Exploration of Locking and Unlocking Mechanisms for an Upper-Body Exoskeleton to Support Leaning

By

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Chapter 1: Introduction

Shoulder and back pain are two of the most common work-related injuries in the world. In 2016, the U.S. Bureau of Labor Statistics found that of all work-related musculoskeletal disorders (WMSD) resulting in days away from work, those involving the back accounted for 38.5%, and those involving the shoulders accounted for 14.9%, the two highest body parts causing WMSD [1]. Many occupations require hours of continuous and prolonged leaning, bending over, stooping, and reaching. This leaves workers with short-term discomfort and soreness and long-term back, shoulder, and arm pain, and in some cases, nerve damage.

In large-scale manufacturing, maintenance, and medical jobs, workers spend most of their time inside an enclosed space or on an assembly line and are often leaning or hunched over to complete a prolonged or repetitive task. This can result in nerve pain, back/shoulder/arm soreness, and bad posture. In the EU, 30% of the work population is exposed to material handling, 63% to repetitive movements, and 46% to awkward body postures, and more than 40% of workers suffer from low back, neck, or shoulder pain annually [2]. The short-term ramifications of performing such tasks become costly and increasingly detrimental to the health and well-being of workers all over the world.

There are currently a handful of available wearable exoskeletons on the market that assist workers with lifting, reaching, and other repetitive tasks, but they can be rigid and restrict user movement and cause discomfort, and some require an external power source. This thesis presents core mechanical components for a lightweight and compact flexible-to-rigid arm exoskeleton that supports the user during leaning, stooping, and kneeling tasks, with a primary focus on the joint locking mechanism. This wearable assistive device will allow the user to offload stress their back and shoulders by anchoring to the user's environment. The goal of this device is to effectively support the user and show a significant reduction in tension and compression on the user's arms, shoulders, and spine. The scope of this paper involves the examination of existing flexible-to-rigid exoskeletons, evaluation of three iterative prototypes, and the locking mechanism design process.

Chapter 2: Background

Existing Upper Arm Exoskeletons

The EksoEVO, developed by Ekso Bionics, is a passive upper-body exoskeleton designed to reduce worker fatigue and shoulder pain for workers performing prolonged and repetitive overhead and in-front tasks [3]. The EVO uses a stacked-link structure and high-force spring actuators to track the user's arms and provide load support during reaching and lifting tasks [3]. The exoskeleton is worn around the user's waist, and the passive actuators run along the user's back and strap into the upper arms. Both arms operate independently, and it was designed with the goal of providing flexibility and increased range of motion. The actuators are activated and asymmetrically controlled via toggle switch on each arm [3].

Figure 1. EksoEVO wearable exoskeleton [2].

Its predecessor, the EksoVest, used similar hinge mechanisms and moment generation to reduce shoulder abduction range of motion by 10% and significantly reduce spine loading during overhead tasks [4]. The EksoEVO provides 5 – 15 lbs. [2.2 – 6.8 kg], of list assistance per arm [3].

The shoulderX exoskeleton by SuitX is a passive assistive device that supports the user's shoulders by transferring the load to the user's hips during prolonged chest to ceiling level tasks

[5]. The exoskeleton weighs 7 lbs. [3.2 kg] and has four torque levels with a peak amplitude of 15 Nm [5]. The shoulderX is worn around the waist with shoulder straps, and the high-power spring actuators run from the shoulders to straps around the upper arms. The actuators can be toggled independently via buttons on each arm.

Figure 2. SuitX’s shoulderX wearable exoskeleton [5].

A study by Van Engelhoven et al. found that the shoulderX reduced anterior deltoid activity by 81% and upper trapezius activity by 46% in static and repetitive overhead tasks involving light tools [6]. A second study by Alabdulkarim et al. found a 16% reduction in anterior deltoid activity and nearly 30% reduction in medial deltoid activity in static and repetitive overhead tasks involving heavy tools [7].

The PAEXO Shoulder, developed by Ottobock Industrial, is a passive and lightweight upper-body exoskeleton used primarily for overhead tasks. Weighing just 3.9 lbs. [1.9 kg], the PAEXO is the lightest upper-body exoskeleton on the market [8]. The PAEXO utilizes rigid support and arm bars connected by a hinge joint, and a passive spring actuator generates the support torque, transferring the load on the user’s arms to the pelvis [9]. The torque must be manually adjusted by the user on each arm by adjusting the length of the lever arm BC, shown in Figure 3. The support structure is connected to the hip belt via passive ball joint, allowing full range of motion of the user’s torso.

Figure 3. PAEXO Shoulder wearable exoskeleton [9].

A study by Schmalz et al. found that for overhead drilling tasks, there was a muscle activity reduction in the deltoid muscles between 40% and 48% and a reduction in the trapezius muscles between 18% and 34% [10]. Maurice et al. found with similar tasks that the anterior deltoid activity was reduced by 55% with the PAEXO without increasing strain in the lower back [9].

Flexible-to-Rigid Devices

The NOGA Holding System is commonly used in industrial applications to fasten objects such as dial indicators and levers in a particular position [11]. Two arms are connected by a swivel clamp, which can be locked and unlocked by tightening and loosening the set screw, respectively. On the outer ends of both arms are ball-and-socket joints, where the bottom arm attaches to a base, and the top arm attaches to a fine adjustment holder for the desired tool. The ball-and-socket joints are also locked and unlocked simultaneously with the swivel clamp.

Figure 4. NOGA NF61003 Holder [12]

The NOGA arms' central locking mechanism is designed to alternate the system between flexible and rigid states with one toggle mechanism.

The Greenberg Retractor and Handrest is a three-level system used for cranial retraction in brain surgeries [13]. The system contains a series of mounts and instrument holders for the surgeon to have ergonomic efficiency during operation and convenient access to the necessary blades and tools.

Figure 5. Greenberg Retractor and Handrest System [13].

One of the components of the Retractor is a flex bar arm that serves as a large instrument holder, with a cantilever clamp that holds shafts up to 1” diameter [14]. The arm consists of a series of cylinders with spherical ends that resemble ball-and-socket joints. These joints are held together by a long cable that runs from the base to the end effector and is pre-loaded to ensure all joints are contacting one another. When the cable tension is loose, the arm is in a flexible state and can be positioned in any orientation within its configuration space. By tightening the cable with the tensioner on the right end of Figure 6, the cable shortens and compresses the joints together in a form of friction locking.

Figure 6. Greenberg large instrument holder [14].

Existing Locking Mechanisms

Fath Inc. produces an aluminum die-cast pivot joint for connecting T-slots and other panels. The joint can rotate 180° on the bearing block and can be fixed in any position with the Kipp locking lever [15]. This joint uses friction-locking to secure the joint by tightening the lever, which compresses the interlocking housing components and prevents free rotation. The frictional resistance can be manually adjusted depending on the required torque for the application.

Figure 7. Friction-locking pivot joint [15].

