Modifications to the Hands-Free Wheelchair for Dance: Development of a Kinetic Armrest Prototype

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ABSTRACT

The University of South Florida created an interdisciplinary team between the Department of Mechanical Engineering and the School of Theatre and Dance to build innovative, mobile devices for the Performing Arts. One device that evolved from the partnership is the Hands-Free Wheelchair for modern dance performance. It is operated and controlled by the user’s weight-shift change in the seat. In order to keep this control “hands-free”, while giving the user a sense of stability, kinetic armrests have been designed for assistance and use as a dance tool. This design incorporates anthropomorphic data, engineering design, and the five basic arm positions of dance into a final prototype. The armrests have specifically been designed to withstand 200 lbs of static loading and 180 degree rotation in the vertical and horizontal planes. Its hardware also includes quick-release locking mechanisms, length-changing capabilities, and illumination. This presentation discusses plans for narrowing down options and improving upon designs through rapid-prototyping and Mechanics of Solids laboratory testing. It also highlights the importance of the Human Factors involved in this essential upgrade.

1 INTRODUCTION

Dance has often been called a mirror of society, a response to historical events, as well as political, economic, and religious
movements. It has signified social statements, no matter where it is and performed by whom. [1] In 1980, Dancing Wheels was formed in Cleveland, Ohio. It was the first modern dance company to integrate professional stand-up and sit-down (wheelchair) dancers. [2] Seven years later, Axis dance company in California joined the ranks of contemporary dance performance where dancers with and without disabilities of all ages and levels of dance experience could create and dance together.

Axis dance members are often asked whether their work is about disability. As political activists, they challenge the notions of normalcy and champion social inclusiveness. As artists, they want to be seen and evaluated as dancers first and foremost. However, searching for dancers is difficult because not many people with a physical disability have been exposed to dance. [3] An additional problem is having access to dance.

1.1 PROJECT FORMULATION

In 2006, the University of South Florida’s College of Engineering partnered with The School of Theatre and Dance in hopes to be a catalyst for this type of change. They aspired to increase exposure, opportunities, and choreographic options in dance for people with disabilities. [4] The result was the fabrication of a rolling dance chair for dance performance. (See Figure 1). With the use of Hall Effect sensors, four compression springs, and two brackets in the base of the first prototype of an electric wheelchair, the seat became the joystick. The body lean-control required for propulsion enables the user to move in a “hands-free”, unconstrained manner. This is vitally
important as carriage of the arms in dance, or “por de bras”, is a distinguishing feature that elevates a dancer’s artistry. [5]

In a previous study, feedback of the rolling dance chair was obtained from 9 participants, 4 whom had disabilities (3 of which regularly use a mobile device). Each participant had 10-minute individual sessions with the prototype. Upon feedback, one user mentioned that the chair “felt freeing because I could use my arms for movement.” However, others noted it being “unsteady”, “wobbly”, or “rocky” to keep the seat in the resting position. When questioned what they would change to make the ‘perfect chair’, “removable armrests” and a “bar to hold onto in front” were suggested. [6]

1.2 ARMREST IMPORTANCE

Armrest implementation for the rolling dance chair is a necessary addition. The use of armrests in industry and the workplace have positively assisted both able-bodied people and those with disabilities while also lowering fatigue. In Newell & Mansfield’s work, it was determined that performance and workload were substantially hindered while seated in a twisted posture with no armrest support. However, the inclusion of armrests significantly improved the test subject’s performance. [7]. Similarly, armrests benefit people with hip and knee disabilities by decreasing the moment experienced by the joints when getting out of a chair. [8] Dynamic armrests have also been produced for hydraulic actuation joystick users. With their implementation, as compared to a traditional armrest or none at all, users had significant decreases in the fatigue experienced by shoulder muscle activation. [9]

2. ARM REST DESIGN

In attempts to give the user a feeling of safety and assist their physical
Capabilities, user needs and metrics for the armrest design were established by the interdisciplinary team. (See Table 1). Once several designs were proposed, they were numerically weighted against the established metrics to determine a single design.

