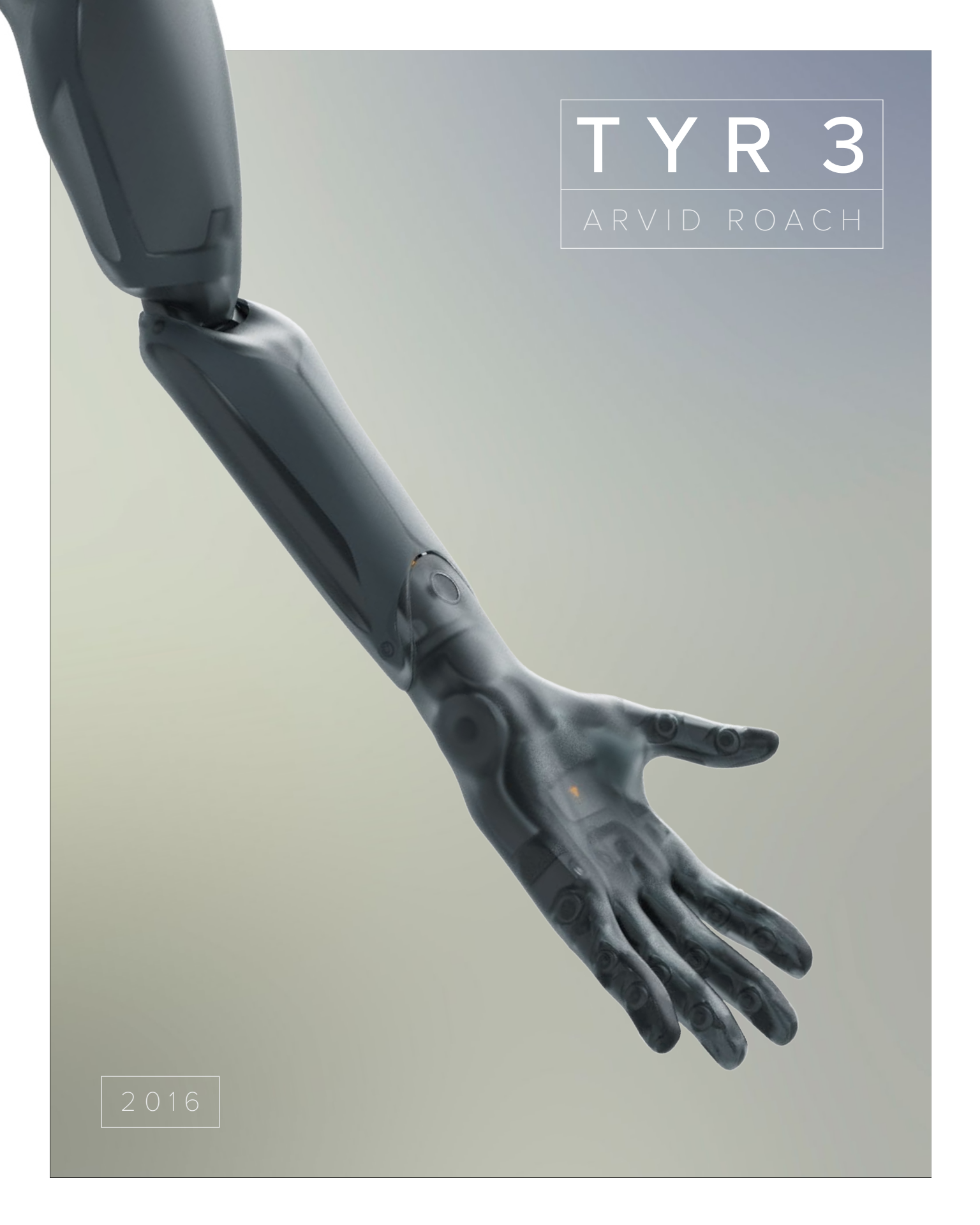

TYR 3
ARVID ROACH
2016

Týr : From Norse mythology, the one handed god of justice and glory.