Friction-locking joints are best used with small loads and low-torque applications because at higher loads, the applied torque can exceed the frictional resistance and cause the joint to slip or fail. Early exoskeleton prototypes often use friction-locking mechanisms such as ball-and-socket joints to test at smaller scales and with lower applied forces. A mechanical locking mechanism would eliminate the risk of slipping and provide a higher factor of safety when dealing with forces from human body weight.

This adjustable locking hub by Carr Lane Manufacturing is a rotary bearing with mechanical locking that is used in industrial applications such as welding fixtures, adjustable work surfaces, and collapsible structures. The stainless-steel joint provides locking at 10° increments with a 220° range and can withstand 80 ft-lbs. [108 Nm] of torque [16]. The locking mechanism is toggled by a push button, entering a flexible state when pressed and a rigid state when released. While the torque support would be sufficient for this design, the stainless steel adds considerable weight, and the overall length of one hub is approximately 5 ¼”.

Figure 8. Adjustable locking hub [16].

Since this hub only satisfies one rotational degree of freedom (DOF), any additional joints would make the exoskeleton too large and uncomfortable for the user. However, the internal locking mechanism and toggle mechanism are viable design solutions, and these will be explored during the design process.

The static progressive serrated hinge kit by North Coast Medical is an adjustable arm brace often used for joint positioning, fracture bracing, and post-cast removal [17]. The locking mechanism concept explored in this arm exoskeleton closely resembles the serrated hinge design. The hinge arm is made of 1/8” thick aluminum attached to a serrated plate joint [17]. The two serrated plates are held in place by a set screw and lock the arm in place when tightened. To adjust the arm brace to a new orientation, the set screw is loosened, separating the plates and allowing the joint to rotate, and then tightened to secure the new joint position.

Figure 9. Elbow serrated hinge arm and locking mechanism [17].

The serrated teeth provide a mechanical locking that eliminates slip often seen in friction-locking mechanisms. These plates are low-profile, lightweight, and allow for simple and fast toggling between flexible and rigid states. This mechanism is a viable solution for the locking component of the exoskeleton.

Chapter 3: Methodology

Arm Exoskeleton Concept

The desired interface for the exoskeleton is a wearable vest consisting of a lightweight and thermally comfortable material. The two arms attached to the vest will provide a sturdy and stable support between the user's upper body and the workspace. The exoskeleton is intended to provide a reaction force to offset the load on the user's back during leaning tasks. The majority of available wearable exoskeletons focus primarily on overhead tasks and provide support between the user's torso and arms, so the goal of this exoskeleton is to break into a new category and target leaning, reaching, and stooping tasks by providing support between the user and an external workspace.

The exoskeleton is comprised of a series of modular 2-DOF segments. In each segment, one DOF represents the flex joint akin to an elbow joint, and one DOF represents the roll joint. While an individual joint has several constraints and a limited domain, connecting these joints in close succession maximizes the range of motion and increases the DOF. The key feature of this exoskeleton is the adjustable joint mechanism that enables the system to have flexible and rigid modes. When the exoskeleton is flexible, the joints run along the user's arm and follow the arm's orientation. The exoskeleton may be contoured to the arm via elastic bands or magnets. In the rigid state, the joints are locked into a position set by the user to support their posture, and the user's arms can be disconnected to perform the task at hand.

Prototype Design and Evaluation

For this design, three prototypes were developed and evaluated. The first two explore various features of the design and help determine the optimal joint type, locking mechanism, and toggle mechanism. The third prototype is the final design that incorporates the desired features and will ultimately be refined and implemented in the arm exoskeleton.

Prototype v0

Prototype v0 was constructed as a proof of concept for a modular flexible-to-rigid segment. The prototype consisted of a chain of off-the-shelf camera mounts. Each camera mount has a ball-and-socket joint on either side that is held in place by two plates, which can be adjusted by tightening or loosening the set screw. The idea is that when the set screw is loosened, the ball-and-socket joints are free to rotate about their three axes, and when the screw is tightened, the joint motion is restricted by friction between the two plates.

Figure 10. SmallRig camera mount for Prototype v0.

This prototype is lightweight, compact, and modular, and each module has two ball-and-socket joints with two degrees of freedom each. When the camera mounts are connected in series, the full arm has a wide range of motion for adequate support in numerous configurations and the flexibility to conform to the user's arm. Figure 11 shows the chain in flexible and rigid configurations.

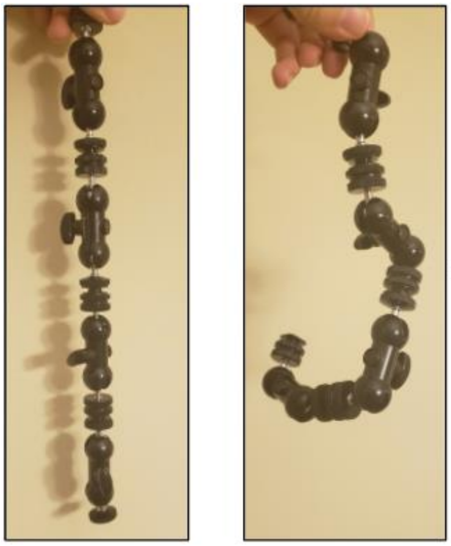

Figure 11. Prototype v0 in flexible (left) and rigid (right) states.

While these qualities are essential for the final design, this prototype’s weakness is the locking mechanism. Given the desired applications, friction locking is too weak and does not sufficiently support the expected loads from the user. When the segment is fully rigid, an applied force of less than 3 lbs. perpendicular to the end effector will result in a change in configuration. An ideal design must optimize size and weight without sacrificing strength and stability. The camera mounts also require the manual loosening and tightening of a set screw, and with each arm consisting of several mounts, toggling between flexible and rigid states would be cumbersome for the user and result in imprecision associated with undesired motion during locking.

Prototype v1

The second design, Prototype v1, implemented a mechanical locking mechanism and explored pivot joints and connecting rods. The joint module is a male-to-female PVC lockable joint from Adjust-A-Joints, and each module is connected via a ¾” Schedule 40 PVC pipe.

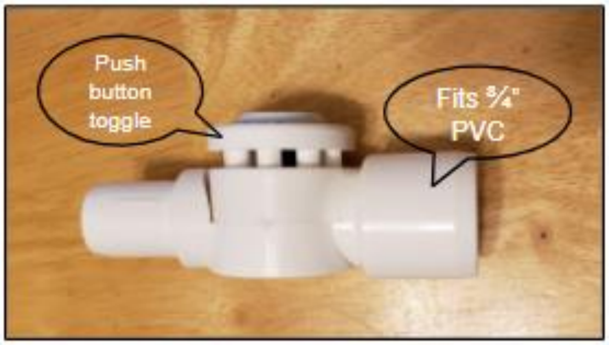

Figure 12. Adjust-A-Joint lockable joint module for Prototype v1.

The adjustable joint has a 180° pivot range with 22.5° increments and is actuated by a push button. The joint's default state, or on-state, is rigid, and when the button is pressed, the joint is toggled to off-state and becomes flexible, or free to rotate. The unique internal locking mechanism, modeled in Figure 13, returns the joint to its default state when the button is released, thus locking the joint. The joint can be locked into 9 different configurations, and two are shown in Figure 14.

