various benefits as well as drawbacks. Benefits of the panels design include: easy fabrication, few pinch points, low section weight, and easy repair. Since the design is made of eight panels, fixturing and stabilizing the panels during the bracketing/welding process would be relatively easy. Also, there are no complicated mechanisms or intricate components with tight tolerances which helps reduces the possibility of fabrication error. Since the panels are not dynamic and have no folding/telescoping elements, there are few pinch points in the design. The design's use of eight panels helps distribute the total weight of the spider cage when disassembled and allows each panel to be repaired individually if necessary. The drawbacks of the panels design are that it may be cumbersome to assemble sides and top and that there are many sections. Multiple people would be needed to hold and align the panels when bolting them together. Once the sides of the panel are connected together, the assemblers would need to lift and position the sections onto the top of the sides.

2.2. Telescoping Design

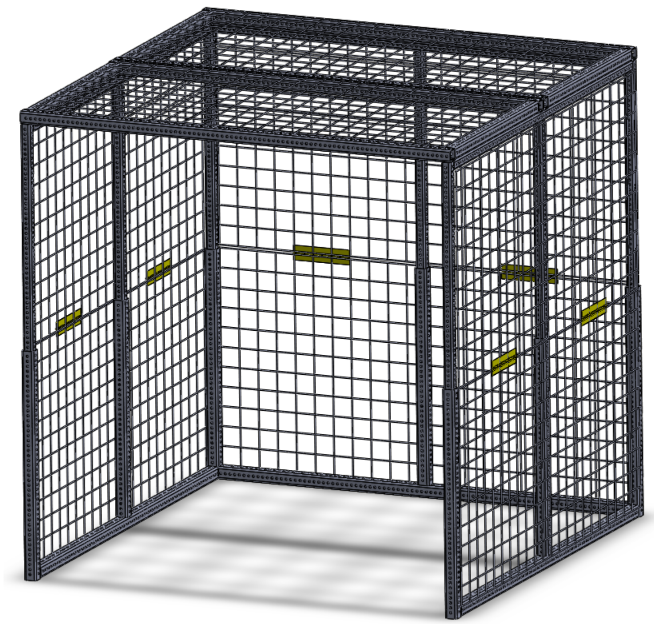

Figure 3: Three dimensional model of the telescoping design. The hinges are colored yellow on the model.

The general concept behind the next design is telescoping. Telespar tubing is manufactured so that particular tube sizes can telescope with one another. With this in mind, the design team began focusing on designs that can utilize the Telespar's telescoping functionality to help reduce the size of the cage sections. The team's telescoping design has a total of five modular sections: one for each of the sides and back of the cage, and two for the top. The two sections on the top of the cage would be almost identical to the sections described in the panel design. Each section would be about 3.5' wide by about 7' long and the sections would have a total of four framing members; two vertical and two horizontal members on the sides and top/bottom, respectively. They would also utilize the same mesh configuration as the panels design. The telescoping design begins to differ when looking at the design of the side and back sections. The side sections would be about 7' x 7' when extended and about 3.5' tall and 7' wide when collapsed. They would be comprised of two horizontal members on the top and bottom of the sections and three telescoping vertical members with one on each edge and the middle of the section. The design would also use the same

Commented [1]: the general concept of the next design is to utilize the Telespar's ability to telescope within one another in order...

wire mesh mentioned in the panels design for all sections. The wire mesh on the bottom half of the sections would be welded on, but the mesh on the top half does not use the same configuration. The top half of the mesh would be hinged onto the lower half so that it can be folded down allowing the frame members to telescope. The top portion of the mesh would be attached to the frame by plates/bolts when the section is in its extended state. The back section of the design is very similar to the side sections, with the exception that there is only one vertical member placed in the middle of the section.

The telescoping design has multiple benefits as well as drawbacks. Benefits to this design are the fewer sections and that the top and sides are relatively easy to assemble. Since there are only five sections in total, the telescoping design has more components of the cage consolidated together resulting in fewer sections to manage. Assembling the top of the cage is safer and more practical with this design since the top can be assembled at a height of around 3.5' and raised instead of being assembled at the full height of 7'. Drawbacks of the telescoping design are: high section weight, pinch points, repairability, and ease of fabrication. Although the telescoping design would have a lower total weight compared to the other designs, it has fewer sections so the weight of each section would be higher. High section weight may make it more difficult for the assemblers during transportation. The dynamic sections that would be used in the design inherently add pinch points due to the telescoping and folding elements. Pinch points are potential sources of injury and would all need to be addressed in the final design to ensure the safety of assemblers. Having only five sections in the design may make it more difficult to repair an individual section due to their size. The dynamic elements of the design increase the potential for maintenance or repair while also adding complications to the fabrication process.