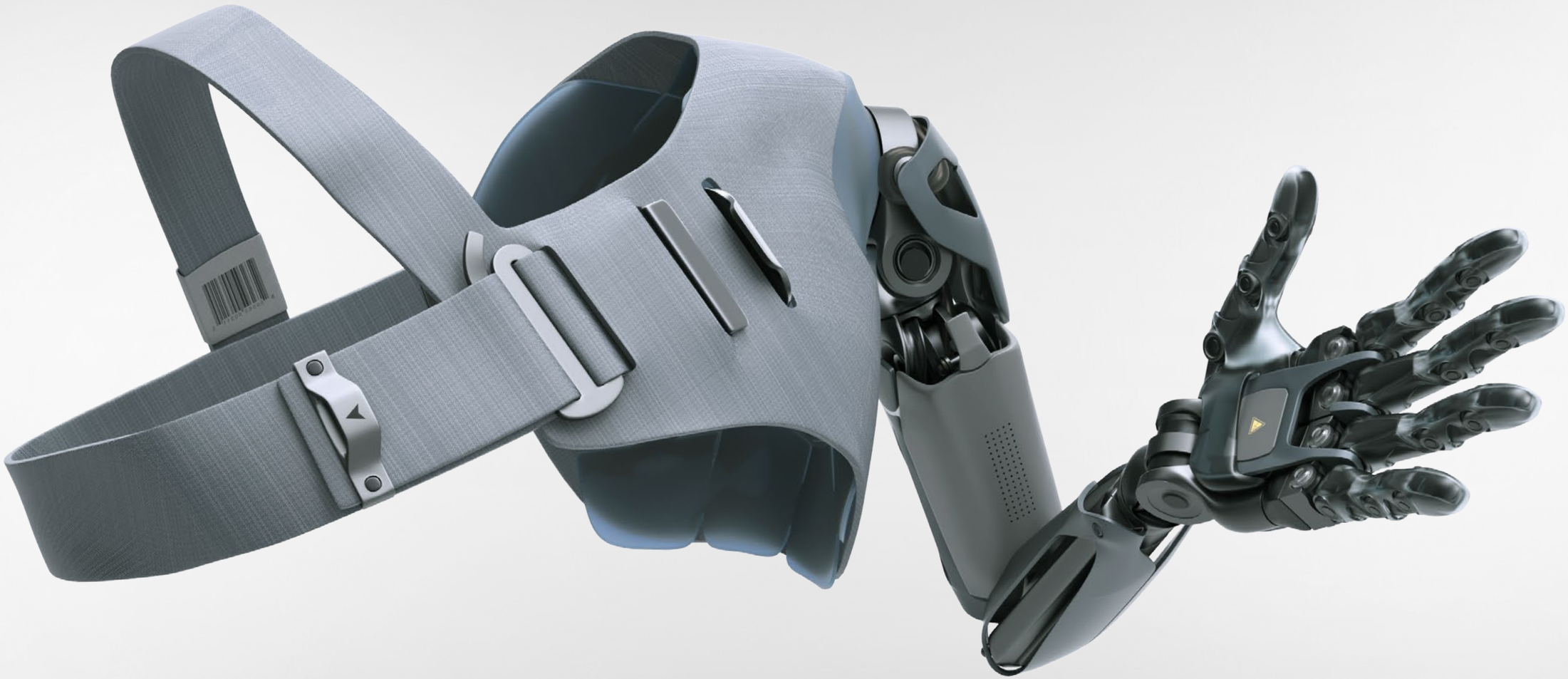
Tier : A level or layer, arranged successively above another.