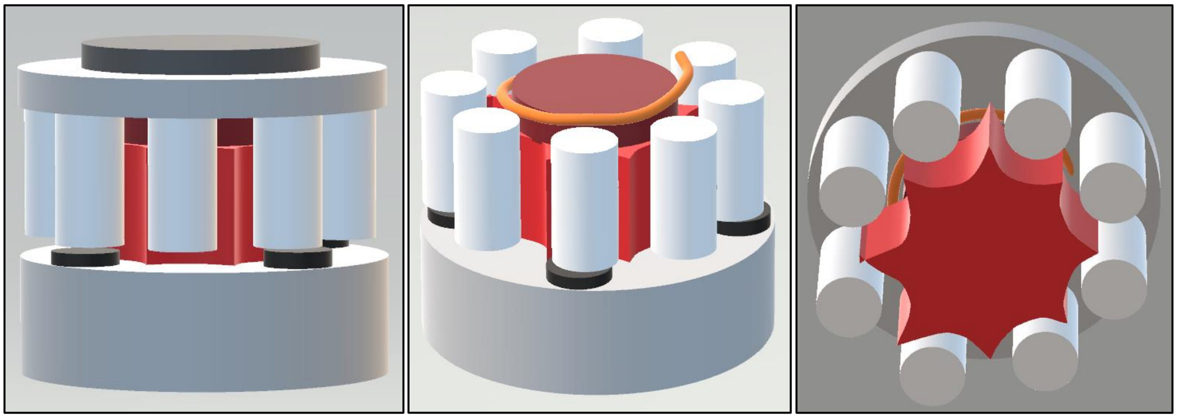

Figure 13. 3D model of Prototype v1's internal locking mechanism.
Front view (left), top cross-section (middle), and bottom cross-section (right)

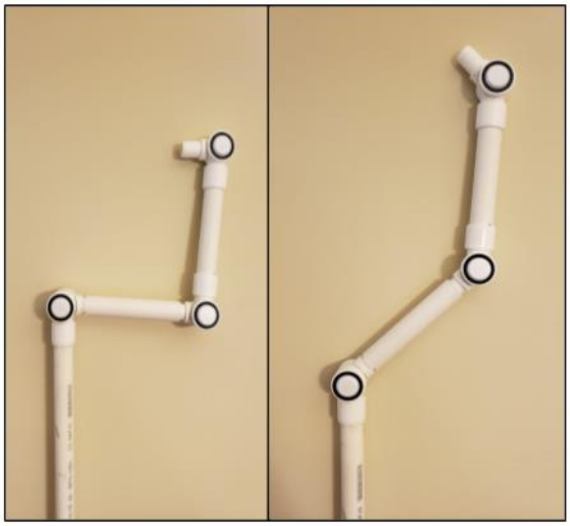

Figure 14. Prototype v1 in rigid 90° (max) configuration (left) and 45° configuration (right).

This prototype is bulkier than its predecessor, but the mechanical locking mechanism and PVC material provide greater support and stability in the rigid state. From preliminary testing, the adjustable locking joint can support approximately $18\ Nm$ of torque with $\sim 5°$ deflection. While the locking mechanism can support increased loads, the PVC material and the large pivot increments in the joint result in deflection due to imprecision within the mechanism. The ideal locking mechanism will minimize pivot increments and have smaller tolerances between the locking components. Prototype v1 introduced a toggle mechanism with a default rigid state that switched to a flexible state when pressed and held down. The optimal toggle mechanism should be a form of binary switch, rather than a momentary button. Since the user will only engage the exoskeleton when performing a task, the default state for the toggle should be denoted as the off-state, or a flexible state, and when the mechanism is engaged, the exoskeleton switches to an on-state, or rigid state.

Joint Selection

Analyzing Prototype v0, the 4-DOF ball-and-socket module is sufficient to achieve the desired range of motion and accommodate the various configurations of the user’s arm, however a 2-DOF ball-and-socket module would also satisfy the user’s range of motion and arm configurations. Therefore, if each module has two orthogonal, rotational 1-DOF joints, and the offset is minimized between the joints, then the module would be akin to a ball-and-socket joint, and the proposed module would satisfy the range of motion and configurations when implemented in series. Prototype v1 utilized one rotational 1-DOF joint to represent the flex joint, but the off-the-shelf Adjust-A-Joint part did not have PVC-compatible mechanisms that allowed the connecting pipes to rotate. With no available off-the-shelf components to meet the criteria, a custom joint module must be developed with two orthogonal, rotational 1-DOF joints in series, adjoined by connecting rods.

Locking Mechanism Concept

The proposed mechanical locking mechanism for this arm exoskeleton design is produced by the meshing of two serrated locking plates. These plastic serrated plates are off-the-shelf from JWWinco, and two different types of plates will be used for this design. The type B plate has a 6.3 mm center bore with two countersunk bores for socket cap screws. The type BC plate has the same features, except it has a guide, as distinguished in Figure 15. The full specification sheets for the plates can be found in Appendix B.

Figure 15. Serrated locking plates for locking mechanism: types B (left) and BC (right).

Each serrated plate has a 32 mm diameter and 60 teeth with a 60° wedge angle. A conical thrust spring is placed between the two plates to allow switching between locked and unlocked positions. A thrust spring was chosen over a wave spring because the minimum stiffness for off-the-shelf wave springs was too high for this application, and the spring would not be able to fully compress as desired. The proof of concept utilized the set screw from the Prototype v0 camera mount, as shown in Figure 16. A conical thrust spring was set inside the type BC serrated plate, and the type B plate was slotted into the guide. The set screw obtained from the camera mount secured the serrated plates together.

Figure 16. Prototype v2 locking mechanism proof of concept.

The module housing is designed to pre-load the spring such that the displacement between states is minimized. The tooth height of the serrated plate is 0.9 mm, so the housing pre-loads the spring to provide a clearance of 1.0 mm between the teeth. In this configuration, the top serrated plate rotates freely, and the system is in the off-state, or flexible state. When the spring is fully compressed, the serrated plates interlock, and the system is in the on-state, or rigid state.

Toggle Mechanism Selection

Prototype v0 explored a set screw to toggle friction-locking, and Prototype v1 utilized a push button to toggle mechanical locking. Both of these mechanisms are viable solutions, however the full arm exoskeleton will implement several joint modules, so the process of switching between flexible and rigid states with either of these mechanisms would be tedious and ineffective. Therefore, the optimal toggle mechanism would toggle all joint modules simultaneously with a form of parallel actuator. The proposed toggle mechanism for the exoskeleton is to implement a tensioned cable similar to the Greenberg Instrument Holder that runs through all joint modules via connecting rods.

