ClosedMold Composites
SpringWalk<sup>TM</sup> Hollow Carbon-Fiber Coil-Spring Prosthetic Feet

Project Overview and Background

Sept. 25<sup>th</sup>, 2020

Figure 1. Professional Amputee, Jack Richmond, Testing Prototype SpringWalk<sup>TM</sup> Design

This is a link to a video of patient testing SpringWalk<sup>TM</sup> prosthetic foot invention.

Comments by Jack Richmond, Amputee Skilled in Marketing and Product Evaluation in the video,

"it has a lot of energy storage and energy release" ... "it's a very dynamic foot" ... "really super stable at mid stance" ... "it still has energy release at toe off" ... "it gives me plenty of support" ... "I don't even notice the transition from heel to toe."

Comments by Gerry Stark, Experienced Certified Prosthetist, Taking part in Test,

"look at the arch collapse just like a regular [human] arch" ... "really stuck to the floor good."
Table of Contents
Tables of Figures .............................................................................................................. 2
Summary ............................................................................................................................ 4
Invention and First Licensee ............................................................................................ 4
Termination of License ...................................................................................................... 5
Subsequent CMC Work ...................................................................................................... 7
Results of Fillauer Funded Work and Subsequent CMC Work ........................................... 7
Current ClosedMold Composites LLC. Ownership ............................................................. 8
Purpose of This Proposal .................................................................................................. 9
Primary Technical Work Items .......................................................................................... 9
Design for Manufacture ..................................................................................................... 10
Increasing the Strength of The Front Half Of The Foot Design ........................................ 14
Earlier Work Funded by Fillauer ....................................................................................... 18
Appendix A. Performance of ClosedMold Composite Hollow Carbon Coil Springs .......... 22
Summary ............................................................................................................................ 22
Theoretical Basis for Comparison ...................................................................................... 23
Summary of Results .......................................................................................................... 24
Calculation of Energy Storage Capacities ......................................................................... 25
Appendix B. Illustration and Mass Properties of Production Design Option 1 Foot ............ 31
Illustration and Mass Properties of Front Torsion Coil Spring ........................................... 31
Illustration and Mass Properties of Foot Plate .................................................................... 33
Illustration and Mass Properties of Upper Connector Block .............................................. 34
Illustration and Mass Properties of Pyramid Adapter ......................................................... 35
Illustration and Mass Properties of Cosmesis .................................................................... 36
Summary of Primary Component Weights ......................................................................... 37
Three View Line Drawing of Complete Foot ...................................................................... 38
Three View Line Drawing of Complete Foot without Cosmesis .......................................... 39
Appendix C – Links to Other Online Information ............................................................... 40
Appendix D - Contact Information .................................................................................... 43
ClosedMold Composites Website ....................................................................................... 43
LinkedIn Profile ............................................................................................................... 43
Docx File Scan Code ....................................................................................................... 43

Tables of Figures
Figure 1. Professional Amputee, Jack Richmond, Testing Prototype SpringWalk™ Design .......... 1
Figure 2. Prototype Foot, Inside View ................................................................................. 4
Figure 3. Prototype Foot, Oblique View ............................................................................ 5
Figure 4. High Performance Composites Article, New SpringWalk Design Heel Coil – Weight 22 gr. – Collapse Load 670 Lb. (No Failure) ............................................................ 6

Project Overview and Background 2
Figure 5. Prototype Foot, Bottom View ................................................................. 7
Figure 6. Prototype Foot, two as-molded pieces .................................................... 8
Figure 7. Prototype Foot, Heel Strike in MTS Test ................................................. 9
Figure 8. Prototype Foot, Toe Off in MTS Test ....................................................... 10
Figure 9. Prototype Foot, Heel Strike and Toe Off, Patient Testing .......................... 10
Figure 10. Old 21 Piece Tool for Prototype Foot ................................................... 11
Figure 11. Old 21 Piece Tool for Prototype Foot ................................................... 12
Figure 12. New Simplified 3 Piece Tool for Heel Coil ........................................... 13
Figure 13. New Simplified 3 Piece Tool for Heel Coil ........................................... 14
Figure 14. Two Concepts for Final Production Design ........................................... 15
Figure 15. Final Production Design Option 1, Oblique View .................................. 16
Figure 16. Final Production Design Option 1, side view ......................................... 16
Figure 17. Final Production Design Option 1, Exploded View .................................. 17
Figure 18. Key Dates in SpringWalk Foot Development ...................................... 18
Figure 19. Three Types of Foot Designs Developed During Fillauer Funding ............ 19
Figure 20. The New SpringWalk Design Heel Coil Was Tested To 670 Lb. at Collapse Using 9 Strain Gages to Record Material Microstrain (1x10^-6, PPM material “stretch”) Readings ........................................... 20
Figure 21. Stiffness of New Heel Coil Compared with Existing Feet ....................... 21