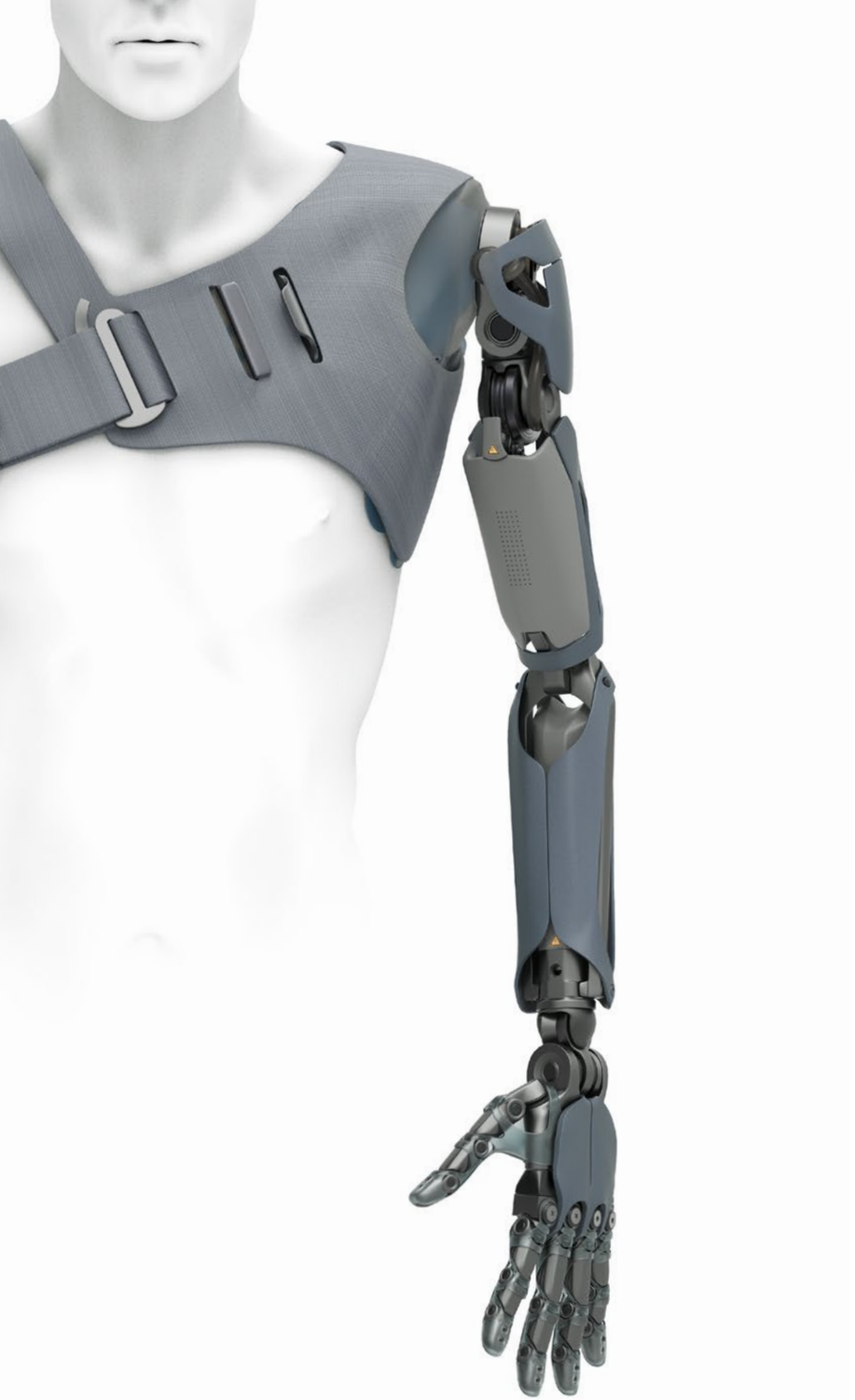
QUICK SILVER WITH SLATE HARDWARE

CONTENTS

WHAT IS TYR 3?

Tyr 3 is a modular prosthetic limb that mimics the layers of the human arm to provide superior comfort, utility, and beauty. It is a three tiered assembly of synthetic skin, muscle forms, and carbon fiber bones that can easily be customized for men, women, and humanoid robots. Tyr 3 is a dynamic platform that offers flexible solutions for the rapidly developing field of prosthetics.





JUST THE FACTS

Shoulder // Easy to detach, it offers a full range of motion. A consolidated rotator layout moves mass closer to the body, reducing the arm's perceived weight. An elastic loop restricts overextension.

Harness // Made of a performance nylon blend that is tear resistant, light weight, and breathable. It can be put on with one hand and is compatible with assistive devices.

Battery // A quick-swap unit in the biceps. One handed operation: rock in to lock in.

Elbow // Linkages connect to a rotator in the shoulder, providing a wider range of more realistic movement and a lower profile.

Snaps // Skin sections attach using snaps to the wrist and elbow.

Forearm // Stores a tool of choice that swings out for use.

Palm // Holds a small electronic sensor of choice.