Chapter 4: Final Design

Prototype v2 Joint Design

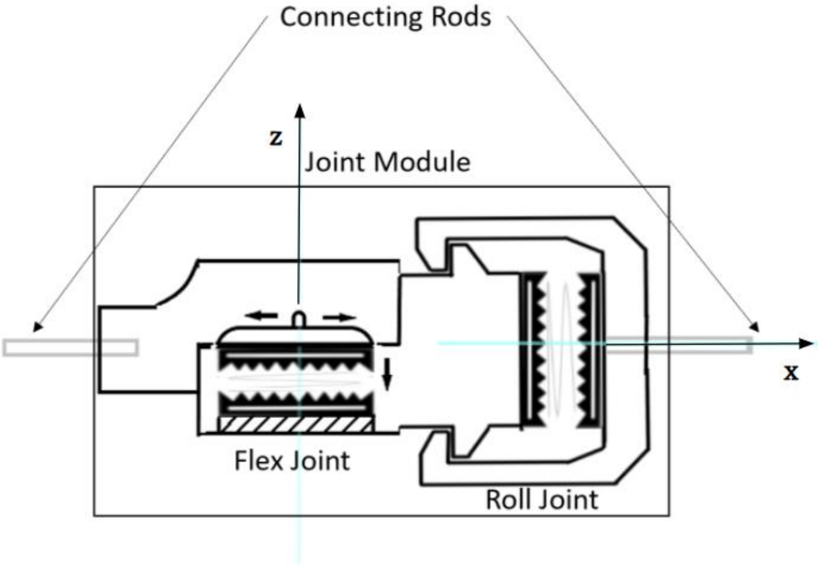

Figure 17. Prototype v2 joint design with nomenclature.

Figure 17 diagrams the proposed design for the exoskeleton's joint module. The joint module consists of two orthogonal, rotational 1-DOF joints, the flex joint and the roll joint. The flex joint represents the rotation about the z-axis and contains a locking mechanism that translates along the z-axis when toggled, akin to the Prototype v1 joint. The roll joint represents the rotation of the connecting rod about the x-axis. The housing that contains the locking mechanism for the flex joint is inspired by the Adjust-A-Joint housing. The housing has upper and lower components that rotate independent of each other when flexible. For the flex joint, the bottom serrated plate is fixed to the lower housing, and the top serrated plate is fixed to the upper housing. The roll joint features an annular snap ring that allows the locking mechanism to translate along the x-axis when toggled. The left serrated plate on the roll joint is fixed to the lower housing, and the right serrated plate is fixed to the snap ring. The opposing forces of the snap ring in the housing grooves and the thrust spring hold the ring in place. The left connecting rod is fixed to the upper housing, and the right connecting rod is fixed to the snap ring.

Prototype v2 Toggle Mechanism

The cable will run through all joint modules and connecting rods, and when the cable is shortened, the roll joint locking plates will interlock, and the top flex joint serrated plate will be pushed down into the bottom serrated plate, switching the segment to a rigid state. Figure 18 and Figure 19 show the joint module and cable positions for flexible and rigid states, respectively.

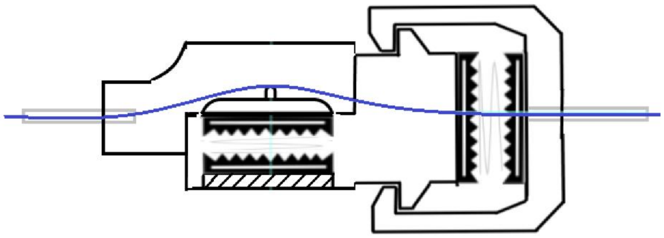

Figure 18. Joint module with cable in flexible state.

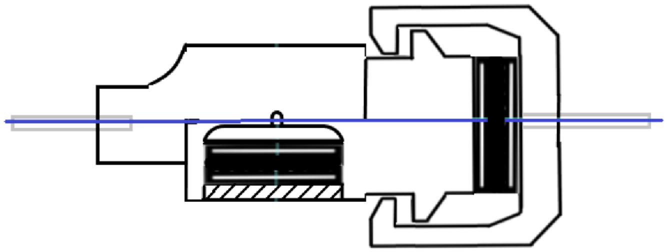

Figure 19. Joint module with cable in rigid state.

Prototype v2 CAD Model

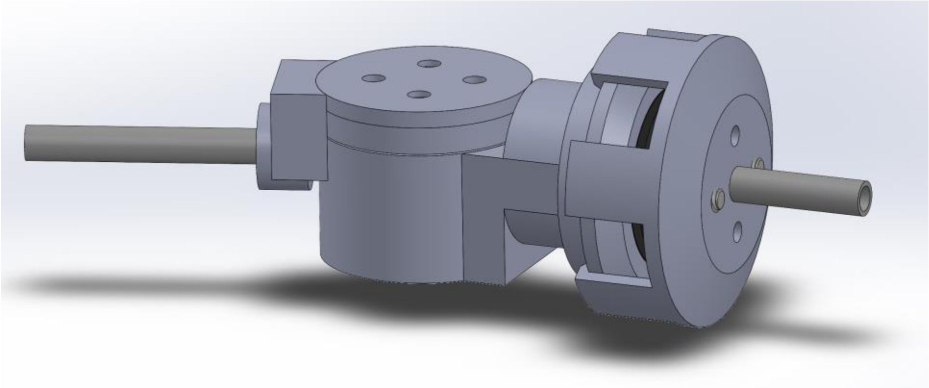

Figure 20. Prototype v2 joint module.

Figure 20 introduces the CAD model of the proposed joint module and locking mechanisms for Prototype v2. This 2-DOF exoskeleton joint has two orthogonal, rotational joints, each with a locking mechanism toggled by a single cable routed through the connecting rods. In this model, note that the cable and toggle mechanism are not present. Further development on this housing design will provide the ability for the cable to be internally routed. When the joint module is oriented straight, as shown in Figure 21, the full length, not including the 4”, ¼” OD connecting rods, is 89.5 mm. The flex joint has a height of 32 mm and a radius of 38.5 mm. The roll joint has a width of 26 mm and a radius of 52 mm.

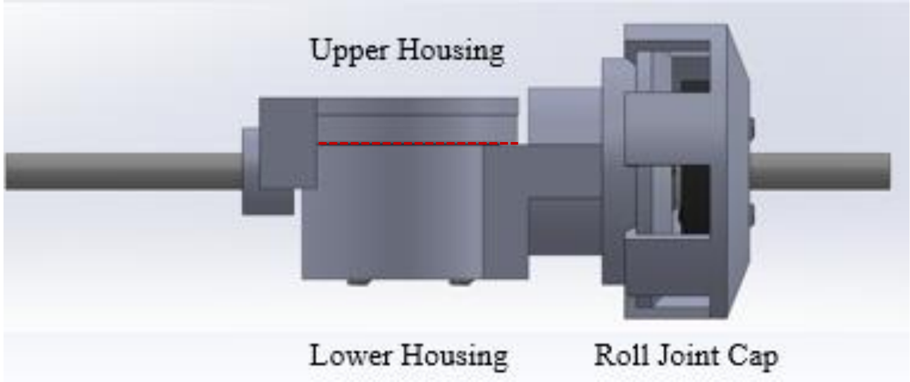

Figure 21. Side view of joint module.