Figure A-1. New Heel Coil Made with Simplified Tooling ........................................ 22
Figure A-2. Testing of New Heel Coil ..................................................................... 23
Figure A-3. Comparison of Energy Storage Capacities of Carbon Fiber hollow spring made With ClosedMold Composites’ Process and Construction with Titanium, Steel, Solid Carbon Laminate ........................................... 25
Figure A-4. Energy Storage Capacity of 30 Msi. Carbon Fiber/Epoxy Made With .................................................. 25
Figure A-5. Energy Storage Capacity of Titanium Ti-6Al-4V (Grade 5), Annealed .................................................. 26
Figure A-6. Energy Storage Capacity of High Strength Steel .................................... 26
Figure A-7. Energy Storage Capacity of Torsion Spring Used On ................................ 26
Figure A-8. Rear Heal Coil Spring Being Made with New Simple Mold Design .......... 27
Figure A-9. Rear Heal Coil Spring Being Made with New Simple Mold Design .......... 28
Figure A-10. Rear Heal Coil Spring Being Made with New Simple Mold Design ......... 29
Figure A-11. Rear Heal Coil Spring Being Made with New Simple Mold Design ......... 30

Figure B-1. Illustration and Mass Properties of Front Torsion Coil Spring .................. 31
Figure B-2. Illustration and Mass Properties of Rear Compression Coil Spring ........... 32
Figure B-3. Illustration and Mass Properties of Foot Plate ...................................... 33
Figure B-4. Illustration and Mass Properties of Upper Connector Block .................. 34
Figure B-5. Illustration and Mass Properties of Pyramid Adapter ................................ 35
Figure B-6. Illustration and Mass Properties of Cosmesis ....................................... 36
Figure B-7. Summary of Component Weights for Production Design Foot .................. 37
Figure B-8. Three View Line Drawing of Complete Foot ....................................... 38
Figure B-9. Three View Line Drawing of Complete Foot without Cosmesis ............... 39

Figure C-1. Online Information on the Prosthetic Foot ........................................... 42
Summary

ClosedMold Composites (CMC) presents the SpringWalk™ carbon fiber prosthetic foot. A lightweight, hollow, carbon fiber coil spring based prosthetic foot that with key advantages over traditional leaf spring carbon fiber feet. The SpringWalk™ coil spring technology is uniquely suited for best terrain compliance and enhanced stability because the coil elements can easily bend and conform to uneven surfaces. This allows the patient to reach stability much faster after heel strike, producing a more stable and natural gait increasing the patient’s self-confidence in the prosthetic limb. The SpringWalk prosthetic foot is also substantially lighter weight than current prosthetic feet (see Appendix A).

The foot uses an ultramodern structural design and manufacturing technologies to significantly improve prosthetic foot performance. Its technology can produce tightly coiled hollow tubular members that fit within the space envelope of a human foot, and exhibit exceptionally good structural properties. The YouTube video of the “Experienced Amputee Testing Prototype of SpringWalk Design” shown in the photos is included at this link. The SpringWalk foot’s unique design is differentiable both visually and performance-wise from the ubiquitous “leaf spring” type feet currently on the market.

Ron H. Nelson, founder of ClosedMold Composites, demonstrates the basic ClosedMold Composites’ manufacturing technology in a video of net “shape” molding of a golf shaft to completion in only 5 minutes. These modern technologies allow the development of high-performance designs that would not have been possible using the older autoclave manufacturing process. See Ron Nelson’s resume at this link.

Invention and First Licensee

Ron H. Nelson invented the SpringWalk carbon fiber prosthetic foot using hollow helical compression coil springs. One article patent has issued, and a second article patent is pending (CIP), work is ongoing for two new patent applications for both “article of manufacture” and “method of manufacturing” applications on the spring.

ClosedMold Composites licensed invention to Fillauer Inc., who funded a $1.3MM development effort (only $230k was spent at CMC). The earlier work performed during the license with Fillauer Inc., performed difficult process-development work needed for manufacturing high-strength tightly coiled...
tubular foot components (coil spring type shapes). The work also included the requisite design and fabrication of tooling and processing equipment, structural design and analyses, and development of materials and fabrication procedures.

The work took far longer, 6 years, and was far more difficult than he expected. In fact, it was the most technically challenging project in his life, which has been filled with many difficult projects. We spent several years developing key hollow molding manufacturing and construction techniques allowing unprecedented shear strengths, 95 Ksi., to be delivered in the very complex tightly wound helical geometry and curved hollow tubular parts in general. Extensive development was conducted on complex manufacturing equipment and new processes, and on new construction techniques. This included development of test fixtures and strain gaged testing, and high vacuum ovens with integral presses using 250 Psi. internal bladder pressures.