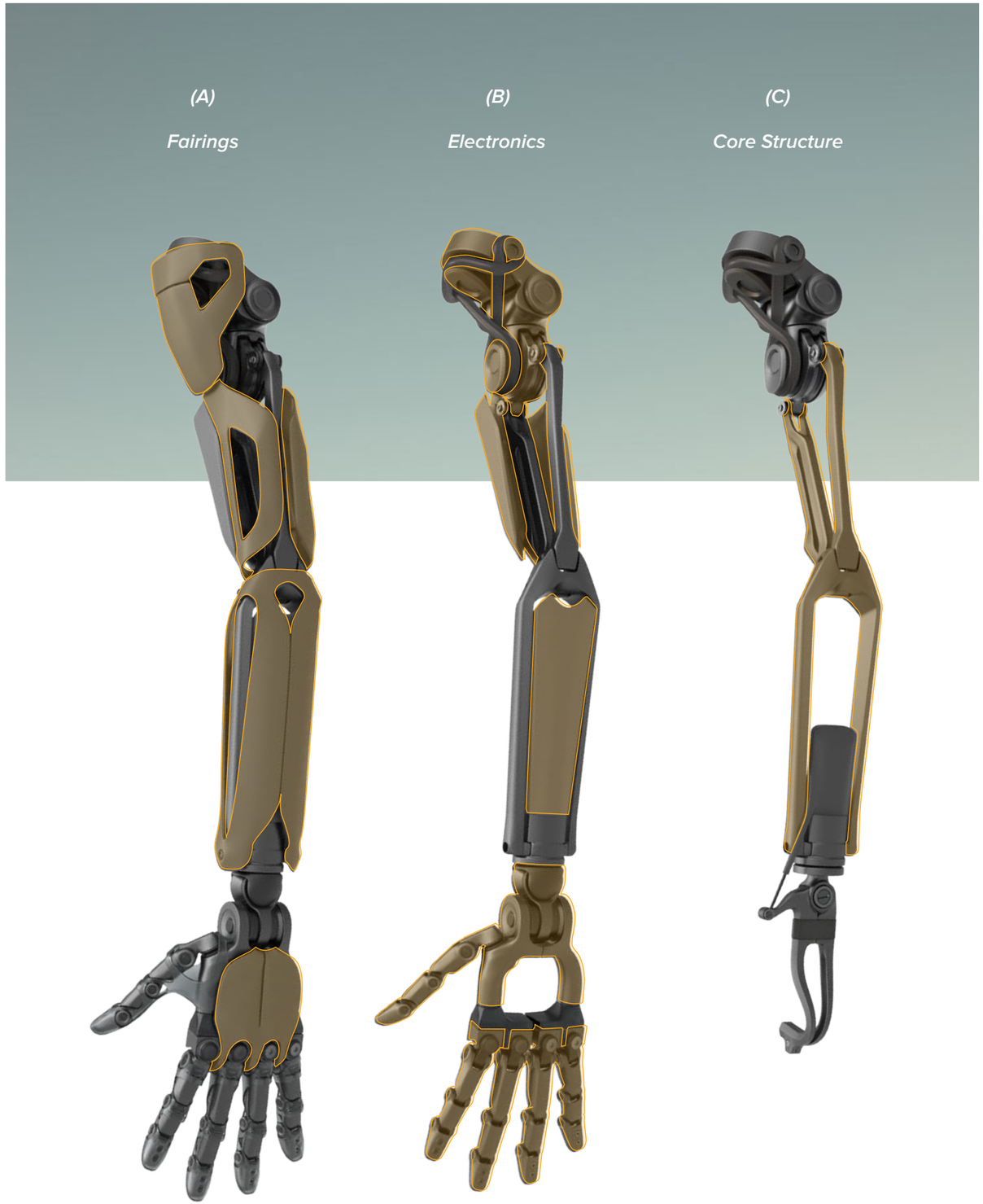
Hand // Split in the center for flexibility, it can bend sideways and inward.

Fingers // Elastic sleeves under the skin fill the joints and improve gripping.

Skin (Not Shown) // A stretchy rubberized fabric is covered in an array of woven wires and sensors that measures pressure, vibration, temperature, and position.

THREE TIERS

Tyr 3 can be configured to meet a range of price points and capabilities. The arm can be a simple body powered prosthetic with a split hook or a highly advanced bionic arm outfitted with tools, sensors, skin, and a fully articulated hand. Instead of offering a single expensive arm to one demographic, anyone can purchase the core structure and upgrade it over time. It is a platform for companies and individuals to build new and exciting solutions based on their personal needs.