The custom-designed housing is split into three parts: the upper housing, lower housing, and roll joint cap. The upper and lower housings contain the flex joint, and the right portion of the lower housing and roll joint cap make up the roll joint. The dotted red line in Figure 21 represents the interface between the upper and lower housings, which rotate independent of each other.

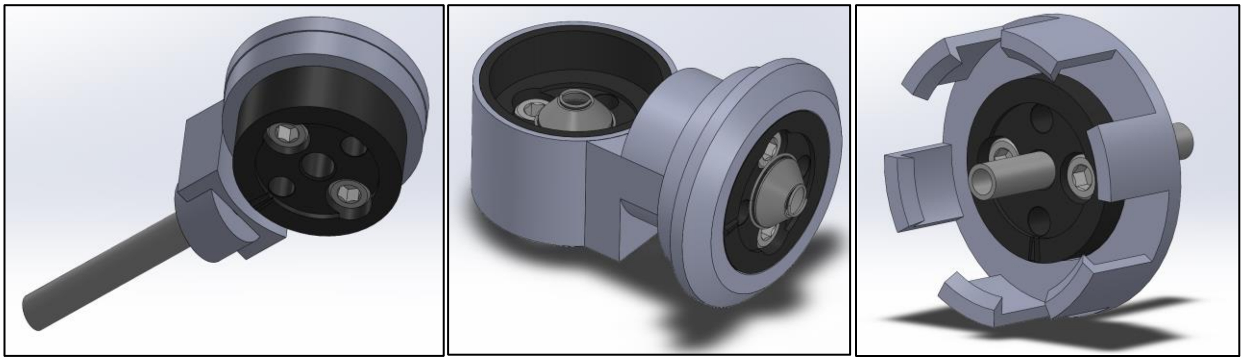

Figure 22. Upper housing, lower housing, and roll joint cap (left to right).

The left connecting rod and top flex joint serrated plate are mounted to the upper housing. As the upper component of the flex joint locking mechanism, the top serrated plate slides into the guide of the bottom serrated plate, which is mounted to the lower housing, and can rotate freely when flexible due to the separation of teeth by the conical thrust spring. When the spring is fully compressed, the teeth interlock, and the joint becomes rigid. Figure 23 illustrates the rotation of the flex joint, which has a range of ±90° at 6° increments, providing 30 different configurations for the flex joint alone. The compact lower housing connects the flex joint to the roll joint. The left serrated plate is mounted inside the housing, and the outer walls are grooved such that an annular snap joint can be fit around the housing. The roll joint cap is a six-pronged annular snap ring that fits onto the lower housing to complete the roll joint. This method allows the right serrated plate and right connecting rod, which are fixed to the roll joint cap, to rotate freely when flexible and translate along the length of the connecting rod when switching between flexible and rigid states.

The force from the thrust spring between the serrated plates is opposed by the reactionary forces of the snap ring against the grooved lower housing.

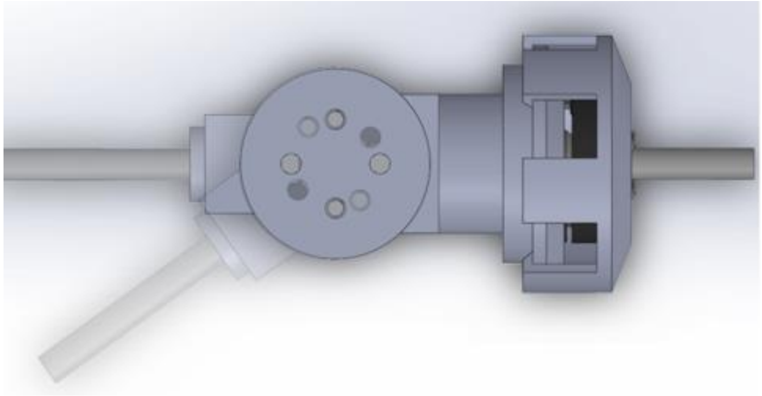

Figure 23. Rotation of flex joint.

The locking mechanisms are better illustrated in the cross-section in Figure 24. The serrated locking plates are highlighted in blue. The locking mechanisms are shown in the flexible state, where the upper housing is elevated, and the roll joint cap rotates about the grooved lower housing. When the mechanisms are toggled to rigid, the upper housing is forced downward into the bottom flex joint serrated plate, compressing the spring. The connecting rod pushes the roll joint cap into the upper housing, causing the roll joint serrated plates to mesh and lock.

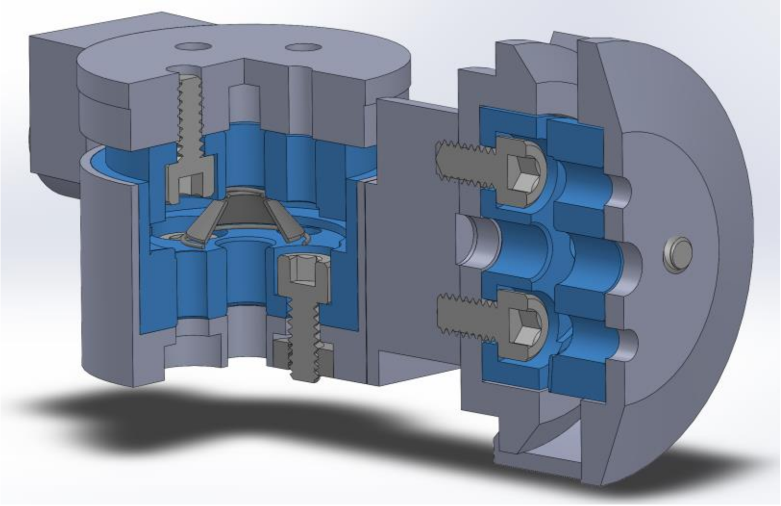

Figure 24. Section view of locking mechanisms.

Future Work

With regards to further development of Prototype v2, several recommendations are provided. From a broad perspective, available flexible-to-rigid exoskeletons can be spring-actuated, low-power, and only assist in alleviating a fraction of the applied load. This mechanical locking mechanism has the potential to provide the load assistance of more rigid systems while also providing flexibility and comfort during use. The housing materials used for the joint module should be tested and validated for strength and stability, taking into consideration size, weight, and thermal comfort. The key to success for this housing design is successful implementation of the tension-actuated cable toggle mechanism. Future iterations of the upper and lower housings should optimize the internal routing of the cable such that the pivot range of the flex joint and the downward force on the top serrated plate are both maximized. The efficacy of this routing method cannot be proven without further testing. The physical assembly of several joint modules will provide reliable testing to determine the optimal number of modules per arm and the torque tolerance in various configurations, as well as the required cable tension to toggle states.