![Prototype Foot, Oblique View](image)

**Figure 3. Prototype Foot, Oblique View**

**Termination of License**

Basically, Fillauer gave up waiting on the development of a hollow molded foot just as we were successfully producing feet. They hired a longtime employee engineer from Springlite/Otto Bock to direct the project. The engineer then shortly thereafter ended the hollow molded foot project and started the new subsidiary to develop a new prosthetic foot using traditional manufacturing processes. The termination with Fillauer involved lengthy negotiations with CMC where misappropriation of manufacturing technology was alleged and wrongful termination and other breaches of the licensing agreement were also alleged. A significant financial settlement was also paid to CMC. Also, CMC was also assigned all the rights to patent applications which they had refused to relinquish to CMC, basically freezing ClosedMold Composites out of any further development. CMC owns all the rights to the SpringWalk technologies pursuant to a Termination Agreement with Fillauer.
Figure 4. High Performance Composites Article, New SpringWalk Design Heel Coil – Weight 22 gr. -- Collapse Load 670 Lb. (No Failure)
Subsequent CMC Work

Later, added development work has been funded and performed directly by CMC. CMC has later funded added work that has been critical in two ways. First, it proved the use of a new improved tool design-technology that is much simpler, much less expensive, and has much shorter lead times than earlier work. The functionality of a simplified tooling design was proven. This tooling approach had been discarded by the licensee who did not feel it would work. This tooling approach reduced tooling cost by a factor of about 20, and lead time by about a factor of 10 relative to what the licensee had used. This tool design drastically reduces the costs and schedules of the development. It also made added improvements in the manufacturing process and material configurations. Taken together, these developments produced a substantial increase in-situ delivered material strengths and stiffnesses, and reduced manufacturing costs.

Secondly, it performed added testing in controlled and simplified test geometry. This supplied reliable and precise measurements of the material’s in-situ mechanical properties in the tightly coiled spring geometry. It verified attainment of the improved high strengths and stiffnesses and did much of what is needed to finish the Prototype Development on the SpringWalk feet. As one insightful engineer remarked after reviewing my spring-foot documents, you are just getting to instituting "design for manufacture."

![Figure 5. Prototype Foot, Bottom View](image)

Results of Fillauer Funded Work and Subsequent CMC Work

Both the new spring construction and the new manufacturing process were critical to dropping fiber wrinkling in the springs. The refined spring construction and manufacturing process produce ultimate shear strengths more than 95,000 psi., unequaled in the composites industry. This is 35% higher than the highest ultimate shear strengths in technical literature for simple flat laminates which is 62 Ksi. These are the highest strength carbon fiber compression coil springs ever produced. Figures 7 thru 9, and 20 and 21 show testing of the foot.

The combination of attaining extremely high shear strengths and the elimination of the parasitic dead weight in the core of the spring wire by making it hollow, dramatically increase energy storage capabilities of coil springs for weight critical applications such as prosthetic feet. A theoretical comparison of material energy storage densities predicted the weight of a carbon spring would be a little bit less than 1/14 the weight of a titanium spring or 1/20th the weight of the steel springs. It also showed that the weight of a hollow carbon spring would be a little bit less than 64% lighter than a carbon torsion spring, and that would be similar to the weight savings relative to over traditional leaf spring carbon fiber feet (a solid laminate in bending). See Appendix A. Performance of ClosedMold Composite Hollow Carbon Coil Springs.
The primary challenge during manufacture is keeping the fibers, which are initially oriented as very thin layers of flat unidirectional fiber, straight or more specifically following their designed path orientations. The spring is laid initially on a straight mandrel, and then several steps later it is formed into a coil shape. So, a process had to be developed to allow the change from straight to coiled while having all the material end up in the right locations, orientations, and free of waves and voids. Cannot disclose more about the manufacturing process or construction since we have not applied for those patents. However, I can say that if I were to detail all steps and construction details, and the logic behind them, it would appear very straightforward. The problem was figuring it all out. Eliminating any waviness in the fibers is essential, and the process is quite difficult to develop when forming against the inside mold surfaces for the highly convoluted geometries used in Hollow Molded Foot. Elimination of fiber waviness and voids in the resin is essential, as they negatively affect compressive strength dramatically also. Voids and wrinkles can knock down material strengths by 50% to 75%.

Some of the manufacturing is shown in figures A-8 thru A-11 in Appendix A, and also at this link taken from Appendix C: View PDF File with Ron’s Work on His Closedmold Composites Internal Pressure Bladder Molded Hollow Compression Spring Prosthetic Foot Invention.

Two related patent prosecution efforts are underway for both “article of manufacture” and “method of manufacturing” applications on the spring. The “article of manufacture” application will cover the construction of the individual carbon fiber plies in the spring, some of which are specially processed with a unique long discontinuous fiber process first. The “method of manufacturing” application will cover the forming the individual plies into the complex curved geometry of a compact coil spring without fiber wrinkles. Click to go to page on project.

Current ClosedMold Composites LLC. Ownership
Mr. Nelson currently owns 80% of CMC, with his longtime patent attorney, Jim Sonntag owning the remaining 20%. Link to Jim’s website is here.
Purpose of This Proposal

CMC is currently trying to finish commercialization of the technology by raising investment capital and/or sell its ownership to an existing prosthetics or composites company. The next phase of development is expected to require 6-8 months. This Phase of work will complete the $1.3MM of work from the earlier development project, and work performed later by CMC independently. CMC expects to complete prototype development of a refined design, fabrication of several copies of the Final Production Design, complete testing to simplified industry test standards, and conduct initial patient trials. The deliverable will be a foot that passed patient testing and static ultimate testing. The funding necessary to achieve this is estimated at $600k to $800K if the work is not done at a teaming prosthetics or composites company. It is estimated to be significantly lower cost if the work is done at a teaming prosthetics or composites company. For reference, the majority of the $1.3MM of earlier work funded by Fillauer Inc. was spent internally at Fillauer. Only $230k of the $1.3MM was spent on development performed at CMC, and/or by CMC personnel.