(Right) Tyr 3, fully outfitted: A sophisticated electromechanical system with a tough synthetic skin, shock-proof electronics, and integrated tool set.

(A) Four soft rubber inserts give Tyr 3 the familiar shape and feel of a human arm. They can be replaced to match any body size.

(B) The array of tools, sensors, and batteries are at the heart of Tyr 3's versatility. It is a computing platform and a power tool in one.

(C) A core of carbon fiber bones with internal cable routing give the arm structure. A LEMNOS wireless hook is shown, but the system is compatible with standard split hooks using back mounted cables.

FEATURES

As with any creative device, the power of Tyr 3 comes from its versatility. In addition to the integrated tools and sensors, the entire surface of the arm (the skin) is a touch sensitive screen. Always powered and always with you, this is the ultimate mobile device.

Tools and sensors

Tyr 3 was engineered from the ground up to accommodate tools in the forearm and a small sensor in the palm. The tools swing out electronically or manually from the elbow if the arm is unpowered.

Tough electronics

The Achilles heel of electronics is water. Tyr 3 is designed to be water resistant (IP67). Electronics are fully sealed and the skeletal design and segmented skin drain water quickly.

Integrated screen

The skin's embedded electronics double as an enormous flexible touch sensitive screen. Users can connect it to their smart device and customize the information they wish to display.

App connectivity

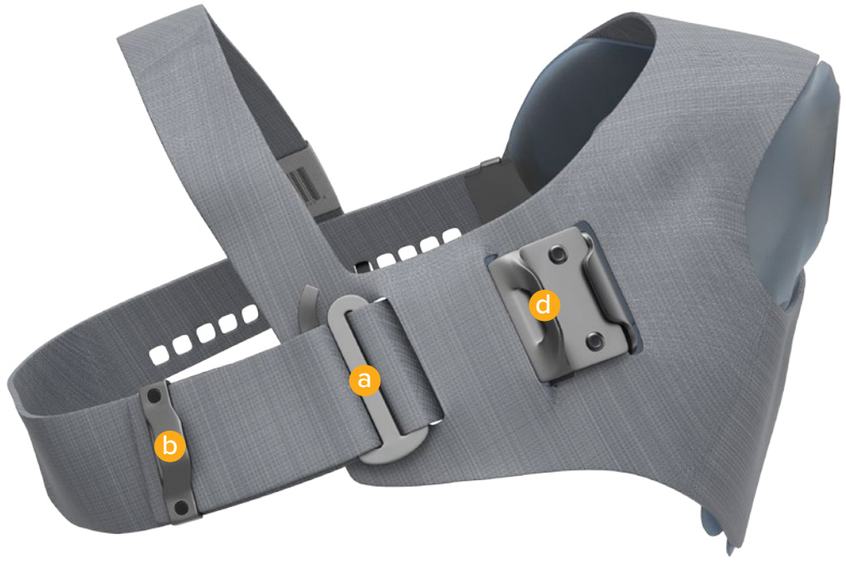
Creating a smart limb offers the opportunity to customize, monitor, and maintain the device using connected smart phones and tablets.

Warmth

Embedded wires in the synthetic skin give off a soft radiant heat, mimicking the warmth of human skin and helping to combat the psychological aspects of phantom limb pain.

Advanced control

Tyr 3 uses a socket designed for users who have undergone targeted muscle reinnervation. The system can also be configured for wireless control using arm bands.

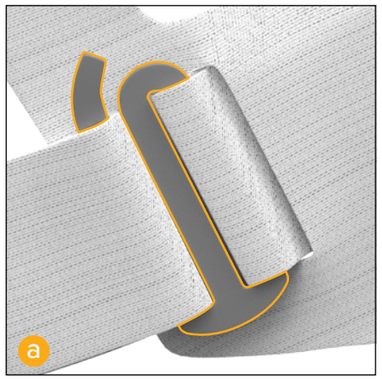


EASE OF USE

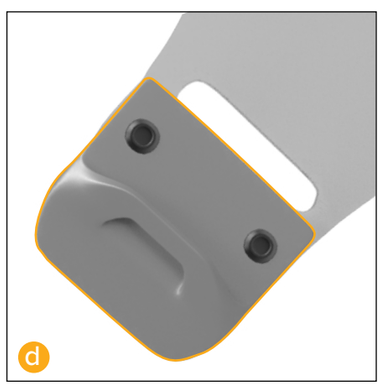
Comfort is the most important aspect of any prosthesis. No matter how advanced it may be, it's no help if it isn't worn. Tyr 3 was designed to be put on with one hand (or none using assistive devices).