Chapter 5: Conclusions

Back- and shoulder-related WMSDs affect a disproportionately large amount of manufacturing, maintenance, and medical workers, caused by prolonged and repetitive leaning, stooping, and kneeling tasks. The short-term ramifications of performing such tasks become costly and increasingly detrimental to the health and well-being of workers all over the world. To combat workers' continual stress and strain, and to prevent long-term WMSDs, this thesis proposed core mechanical components for a lightweight and compact flexible-to-rigid arm exoskeleton using a mechanical locking mechanism. After analysis of several upper-limb wearable exoskeletons and flexible-to-rigid devices, three iterative prototypes were developed, and the optimal joint design, locking mechanism, and toggle mechanism were determined and implemented in the final design. Prototype v2 incorporated a 2-DOF joint module with two orthogonal, rotational joints, a mechanical locking mechanism comprised of serrated locking plates and a conical thrust spring, and a tension-actuated cable mechanism to toggle between flexible and rigid states. While physical testing metrics have not been evaluated for Prototype v2, the compact joint module is a promising solution that motivates future work on this design. Once further development and testing are completed, this approach to a wearable upper-limb exoskeleton could provide increased back and shoulder support for leaning and reaching tasks in an enclosed workspace, and the locking mechanism has potential for numerous applications as an effective flexible-to-rigid joint. The concepts and designs introduced in this thesis pave the way for a new category of wearable exoskeletons that can have a profound impact on the physical health and well-being of workers across the globe.

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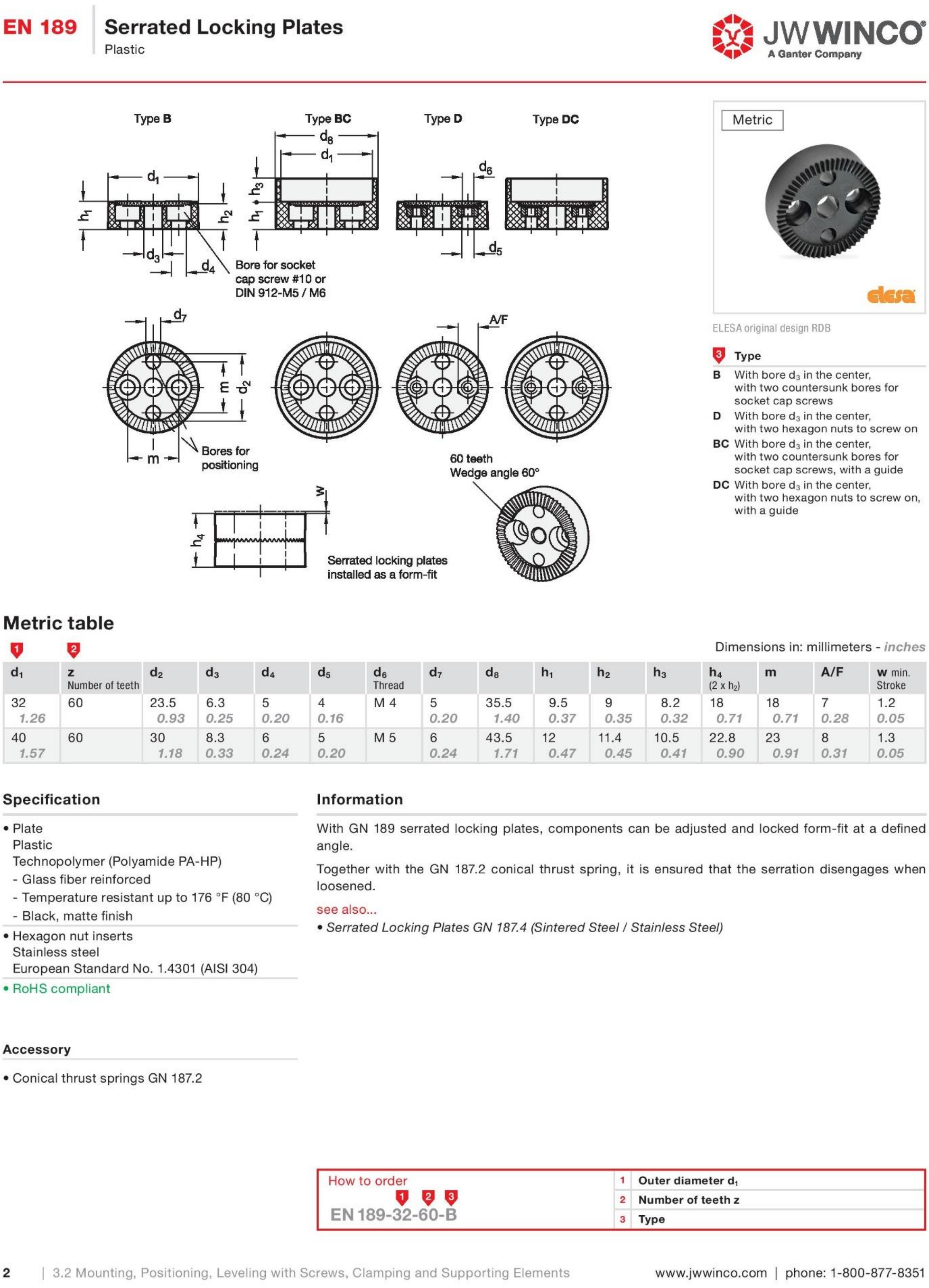
APPENDIX A: BILL OF MATERIALS

Table 1. Bill of Materials

Qty.	Item	Supplier	Part No.	Description
1	Lower Joint Module Housing	Custom	N/A	Custom housing for flex and roll joint locking mechanisms
1	Upper Joint Module Housing	Custom	N/A	Custom housing for left connecting rod and top plate of flex joint
1	Roll Joint Cap	Custom	N/A	Custom snap-ring design for roll joint locking mechanism
1	Serrated Locking Plate Type BC	JWWinco	EN 189-32-60-BC	Bottom plate for flex joint locking
3	Serrated Locking Plate Type B	JWWinco	EN 189-32-60-B	1 for top plate of flex joint, 2 for roll joint locking mechanisms
2	Conical Thrust Spring	JWWinco	GN 187.2-15	Positioned between serrated plates to return locking mechanisms to flexible
6	Socket Head Cap Screw #10-24 3/8"	McMaster	91251A240	Mount (3) serrated plates to joint module housings, 2 screws each
2	Socket Head Cap Screw #10-24 1/4"	McMaster	91251A083	Mount serrated plate to roll joint cap
2	Hex Nut #10-24	McMaster	90480A011	Secures serrated plate Type BC to lower joint module housing
2	4" Al 6061 Tubing	McMaster	9056K615	Connecting rods, one fixed to upper joint module housing, one fixed to roll joint cap

APPENDIX B: SPECIFICATION SHEETS

B1: JWWinco Serrated Locking Plates



EN 189 | **Serrated Locking Plates**
Plastic

JW WINCO
A Ganter Company

ELESA original design RDB

3 Type

B	With bore d_3 in the center, with two countersunk bores for socket cap screws
D	With bore d_3 in the center, with two hexagon nuts to screw on
BC	With bore d_3 in the center, with two countersunk bores for socket cap screws, with a guide
DC	With bore d_3 in the center, with two hexagon nuts to screw on, with a guide