2.3. Foldable Design

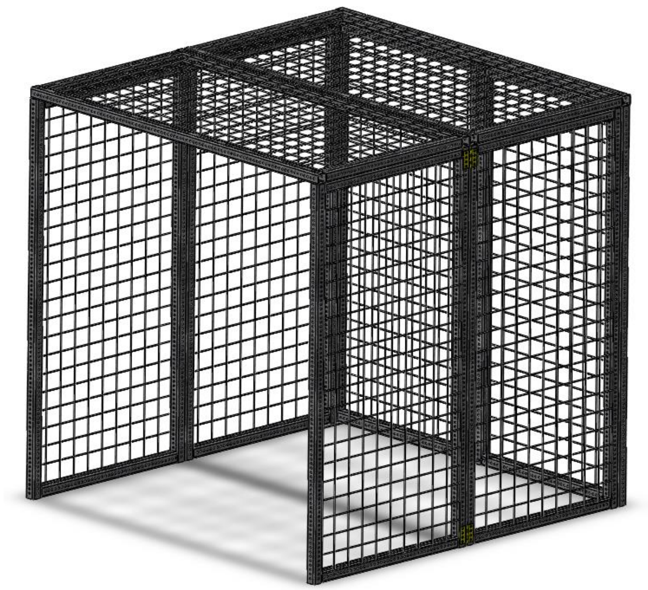

Figure 4: Three dimensional model of the foldable design. The hinges are colored yellow and are on the top and bottom of the side sections.

The foldable design is very similar to the panels design with the exception that the two panels on each of the sides and back are hinged together. The panels that comprise each section would be the same as those used in the panels design, yet they would be hinged together instead of bolted; resulting in a total of five sections (the panels used for the top section would not be hinged together to simplify the assembly of the top). The hinges would allow the sections to fold along a vertical axis to reduce the size of the sections during transportation.

Like the other two designs, the panels design has various benefits as well as drawbacks. Some of the design's benefits include ease of fabrication and the relatively few number of sections used. Since each of the sections is comprised of at most two panels, it would be easy for the design team to individually fabricate the sections then hinge them together. Having only five sections in design helps to consolidate the amount of components that need to be transported and kept track of. Some of the drawbacks for the foldable design include high section weight, pinch points, and top section assembly difficulty. Although the sides and back section can fold to reduce the general size of the sections, the weight of each section goes up. High section weight can make it more difficult to maneuver the sections during transportation. The hinging element of the sections also adds to the potential for injury caused from pinch points when folding. Similar to the panels design, this design would require the assemblers to lift the top section about 7' high to attach it to the back and side sections. This action may be difficult and cumbersome for the assemblers.

2.4. Evaluation of Preliminary Designs

When comparing the three designs, the team assumed all designs will be as functional as a commercially available spider cage. Without functionality, the team decided on five factors to evaluate which design would produce the best product for the client. Factors were weighted as a percentage and the total of all the factors equalled 100%. Working together, the design team scored each design from 0-5 for each factor: 5 being the best and 0 being the worst.

Cost: Some of material for the spider cage was purchased ($1,100 total) by the previous design team which left the current team with no funding from the client. However, the BME and ME department will contribute up to $500 each for the project's budget. Since there is already material for the project and there is a budget supplied from each department, cost was not a high priority. It was weighted as a 10% factor of the total design.

Safety of Assembly: This was a heavily weighted factor in the design matrix as the client will be assembling the cage. All pinch points and heavy lifting must be considered while evaluating each design and the risk associated while assembling the cage. This category was not addressed by the client, but the team must consider this a very important factor as it is one of the largest risks of injury associated with the cage. The safety of assembly was weighted at 25% while evaluating the design as it pertains directly to the safety of the client.

Ease of Assembly: This was addressed by the client, thus it was a highly weighted factor in choosing the final design. Assembly is important because the cage will be assembled by the client with the assistance of 1 to 3 others involved with UCP, thus, assembly will be with instructions but without training. Assembly and disassembly of the cage was weighted heavily because if the cage cannot be assembled and disassembled more than once relatively easily, it will not be able to move facilities as needed. The assembly was addressed by the client and was weighted as 25% of the design.

Portability (Weight & Size): This criteria was required by the client. Portability is important to the initial assembly of the cage and will also give the cage a much longer life as it might move facilities in the future. The assembly and portability aspect of the design helps distinguish this spider cage from existing spider cages on the market. Portability gives the physical therapist more freedom and flexibility by expanding potential therapy locations. This factor was weighted 15%.