Primary Technical Work Items

The most important part of the Phase I work will involve the dramatic improvements that will be made in the foot designs and tooling designs, which entail:

1. Design for Manufacture, redesigning the foot elements and their tooling for manufacturability.
2. Increasing the strength of the front half of the foot design.

These were the two shortcomings in the earlier development efforts that prevented final development and commercialization. Phase I will implement technology improvements developed and proven by CMC after the foot development work directed by the Earlier licensee, Fillauer Inc. ended.

Figure 7. Prototype Foot, Heel Strike in MTS Test
Design for Manufacture

A vastly simpler, less costly, and shorter lead time tool design will be used in this project. The feasibility of this tooling approach has been proved (as shown in the coil testing in Appendix A, Performance of ClosedMold Composite Hollow Carbon Coil Springs). This approach has been having been used on a Rear Heel Coil Spring and evaluated to verify that it works. Figures 10, 11, 12 and 13 illustrate the developments. The two as-molded components of the old design are shown in Figure 6.

This will have a profound positive effect on the project going forward. A major impediment in the earlier licensee, Fillauer Inc.’s development work on the coil spring designs was using a very complex helical parting plane (places where the tool segments separate, see note in photo) surface spiraling
around the central spring axis. Another flat axial parting plane further complicated the tool. The earlier licensee, Fillauer Inc. assumed that the molded parts, i.e. coil springs, would not be removable from tools with simpler parting surfaces. That assumption was based on inexperience and faulty information from a 3D modeling software’s (Autodesk Inventor) utility for checking interference and cavity draft in closed molding tooling.

This led to the design and use of tools vastly more complex, more expensive, and with much longer lead times than required. This profoundly affected the earlier development efforts by almost cutting the ability to do a systematic development process, building subcomponents, testing them, iteratively because the tool cost and lead times were so high.

The earlier tool design, the Old Complex Mold Design, shown in Figures 10 and 11, will be changed to that using a simple conical and flat parting plane design shown in Figures 12 and 13. This allows for the use of only 3 primary tool pieces. It is notable that only a “single core piece” is used in the coil replacing 20 tool pieces that extend into the core area in the earlier approach.

Figure 10. Old 21 Piece Tool for Prototype Foot
Figure 11. Old 21 Piece Tool for Prototype Foot
Figure 12. New Simplified 3 Piece Tool for Heel Coil
Increasing the Strength of The Front Half Of The Foot Design.

One class of developments from the earlier work was the development of a double coil foot design that worked well in the limited patient testing done. Its "handling characteristics" were quite good. The primary failure or limitation of the double coil foot development was the lack of durability and strength on the front coil, i.e. it broke relatively easily. The operating stress in a coil spring can be reduced by increasing the number of coils and then making a corresponding change to increase the cross-sectional dimensions of the wire, i.e. increase the wire diameter. The only limitation of this approach is if the solid height of the resulting spring does not allow the desired deflection to occur. There is plenty of space, however. Therefore, another coil will be added to the front coil to reduce its operating stresses and increase its strength.

Adding another coil to the existing single front coil in the Prototype Foot SpringWalk Design will also a significant reduction in the operating stresses. The new manufacturability changes, i.e. tool design changes, will allow another coil to be added easily, while it was prohibitively expensive and time consuming to do it with the earlier manufacturing/tooling approach.

Figure 14 illustrates two concepts for final production design. The vertical coil design similar to the prototype Foot is denoted Production Design Option 2, and a design where the forward coil axis is rotated 90 degrees to put the front coil in a torsional loading is denoted Production Design Option 1. Figures 15 thru 17 illustrate Production Design Option 1 in slightly more detail, while it is shown in great detail in detail in Appendix B. Illustration and Mass Properties of Production Design Option 1 Foot.
Project Overview and Background

Production Design Option 1.
Horizontal Front Torsion Coil Spring and Vertical Rear Compression Coil Spring Foot

Production Design Option 2.
Double Vertical Coil spring

Figure 14. Two Concepts for Final Production Design
Figure 15. Final Production Design Option 1, Oblique View
Figure 16. Final Production Design Option 1, Side View

Figure 17. Final Production Design Option 1, Exploded View
Earlier Work Funded by Fillauer

There were many significant findings and accomplishments from the work. The first involves verifying the superior “handling characteristics” of the foot and the desirability of the foot from the amputee’s feeling. The second was development of manufacturing methods to produce tightly curved coils with high strengths and stiffnesses. Item 18 in Appendix C has a Project Photo Appendix for SpringWalk Hollow Carbon Fiber Coil Spring Prosthetic Foot that illustrates a lot of the work items photographically.