Metric table

Dimensions in: millimeters - *inches*

1 d_1	2 z Number of teeth	d_2	d_3	d_4	d_5	d_6 Thread	d_7	d_8	h_1	h_2	h_3	h_4 (2 x h_2)	m	A/F	w min. Stroke
32 *1.26*	60	23.5 *0.93*	6.3 *0.25*	5 *0.20*	4 *0.16*	M 4	5 *0.20*	35.5 *1.40*	9.5 *0.37*	9 *0.35*	8.2 *0.32*	18 *0.71*	18 *0.71*	7 *0.28*	1.2 *0.05*
40 *1.57*	60	30 *1.18*	8.3 *0.33*	6 *0.24*	5 *0.20*	M 5	6 *0.24*	43.5 *1.71*	12 *0.47*	11.4 *0.45*	10.5 *0.41*	22.8 *0.90*	23 *0.91*	8 *0.31*	1.3 *0.05*

Specification

- Plate
  Plastic
  Technopolymer (Polyamide PA-HP)
  - Glass fiber reinforced
  - Temperature resistant up to 176 °F (80 °C)
  - Black, matte finish
- Hexagon nut inserts
  Stainless steel
  European Standard No. 1.4301 (AISI 304)
- RoHS compliant

Information

With GN 189 serrated locking plates, components can be adjusted and locked form-fit at a defined angle.

Together with the GN 187.2 conical thrust spring, it is ensured that the serration disengages when loosened.

see also...

- *Serrated Locking Plates GN 187.4 (Sintered Steel / Stainless Steel)*

Accessory

- Conical thrust springs GN 187.2

How to order

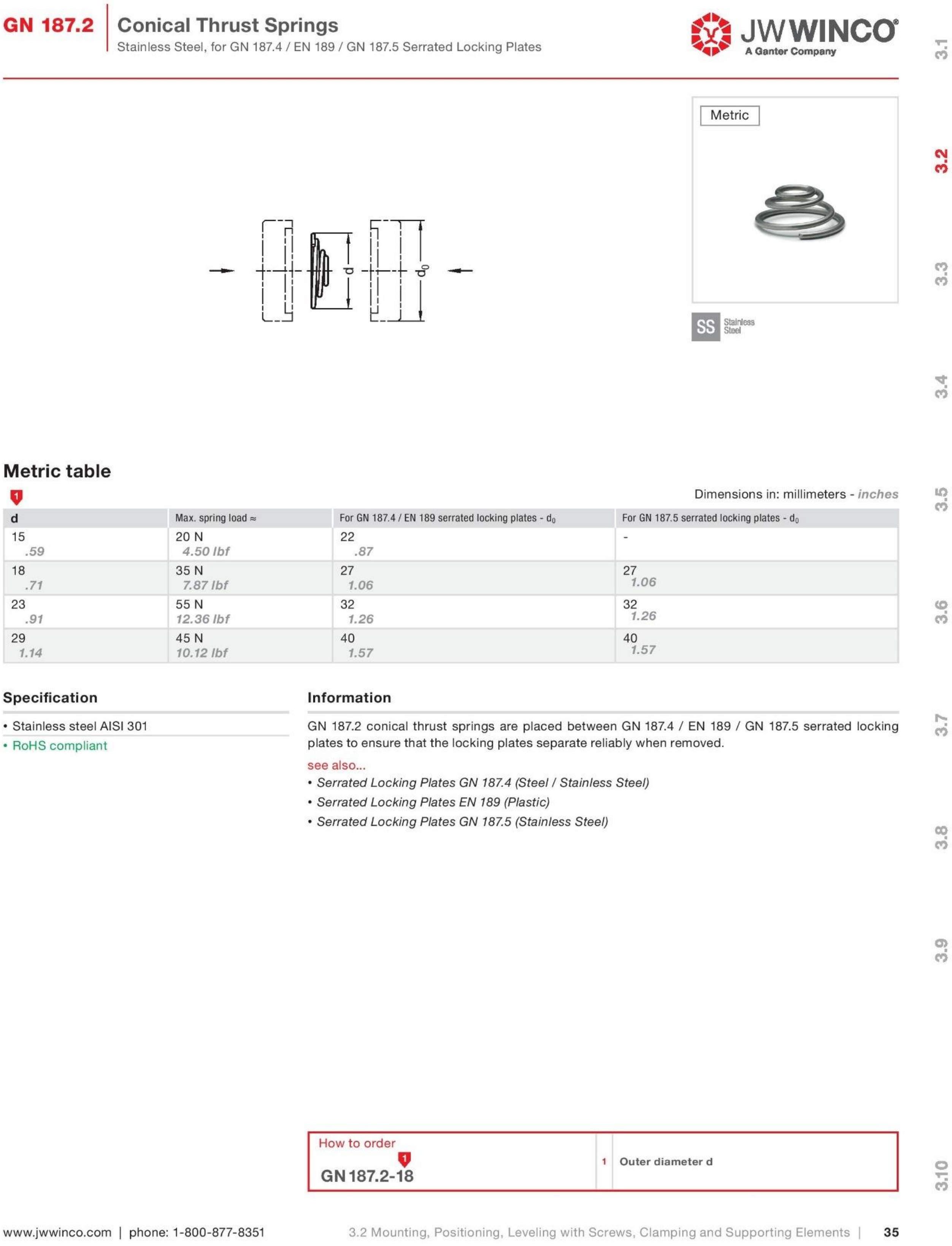
1 2 3
EN 189-32-60-B

1	**Outer diameter d_1**
2	**Number of teeth z**
3	**Type**

2 | 3.2 Mounting, Positioning, Leveling with Screws, Clamping and Supporting Elements

www.jwwinco.com | phone: 1-800-877-8351

B2: JWWinco Conical Thrust Spring



GN 187.2 | **Conical Thrust Springs**

Stainless Steel, for GN 187.4 / EN 189 / GN 187.5 Serrated Locking Plates

JWWINCO® A Ganter Company

Metric table

Dimensions in: millimeters - *inches*

d	Max. spring load ≈	For GN 187.4 / EN 189 serrated locking plates - d_0	For GN 187.5 serrated locking plates - d_0
15 *.59*	20 N *4.50 lbf*	22 *.87*	-
18 *.71*	35 N *7.87 lbf*	27 *1.06*	27 *1.06*
23 *.91*	55 N *12.36 lbf*	32 *1.26*	32 *1.26*
29 *1.14*	45 N *10.12 lbf*	40 *1.57*	40 *1.57*

Specification

- Stainless steel AISI 301
- RoHS compliant

Information

GN 187.2 conical thrust springs are placed between GN 187.4 / EN 189 / GN 187.5 serrated locking plates to ensure that the locking plates separate reliably when removed.