Ease of Fabrication: This criteria is in regards to the design team. Given the year-long deadline, this is an aspect that the team must consider. The client has had previous teams on this project with no cage to show for it so it is important that the team has a deliverable product at the end of the year. However, a more difficult fabrication will only result in more work for the design team and reduce the likelihood of presenting the client with a finished product, thus it was a 15% factor.

Repairability: This criteria also incorporates the life of the design. If there happens to be a failure on the cage, the client must be able to repair it with relative ease. This means that the components must be commercially available and if something fails that is not a main member in the cage, the client should be able to fix or replace the failure without disassembling the entire cage. This factor is for a scenario where a component on the cage fails and is not expected, however, it must be considered in order to guarantee a longer life for the cage, thus it was a 10%.

Table 1: Design matrix evaluation of the three proposed designs

		Panels		Telescoping		Foldable	
Design Considerations	**Weight**	**Score**	**Weighted**	**Score**	**Weighted**	**Score**	**Weighted**
Cost	10	3	6	4	8	3	6
Safety of Assembly	25	2	10	4	20	2	10
Ease of Assembly	25	2	10	4	20	3	15
Portability (Weight & Size)	15	4	12	3	9	2	6
Ease of Fabrication	15	5	15	1	3	5	15
Repairability	10	4	8	2	4	3	6
SUM	100		61		64		58

After evaluating the three designs, the team will move forward with the telescoping design. The ability for the client to assemble the top of the cage with the sides at a lower level is what gave this design an advantage. This increased the safety and ease of assembly, which are the criteria that are most important to this design. The disadvantages to this design, relative to the other designs, are the portability of the sections as well as the difficulty of fabrication. Portability is less of a factor as the cage will originally be moved to the UCP facility and then once again only if UCP changes facilities. Difficulty of fabrication is mostly a factor for the design team, thus it is weighted less and a lower score does not deter the team completely from that design. Although it will be most difficult to make the telescoping design, it will be the best design for the client's requirements.

3. Future Work

Looking forward, the team will look into ways to reduce the overall weight of the cage. Since the past BME design team ordered the Telespar tubing but was unable to use it to create a product, the team will be incorporating that material into the frame of the spider cage. The Telespar tubing is essentially galvanized steel, so it is considerably heavy. The team is looking into materials for the mesh that are relatively lightweight in order to reduce the overall weight of the cage, as well as structurally sound to support the weight of a patient. The structural stability of the mesh is important because the resistance bands that the patients will be supported by will be attached to the mesh. The team also needs to order materials for attaching the sides of the cage (bolts, hinges, etc.) and materials for the telescope locking mechanism (plungers, spring-loaded mechanisms). The team will then need to consider fabrication methods. The mesh will be welded into the Telespar tubing frame and the top panel will be bolted on. Due to the scale of the product, the fabrication will take a considerable amount of time. While fabricating the cage, the team can run non-destructive testing simulations in software so as to see how structurally sound the cage is calculated to be. Once fabrication is complete, the cage's ability to support the weight of a patient will be tested. It will first be tested on members of the team to see if the cage can hold enough weight. The cage is meant for children with cerebral palsy so the weight of members on the team should give an accurate result of whether the cage will hold the weight of a patient. After that, the team would ideally like to test the cage on patients with cerebral palsy so that their progress with the cage can be monitored, as that is the ultimate function of the spider cage. For testing with cerebral palsy patients, the team will need to go through the Institutional Review Board (IRB) and get approval for human subject testing.

4. Conclusion

Spider cages are a common tool used in physical therapy for motor conditions such as cerebral palsy. Though these structures are commercially available, they are typically expensive and difficult to relocate. The client, Matt Jahnke, would like a spider cage to be fabricated for a reasonable cost and easy assembly for UCP to use in its facility. After evaluation of three designs, communication with the client, advisor, and occupational therapy students, the team has decided to go forward with the telescoping spider cage design. This option offers the greatest ease and safety of assembly than the other two options and will still meet the same therapy functions.

5. References (in IEEE format)

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6. Appendix

6.1. Product Design Specifications

Product Design Specifications | September 23, 2016

Client: Mr. Matt Jahnke

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Function:

A spider cage is a structure that is used by therapists to help develop muscles of patients with muscle disorders, specifically, cerebral palsy. Patients develop muscle strength through the use of therapy bands that can be attached to various points on the spider cage. Commercial spider cages are available, but are expensive. This spider cage needs to be made with the materials already purchased by the client, transportable, able to be set up by the client and also support the any patient.