Three different foot designs were developed and evaluated, mainly because of the lack of the licensee’s experience with development projects and composite materials specifically. The designs fell into three primary categories, double coil feet, U limbed feet, and straight limbed feet. These are illustrated in Figure 19. The work also included the design and fabrication of tooling and processing equipment, structural design and analyses, and development of materials and fabrication procedures. Key dates for the SpringWalk project are shown in Figure 18.

<table>
<thead>
<tr>
<th>Description</th>
<th>start date</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMC-Fillauer Development and Licensing Agreement signed</td>
<td>Feb. 2003</td>
</tr>
<tr>
<td>J. Richmond &amp; B. Holyfield, Fillauer “below the knee” Amputees, walk on Double Coil Foot #2 Prototypes</td>
<td>July 2008</td>
</tr>
<tr>
<td>Development of Double Coil Foot #2 stopped per New Fillauer Project Manager</td>
<td>August 2008</td>
</tr>
<tr>
<td>Final Termination agreement between Fillauer and CMC reached assigning all hollow molded foot technology ownership to CMC along with significant financial payment to CMC.</td>
<td>Feb. 2009</td>
</tr>
</tbody>
</table>

Figure 18. Key Dates in SpringWalk Foot Development
<table>
<thead>
<tr>
<th>“Double Vertical Coil” Foot Prototype Foot design shown, and Early Prototype Foot is same basic construction.</th>
</tr>
</thead>
<tbody>
<tr>
<td>“U limbed Foot” Fillauer did a crude version of this (U shapes were different) with no structural analysis.</td>
</tr>
<tr>
<td>“Straight Limbed Foot” “Straight Limbed Foot” (lightly curved) (shown as Figures 3 and 4 in the SpringWalk patent application)</td>
</tr>
</tbody>
</table>

Figure 19. Three Types of Foot Designs Developed During Fillauer Funding
Figure 20. The New SpringWalk Design Heel Coil Was Tested To 670 Lb. at Collapse Using 9 Strain Gages to Record Material Microstrain (1x10^-6, PPM material "stretch") Readings
Figure 21. Stiffness of New Heel Coil Compared with Existing Feet
Appendix A. Performance of ClosedMold Composite Hollow Carbon Coil Springs

Summary

Included here is comparison of energy storage capacities of ClosedMold Composites' carbon fiber hollow carbon fiber compression coil springs vs. Titanium, steel, and a carbon fiber torsion spring used on the Boeing 767 door counterbalance mechanism is made here. The
carbon fiber springs use a novel new construction that ClosedMold Composites developed over a several year period with a new manufacturing process it developed simultaneously.

Theoretical Basis for Comparison

Spring designers and engineers use the maximum strain energy densities of candidate spring materials to compare their efficiencies on a weight basis. The strain energy density of a material is its theoretical maximum strain energy per unit volume of the material divided by its density. For compression coil springs which store their energy in shear stress, its value for varied materials can be calculated by the following simple equation.
\[ \mu = \frac{\tau^2}{2\rho G} \]

Where:

\[ \mu = \text{energy storage density} \ (\text{lb.}^2/\text{in.}^4/(\text{lb.} \cdot \text{in.}^3 \cdot \text{lb.}/ \text{in.}^2) = \text{in.}) \]

\[ \tau = \text{ultimate shear strength} \]

\[ \rho = \text{material density} \]

\[ G = \text{shear modulus} \]

An online reference is linked here.

For torsion coil springs which store their energy in tensile stress, its value for varied materials can be calculated by the following simple equation.

\[ \mu = \frac{\sigma^2}{2\rho E} \]

Where:

\[ \mu = \text{energy storage density} \ (\text{lb.}^2/\text{in.}^4/(\text{lb.} \cdot \text{in.}^3 \cdot \text{lb.}/ \text{in.}^2) = \text{in.}) \]

\[ \sigma = \text{ultimate tensile strength} \]

\[ \rho = \text{material density} \]

\[ E = \text{tensile modulus} \]

I added to these another factor of one half to the hollow carbon spring that because on the carbon spring we cut out the dead material in the center of the core of the wire, i.e. it's hollow.

**Summary of Results**

A table with the resulting weight saving of ClosedMold Composites’ carbon fiber hollow carbon fiber compression coil springs vs. Titanium, steel, and a carbon fiber torsion spring used on the Boeing 767 door counterbalance mechanism is shown in Figure A-3 below.
Spring Material & Strain Energy Density & Relative Weight & Including Factor Of 2 For Hollow Springs & Weight Savings of Hollow Springs