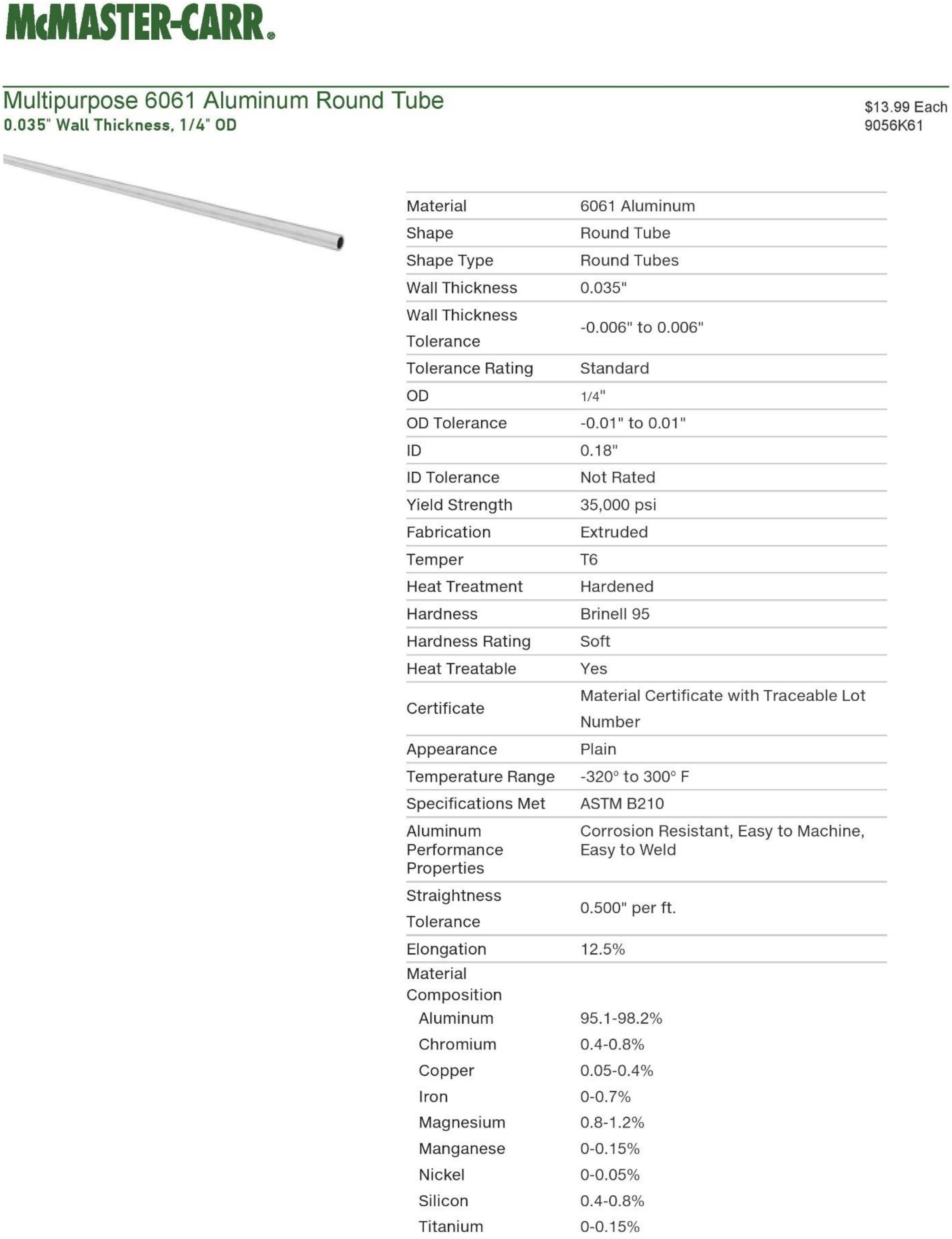
see also...

- *Serrated Locking Plates GN 187.4 (Steel / Stainless Steel)*
- *Serrated Locking Plates EN 189 (Plastic)*
- *Serrated Locking Plates GN 187.5 (Stainless Steel)*

How to order	1	Outer diameter d
GN 187.2-18		

www.jwwinco.com | phone: 1-800-877-8351 3.2 Mounting, Positioning, Leveling with Screws, Clamping and Supporting Elements | 35

B3: Aluminum Connecting Rods



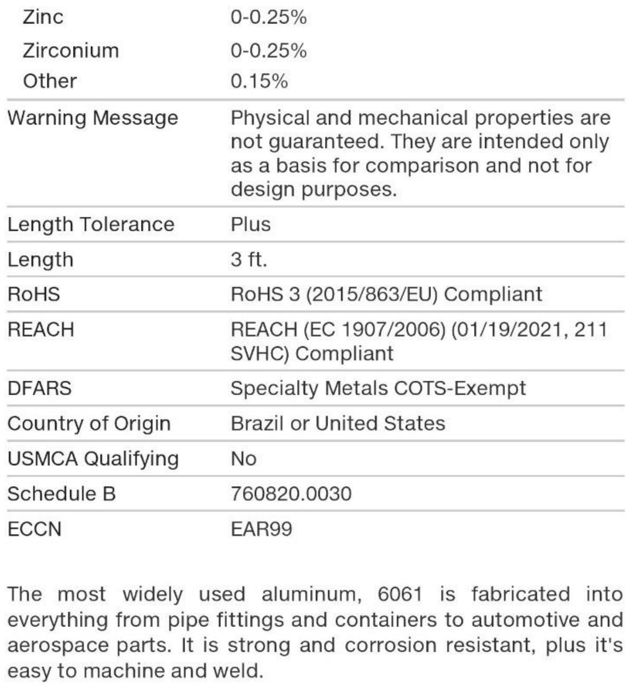
McMASTER-CARR

Multipurpose 6061 Aluminum Round Tube

0.035" Wall Thickness, 1/4" OD

$13.99 Each
9056K61

Material	6061 Aluminum
Shape	Round Tube
Shape Type	Round Tubes
Wall Thickness	0.035"
Wall Thickness Tolerance	-0.006" to 0.006"
Tolerance Rating	Standard
OD	1/4"
OD Tolerance	-0.01" to 0.01"
ID	0.18"
ID Tolerance	Not Rated
Yield Strength	35,000 psi
Fabrication	Extruded
Temper	T6
Heat Treatment	Hardened
Hardness	Brinell 95
Hardness Rating	Soft
Heat Treatable	Yes
Certificate	Material Certificate with Traceable Lot Number
Appearance	Plain
Temperature Range	-320° to 300° F
Specifications Met	ASTM B210
Aluminum Performance Properties	Corrosion Resistant, Easy to Machine, Easy to Weld
Straightness Tolerance	0.500" per ft.
Elongation	12.5%
Material Composition	
Aluminum	95.1-98.2%
Chromium	0.4-0.8%
Copper	0.05-0.4%
Iron	0-0.7%
Magnesium	0.8-1.2%
Manganese	0-0.15%
Nickel	0-0.05%
Silicon	0.4-0.8%
Titanium	0-0.15%



Zinc	0-0.25%
Zirconium	0-0.25%
Other	0.15%
Warning Message	Physical and mechanical properties are not guaranteed. They are intended only as a basis for comparison and not for design purposes.
Length Tolerance	Plus
Length	3 ft.
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (01/19/2021, 211 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	Brazil or United States
USMCA Qualifying	No
Schedule B	760820.0030
ECCN	EAR99

The most widely used aluminum, 6061 is fabricated into everything from pipe fittings and containers to automotive and aerospace parts. It is strong and corrosion resistant, plus it's easy to machine and weld.