Client Requirements:

- The cage shall be able to be transported by trailer
  - The structure will need to fit through a doorway.
- The client cannot offer any budget.
  - The client has already supplied the previous Spider Cage team with money, with which steel for the structure was purchased. These members must make up the Spider Cage.

- The cage shall be able to be assembled by the client (2-4 assemblers), must include instructions.
- Locations of where bungees can be attached to the cage
    - The Spider Cage shall have members on the three walls and the ceiling of the cage that are moveable. This will allow the client to attach therapy bands to any location on each wall and the ceiling of the cage.
- The cage shall be able to hold 350 lbs. of weight from any point on the cage.
- Therapists shall be able to reach any point on the cage to attach a therapy band. A maximum height shall be set to 7'.
- The cage shall be able to fit any size patient.

Design Requirements:

1. **Physical and Operational Characteristics**
    a. ***Performance Requirements*****:** The cage must be able to hold 350 lbs from any structural component/frame member or resistance band connection point. The cage must have at least four adjustable/movable resistance band connection points on each section of the cage (top, back, left side, right side). The maximum height of the cage must not exceed 7'. Any portion of the cage used for resistance band connections or adjustments may not exceed a maximum height of 7'. There must be enough room within the cage for patient and physician to work comfortably and simultaneously. The cage must be modular for transportation and installation using a maximum of four persons and a generic towable trailer. Modular sections must be able to fit through a standard 82" X 42.5" doorway.

    b. ***Safety*****:** Ensure the cage can perform as expected with a safety factor of 3 when a load is applied in a "worst-case" loading scenario. Mark, protect, or remove all possible pinch points. Use non-corrosive and non-toxic materials. Remove all sharp edges. Develop an instruction manual informing users of proper lifting and handling techniques to avoid injury when transporting. Develop a maintenance plan for maintaining and cleaning intricate/detailed portions of the cage to avoid dust/dirt build up.

c. ***Accuracy and Reliability*****:** Resistance band connection points must have fixed adjustment locations or position references for tracking patient progress. Connection points for the modular sections must have appropriate tolerances for proper rigidity while in use, yet must they must have enough clearance for assembly/disassembly.

d. ***Life in Service*****:** The cage is expected to remain functional for as long as possible without replacing structural/critical components and while being used an average of 6 times a day.

e. ***Shelf Life*****:** Cage and its components should be stored in a dry, temperature controlled area.

f. ***Operating Environment*****:** The cage will be used in a clinical setting such as a physical therapist's office as well as in the patient's home. Not meant for climbing, only to support body weight via bungee cords.

g. ***Ergonomics*****:** Cage must be easy and relatively quick to assemble and disassemble; instructions for doing so should be included with cage.

h. ***Size*****:** Large enough for a therapist and patient to stand up comfortably and perform exercises but small enough to fit in a trailer. The height must not exceed 7 ft.

i. ***Weight*****:** There is currently no minimum weight, however, the weight should not compromise the stability of the cage. If it is designed as a kit to be assembled, each piece of the kit must have a low enough weight to allow it to be transported to and from a trailer and must be small enough to fit through a door.

j. ***Materials*****:** The material should be as lightweight as possible while still retaining its structural integrity. An ideal material may be rigid plastic, as opposed to steel, however, this may exceed the project's budget. Overall, the heavier the material, the more pieces the cage must be disassembled into to allow for easy transportation of the cage.

k. ***Aesthetics, Appearance, and Finish*****:** The cage should be free of sharp corners or places that could snag on clothing or the harnessing itself. If the cage folds, the folded structure must also not pinch the customer while it is being transported. The functionality of the cage is more important than the appearance, but the cage should appear clean, with no points of concern such as material defects visible. Harnessing for the patient should look or be professionally sewn with sturdy attachments to the bungee cords.

2. Production Characteristics

a. ***Quantity*****:** Only one spider cage needs to be created and tested, there will be no mass manufacturing of the design. An instruction manual on how to assemble the cage and a fabrication manual on how to build the cage should be included.

b. ***Target Product Cost*****:** Spider cages go for ~$4,000, therefore, a final cost that is less than half of this is the desired target.

3. Miscellaneous

a. ***Standards and Specifications*****:** None required as of now.

b. ***Customer*****:** The cage is being designed for a patient with cerebral palsy. There is no specific customer that this product is being built for so the only customer requirements are that the cage support the height and weight of a given patient.

c. ***Patient-related Concerns*:** The cage will need to be used with a patient under the supervision of an occupational therapist.

d. ***Competition*:** There are a few cages available online for purchase but they are not as similar to the design that the client, Mr. Jahnke is looking for.