<table>
<thead>
<tr>
<th>Spring Material</th>
<th>Strain Energy Density</th>
<th>Relative Weight</th>
<th>Including Factor Of 2 For Hollow Springs</th>
<th>Weight Savings of Hollow Springs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium Ti-6Al-4V (Grade 5), Annealed</td>
<td>3,119.14</td>
<td>7.18</td>
<td>14.35</td>
<td>-93.0%</td>
</tr>
<tr>
<td>High Strength Steel</td>
<td>2,158.92</td>
<td>10.37</td>
<td>20.74</td>
<td>-95.2%</td>
</tr>
<tr>
<td>Carbon Fiber Torsion Spring Used on The Boeing 767 Door Counterbalance Mechanism</td>
<td>8,059.32</td>
<td>2.78</td>
<td>2.78</td>
<td>-64.0%</td>
</tr>
<tr>
<td>30 Msi. Carbon/Epoxy Made in ClosedMold Composites LLC. Process and Construction</td>
<td>22,383.43</td>
<td>na</td>
<td>na</td>
<td>na</td>
</tr>
</tbody>
</table>

[1] Ratio of Strain Energy Density of Carbon Hollow Spring Divided by Carbon Torsion Spring

Figure A- 3. Comparison of Energy Storage Capacities of Carbon Fiber hollow spring made with ClosedMold Composites’ Process and Construction with Titanium, Steel, Solid Carbon Laminate

The analysis showed that the weight of a hollow carbon spring would be a little bit less than 1/20th the weight of a steel spring. It also showed that you had cut out 93% of the weight of a titanium spring. It also showed that the weight of a hollow carbon spring would be a little bit less than 64% lighter than a carbon torsion spring, and that would be similar to the weight savings relative to over traditional leaf spring carbon fiber feet.

**Calculation of Energy Storage Capacities**

The calculations for each material are shown in the tables below.

| 30 Msi. Carbon/Epoxy Made in ClosedMold Composites LLC. Process and Construction |
|-----------------------------------|-----------------|-----------------|-----------------|
| Peak Shear Strength               | 95,000          | Psi.            |                 |
| Shear Modulus                     | 3,600,000       | Psi.            |                 |
| Ave. Shear Strain                 | 1.80%           | %               |                 |
| Ave. Shear Strength               | 65,000          | Psi.            |                 |
| Density                           | 0.056           | lb./cu. in.     |                 |
| Strain Energy Density             | 22,383.43       | in.             |                 |

Figure A- 4. Energy Storage Capacity of 30 Msi. Carbon Fiber/Epoxy Made With ClosedMold Composites’ Process and Construction

Project Overview and Background
### Project Overview and Background

#### Titanium Ti-6Al-4V (Grade 5), Annealed

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate Shear Strength</td>
<td>79,800</td>
<td>Psi.</td>
</tr>
<tr>
<td>Shear Modulus</td>
<td>6,380,000</td>
<td>Psi.</td>
</tr>
<tr>
<td>Calculated Peak Shear Strain</td>
<td>1.25%</td>
<td>%</td>
</tr>
<tr>
<td>Density</td>
<td>0.16</td>
<td>lb./cu. in.</td>
</tr>
<tr>
<td>Strain Energy Density</td>
<td>3,119.14</td>
<td>in.</td>
</tr>
</tbody>
</table>

Figure A-5. Energy Storage Capacity of Titanium Ti-6Al-4V (Grade 5), Annealed

#### High Strength Steel

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate Shear Strength</td>
<td>120,000</td>
<td>Psi.</td>
</tr>
<tr>
<td>Shear Modulus</td>
<td>11,500,000</td>
<td>Psi.</td>
</tr>
<tr>
<td>Calculated Peak Shear Strain</td>
<td>1.04%</td>
<td>%</td>
</tr>
<tr>
<td>Density</td>
<td>0.29</td>
<td>lb./cu. in.</td>
</tr>
<tr>
<td>Strain Energy Density</td>
<td>2,158.92</td>
<td>in.</td>
</tr>
</tbody>
</table>

Figure A-6. Energy Storage Capacity of High Strength Steel

#### Carbon Fiber Torsion Spring Used on The Boeing 767 Door Counterbalance Mechanism

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate Tensile Strength</td>
<td>119,800</td>
<td>Psi.</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>15,900,000</td>
<td>Psi.</td>
</tr>
<tr>
<td>Calculated Peak Tensile Strain</td>
<td>0.75%</td>
<td>%</td>
</tr>
<tr>
<td>Density</td>
<td>0.06</td>
<td>lb./cu. in.</td>
</tr>
<tr>
<td>Strain Energy Density</td>
<td>8,059.32</td>
<td>in.</td>
</tr>
</tbody>
</table>

Figure A-7. Energy Storage Capacity of Torsion Spring Used On The Boeing 767 Door Counterbalance Mechanism
Figure A-8. Rear Heal Coil Spring Being Made with New Simple Mold Design
Figure A-9. Rear Heal Coil Spring Being Made with New Simple Mold Design
Figure A-10. Rear Heal Coil Spring Being Made with New Simple Mold Design
Figure A-11. Rear Heal Coil Spring Being Made with New Simple Mold Design
Appendix B. Illustration and Mass Properties of Production Design Option 1 Foot