2.1 PARAMETERS

The Kinetic Parameters demonstrate the wide range of motion needed for choreography and dance so the device can move with the user. The five basic arm positions of ballet were evaluated to determine the space the user needs to execute the movements properly. (See Figure 2). These arm positions not only require horizontal abduction and adduction, but also shoulder movement; as this creates aesthetic and gestural importance as well as functional performance in dance. [11].

3. ARMREST PARTS

The armrest design was divided up into three main portions: the arm portion and the locking portion (for the x and y planes). Separation of the components allows for easier assembly/disassembly of the design and facilitates any maintenance that may be needed. Specifics of the armrest parts are outlined in the sections to follow.

3.1 THE ARM PORTION

Bio-design has been accomplished in a number of assistive devices for various ranges of dynamic motion. [12] Since the human arm mimics the established kinetic parameters, while negating extraneous bulkiness, the armrest was modeled after the upper limbs and five positions of dance.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Established Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinetic Parameters</td>
<td>180° Rotation in the X-Plane (Horizontal Plane)</td>
</tr>
<tr>
<td></td>
<td>180° Rotation in the Y-Plane (Vertical Plane)</td>
</tr>
<tr>
<td></td>
<td>Adjustable Length</td>
</tr>
<tr>
<td></td>
<td>Frame Support is Height Adjustable</td>
</tr>
<tr>
<td>Safety Factors</td>
<td>Locking Capabilities in the X-Plane</td>
</tr>
<tr>
<td></td>
<td>Locking Capabilities in the Y-Plane</td>
</tr>
<tr>
<td></td>
<td>Locking Capabilities of the Arm at Various Lengths</td>
</tr>
<tr>
<td></td>
<td>Withstands a 200 lb. Static Load</td>
</tr>
<tr>
<td>Human Factors</td>
<td>Aesthetics</td>
</tr>
<tr>
<td></td>
<td>Ease of Assembly/Disassembly</td>
</tr>
<tr>
<td></td>
<td>Ease of Manufacturing</td>
</tr>
<tr>
<td></td>
<td>Ease of Movement</td>
</tr>
</tbody>
</table>

Table 1: Team Established Metrics & Needs

Figure 2: Five Basic Arm Positions of Dance
When determining how to create an armrest that had adjustable length, our team worked on a design that had dynamic properties similar to the flexion and extension of an elbow. Unfortunately, problems surfaced from high moment forces and torsion at the elbow-style joint when the device was fully extended. (See Moment Force Equation 1).

\[ M = F \times r \]  
\[ \text{(1)} \]

Where:

- \( M \) = Moment
- \( F \) = Force applied
- \( R \) = Distance the force is applied

In terms of geometrical constraints, a tubular shaft withstands the best loads from available stock material. (See the Maximum Torsional Stress Equation (2) and the effects of geometry on the Polar Moment of Inertia (3)).

\[ \tau_{\text{max}} = \frac{\tau_{\text{c0}}}{J} \]  
\[ \text{(2)} \]

\[ J = \frac{\pi}{2} (c_0^4 - c_i^4) \]  
\[ \text{(3)} \]

Since torsion is greatest at the surface of an object, our design implements telescoping tubes to decrease this matter and counteract large moments from loads when the device is functioning at full extension.

### 3.1.1 ARM LENGTH

Data from *The Anthropometry and Biomechanics Guide* was used to determine the armrest length. The 5th percentile of the female distribution was chosen to ensure that most male and female users (except those smaller than the 5th percentile) would be accommodated. Likewise, clearance dimensions, which allow passage of the body (or parts) into and out of the chair (the armrest mounting width) are based on the 95th percentile of the male distribution. [13] (See Table 2).
Table 2: Calculated Limb Measurements

<table>
<thead>
<tr>
<th>Code</th>
<th>Body Reference</th>
<th>Statistic</th>
<th>cm</th>
<th>in</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Shoulder (Deltoid) Breadth</td>
<td>53.5</td>
<td>21.1</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Elbow-Fingertip Length</td>
<td>40.6</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Elbow Rest Height</td>
<td>17.6</td>
<td>6.9</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Elbow-Grip Length</td>
<td>30.0</td>
<td>11.8</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Functional (Thumb-Tip) Reach</td>
<td>67.7</td>
<td>26.7</td>
<td></td>
</tr>
</tbody>
</table>

Note: ‘A’ represents the calculated 95\textsuperscript{th} percentile Clearance Dimension with light clothing in the Male Population. ‘B-E’ are the limiting dimensions of the 5\textsuperscript{th} percentile Female Population. This data also allowed us determine the proper radius of curvature for the curved arm portion of the arm rest. For curvature, a dancer held their arms in first position under an overhead light. The image of their arm was traced, the centerline of the body noted, and the length of their limbs were measured. These measurements were then correlated with those in Table 2, alongside the arc length equation to determine a general curvature of the two pieces involved in the telescoping design.

\[ s = r\theta \]  

Where:

- \( s \) = Arc Length
- \( r \) = Radius of the Circle
- \( \theta \) = Central Angle

For our design, the radius of curvature was determined to be 25.83cm as measured from the midline of the body. A constant radius of curvature will allow the arm design to telescope out and in, while mimicking upper limb curvature of the five main dance positions.

General industry regulations require metal handrails to be at least 1.5 inches in diameter. [14] For ergonomics, comfort, and OSHA standards, the forearm portion of armrest is padded with \( \frac{1}{4} \)” thick foam padding. An industry foam handle will also be added to the end of the telescoping portion for easy grip and maneuverability. Black foam was chosen to deter reflection from stage lights and costumes. (See Figure 3).

Figure 3: Telescoping Arm
3.2 QUICK-RELEASE LOCKING

Due to the armrest’s dynamic properties, it’s necessary to have locking mechanisms housed within the x-plane (that which is parallel with the floor) and the y-plane (which is perpendicular with the floor.) By implementing quick-release components, the armrest can quickly move with the choreography and dancer, while also serving as a point of safety and stability in a range of positions.

3.2.1 X-PLANE LOCKING

The X-Plane locking mechanism is housed inside a flange portion of the armrest. The compression spring is (with a rate of 3.7 lbs/in) is compressed against the flange wall to allow the user to easily facilitate the arm up and around the before locking it back down into a channel. (See Figures 4 & 5). The channels prevent sideways translation and slipping of the armrest.

3.2.2 Y-PLANE LOCKING

The Y-Plane locking mechanism also utilizes a compression spring to translate the
armrest. Its base component consists of multiple splines. (See Figure 6).

Y-Plane Translation

The locking mechanism for the Y-Plane has been the most difficult to design, since it bears the greatest force. We looked at two locking styles: the spherical option or the keyway option. The spherical option allows for high compressive forces, since the steel ball will cause little, if any deformation. (See Figure 7). The downside of its geometry is the rocky play that occurs while assembled in cylinder and the base’s square channel. (See Figure 8).

The keyway option uses a key and key stock to fit snugly into the channels. (See Figure 9). The downside of this option is potential shearing and the need for larger arm housing.
This dance tool and assistive device is undergoing final engineering drawing revisions. Drawings will be sent to the machine shop by the end of the week. Testing for the device’s limits, weaknesses, and strong points is planned. This will ultimately help us determine how the design can be improved upon and provide the rolling dance chair users the experience of unhindered dance.

4.0 ASSEMBLY

The fully assembled design is fairly compact, with the flange portion having a diameter of 6 inches. The assembled components are noted in Figure 10.

5.0 CONCLUSIONS/ FUTURE WORK

A kinetic armrest has been designed to provide stability and comfort for the rolling dance chair. Human Factors, Biomimicry, and the need for safety contributed to the final design.
REFERENCES