Illustration and Mass Properties of Front Torsion Coil Spring

Spring being referenced shown with green and blue markings

<table>
<thead>
<tr>
<th>Mass properties of selected Solid Bodies:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output coordinate System: -- default --</td>
</tr>
<tr>
<td>Density = 0.0560 pounds per cubic inch</td>
</tr>
<tr>
<td>Mass = 0.0903 pounds</td>
</tr>
<tr>
<td>Volume = 1.4333 cubic inches</td>
</tr>
<tr>
<td>Surface area = 41.1855 inches^2</td>
</tr>
<tr>
<td>Center of mass: (inches)</td>
</tr>
<tr>
<td>X = -0.0438</td>
</tr>
<tr>
<td>Y = 0.5664</td>
</tr>
<tr>
<td>Z = 3.0606</td>
</tr>
</tbody>
</table>

Principal axes of inertia and principal moments of inertia: (pounds * square inch)
Taken at the center of mass,

\[ I_x = (-0.1314, -0.5041, 0.8853) \]
\[ I_y = (-0.5751, -0.0619, -0.4795) \]
\[ I_z = (0.8067, -0.5548, -0.2034) \]

\[ I_{xy} = 0.0347 \]
\[ I_{yz} = 0.1250 \]
\[ I_{xz} = 0.1258 \]

Moments of inertia: (pounds * square inches)

<table>
<thead>
<tr>
<th>Lxx</th>
<th>Lyy</th>
<th>Lzz</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0076</td>
<td>0.1032</td>
<td>0.0095</td>
</tr>
<tr>
<td>0.0076</td>
<td>0.0095</td>
<td>0.0095</td>
</tr>
</tbody>
</table>

Figure B-1. Illustration and Mass Properties of Front Torsion Coil Spring

Illustration and Mass Properties of Front Torsion Coil Spring Finished weight as shown is 36.7 gr. Design is one-piece carbon fiber. Weight/design Based on .070” wall thickness and .5127” outer diameter main coil and upper extension. Weight includes straight upper part and forward member with flattens and widens at its tip.
Illustration and Mass Properties of Rear Compression Coil Spring

Spring being referenced shown with green markings

Figure B-2. Illustration and Mass Properties of Rear Compression Coil Spring

Finished weight as shown is 18.6 gr. Design is one-piece carbon fiber. Weight/design Based on .050″ wall thickness and .330″ outer diameter. For reference, the prototype rear coil spring shown in other documents has an outer diameter of .360″. Note that the spring ends have been “squared off” after molding is complete.
Illustration and Mass Properties of Foot Plate

Part being referenced shown with green and blue markings

Figure B-3. Illustration and Mass Properties of Foot Plate

Finished weight as shown is 46.4 gr. Design is one-piece carbon fiber. Weight/design Based on .050” wall thickness on the base plate. The upper protuberances supply interfaces to the springs. For simplicity, these protuberances are shown and solid. In the final design these will most likely be hollowed using the hollow molding process, either with open cavities, but more likely with hollow cavities, i.e. the final weight of this component will be more like 30 to 35 gr.
Illustration and Mass Properties of Upper Connector Block

Part being referenced shown with green markings

Figure B-4. Illustration and Mass Properties of Upper Connector Block
Finished weight as shown is 83.0 gr. Design is one-piece aluminum.
Illustration and Mass Properties of Pyramid Adapter
Part being referenced shown with green markings

Figure B-5. Illustration and Mass Properties of Pyramid Adapter
Finished weight as shown is 53.9 gr. Design is one-piece titanium.
Illustration and Mass Properties of Cosmesis
Part being referenced shown with green markings

Figure B-6. Illustration and Mass Properties of Cosmesis
Finished weight as shown is 92.9 gr., based on wall thickness of .12" and 30 lb./cu. Ft. density, i.e. "medium firm" stiffness polyurethane rubber.
### Summary of Primary Component Weights

<table>
<thead>
<tr>
<th>Part</th>
<th>Weight – gr.</th>
<th>Material</th>
<th>Manufacturing Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Torsion Coil Spring</td>
<td>36.7</td>
<td>Carbon fiber – Epoxy</td>
<td>CMC Hollow Spring Molding</td>
</tr>
<tr>
<td>Rear Compression Coil Spring</td>
<td>18.6</td>
<td>Carbon fiber – Epoxy</td>
<td>CMC Hollow Spring Molding</td>
</tr>
<tr>
<td>Foot Plate</td>
<td>46.4</td>
<td>Carbon fiber – Epoxy</td>
<td>CMC Hollow Molding</td>
</tr>
<tr>
<td>Upper Connector Block</td>
<td>83.0</td>
<td>Aluminum</td>
<td>CNC, computer machined</td>
</tr>
<tr>
<td>Pyramid Adapter</td>
<td>53.9</td>
<td>Titanium</td>
<td>CNC, or cast/CNC, or purchase</td>
</tr>
<tr>
<td>Cosmesis</td>
<td>92.9</td>
<td>Polyurethane Rubber</td>
<td>Cast, or vacuum cast</td>
</tr>
<tr>
<td>Total in gr.</td>
<td>331.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total in Lb.</td>
<td>.731</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Carbon in gr.</td>
<td>101.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Carbon in Lb.</td>
<td>.224</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure B- 7. Summary of Component Weights for Production Design Foot.
Three View Line Drawing of Complete Foot

Figure B- 8. Three View Line Drawing of Complete Foot
Three View Line Drawing of Complete Foot without Cosmesis

Figure B- 9. Three View Line Drawing of Complete Foot without Cosmesis
# Appendix C – Links to Other Online Information

## Online Information on the Prosthetic Foot

<table>
<thead>
<tr>
<th>Category</th>
<th>#</th>
<th>Description and Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magazine Article</td>
<td>1</td>
<td>View PDF File with a High-Performance Composites Magazine Article About His Hollow Compression Spring Prosthetic Foot.</td>
</tr>
<tr>
<td>LinkedIn Document</td>
<td>2</td>
<td>View Webpage Format File with An Article, &quot;Closedmold Composites (CMC) Presents the Hollow Compression Spring Prosthetic Foot&quot; That Ron Wrote on LinkedIn About His Project to Develop His Prosthetic Foot.</td>
</tr>
<tr>
<td>LinkedIn Document</td>
<td>3</td>
<td>View PDF File of LinkedIn Article, &quot;Closedmold Composites (CMC) Presents the Hollow Compression Spring Prosthetic Foot&quot;, That Ron Wrote on His Development of Hollow Carbon Fiber Compression Springs for It. He Has a Patent Covering This.</td>
</tr>
<tr>
<td>LinkedIn Document</td>
<td>4</td>
<td>View Webpage Format File with Article Ron Wrote a LinkedIn Article, &quot;Hollow Carbon Coil Springs Cut Out 95% of the Weight of Steel Springs&quot;, on the Energy Storage Capacities of His Hollow Carbon Fiber Coil Springs Vs. Titanium and Steel.</td>
</tr>
<tr>
<td>LinkedIn Document</td>
<td>5</td>
<td>View PDF File a LinkedIn Article Ron Wrote, &quot;Hollow Carbon Coil Springs Cut Out 95% of the Weight of Steel Springs&quot;, on the Energy Storage Capacities of His Hollow Carbon Fiber Coil Springs Vs. Titanium and Steel.</td>
</tr>
<tr>
<td>Documents for Potential Investors</td>
<td>6</td>
<td>View PDF File with the Documents Ron Prepared for Potential Investors of Ron’s Prosthetic Foot.</td>
</tr>
<tr>
<td>Folder of Documents for Potential Investors</td>
<td>7</td>
<td>View Folder of Documents and Photos Ron Prepared for Potential Investors of Ron’s Prosthetic Foot.</td>
</tr>
<tr>
<td>Folder of Documents</td>
<td>8</td>
<td>View Folder of Documents and Photos for Ron’s Prosthetic Foot Project.</td>
</tr>
<tr>
<td>LinkedIn Document</td>
<td>9</td>
<td>View PDF File with &quot;Ron Wrote an Article on LinkedIn About How Engineers Can Use This Article, &quot;Hollow Compression Coil Spring Calculations&quot;, to Design Hollow Carbon Fiber Suspension Springs.&quot;</td>
</tr>
<tr>
<td>Photos &amp; Documents of Project</td>
<td>10</td>
<td>View PDF File with Ron's Work on His Closedmold Composites Internal Pressure Bladder Molded Hollow Compression Spring Prosthetic Foot Invention.</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----</td>
<td>----------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Video of a Professional Amputee Testing</td>
<td>11</td>
<td>View Ron's Video of a Professional Amputee Testing of Ron's Hollow Compression Spring Prosthetic Foot. It is on the &quot;Closedmold&quot; YouTube Channel. It has 8,000 views.</td>
</tr>
<tr>
<td>ClosedMold Composites - Fillauer Settlement Agreement</td>
<td>14</td>
<td>View the ClosedMold Composites - Fillauer Settlement Agreement</td>
</tr>
<tr>
<td>Fillauer Patent Transfer to ClosedMold Composites Agreement</td>
<td>15</td>
<td>View the Fillauer Patent Transfer to ClosedMold Composites Agreement</td>
</tr>
<tr>
<td>Fillauer Patent Assignment to ClosedMold Composites Agreement</td>
<td>16</td>
<td>View the Fillauer Patent Assignment to ClosedMold Composites Agreement</td>
</tr>
<tr>
<td>Transcription of Patient Testing Videos</td>
<td>17</td>
<td>View the Transcription of Patient Testing Videos of Double Coil #2 Foot on 10-18-07</td>
</tr>
<tr>
<td>Project Photo Appendix for SpringWalk Project</td>
<td>18</td>
<td>View the Project Photo Appendix for SpringWalk Hollow Carbon Fiber Coil Spring Prosthetic Foot</td>
</tr>
</tbody>
</table>
Figure C- 1. Online Information on the Prosthetic Foot
Appendix D - Contact Information

ClosedMold Composites, LLC
3861 South Congress Drive
Taylorsville, Utah 84123
Call: 801-666-9977
Email: Ron Nelson (closedmold@outlook.com)

ClosedMold Composites Website

LinkedIn Profile

Docx File Scan Code