Tyr 3 uses a performance nylon blend that is tear resistant, light weight, and stretchy. The breathable fabric wicks moisture from the skin to the fabric's surface for evaporation.

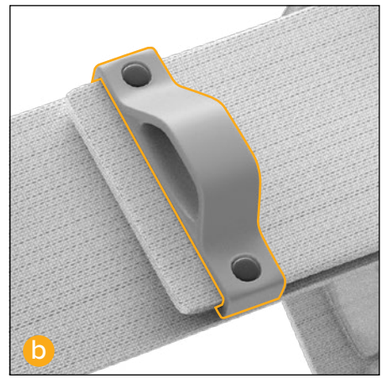
Loop the Velcro strap around the hook and pull to tighten it.



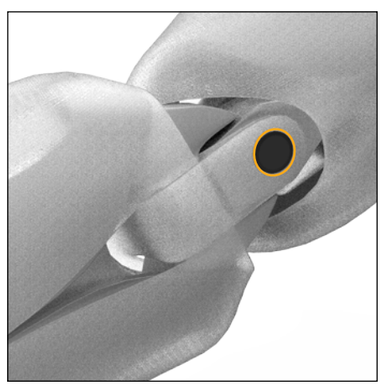
A simple tab fastens the synthetic shoulder skin to the harness.



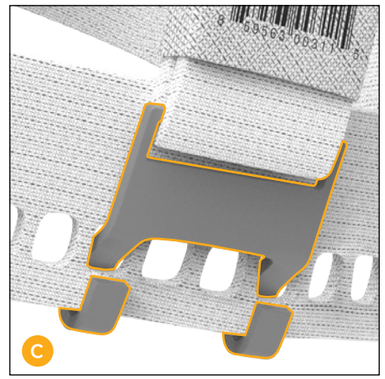
An optional assistive device can be added to help pull the strap.



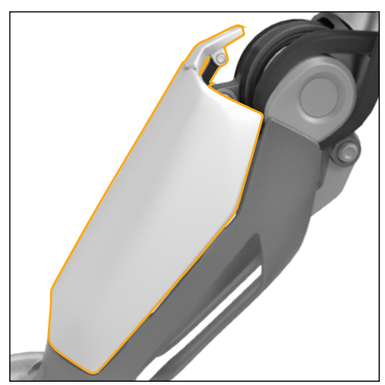
An elbow snap connects the skin to the onboard computer.



Low-profile hardware on the back makes sitting comfortable.



A quick swap battery in the biceps can be changed easily with one hand.



(Left) Mapping the socket's pressure points and sensors

THE SOCKET

Tyr 3 uses an individually molded socket that minimizes pressure points for all day comfort. It is made of connected plates that offer flexibility while moving and breathing but still maintain the stiffness and support needed to hold the arm in place.

85 sensors mapped across 18 plates measure electrical signals generated by muscle movements in the shoulder and chest. These signals are used to control the arm's movement.

The arm connects to the socket using a quick detach mechanism, allowing the amputee to put on his socket and harness without the additional weight of the limb.

NEW CAPABILITIES

The Tyr 3 hand is split down the center and along the palm, giving the hand flexibility and allowing it to bend inward (a). Around each finger is an elastic sleeve that fills the joints as they move and gives the hand a soft, natural grip (b).

The center cavity accepts a rubber insert (c) that holds the hand together as it flexes. The insert houses a sensor (d) for amputees (transhumeral and above) and a battery that powers the hand for transradial amputees.

A glove of synthetic skin (e) slides on and snaps to the wrist. The elastic finger sleeves add friction, helping to keep the skin in place.

Tyr 3's hand uses individual rotators to move the fingers instead of wires (simulating tendons). This was done primarily to free up space in the forearm that would normally house the motors that pull these wires.

While using wires does have a number of advantages, including improved strength and speed, it requires a complex system that does not lend itself to modification.

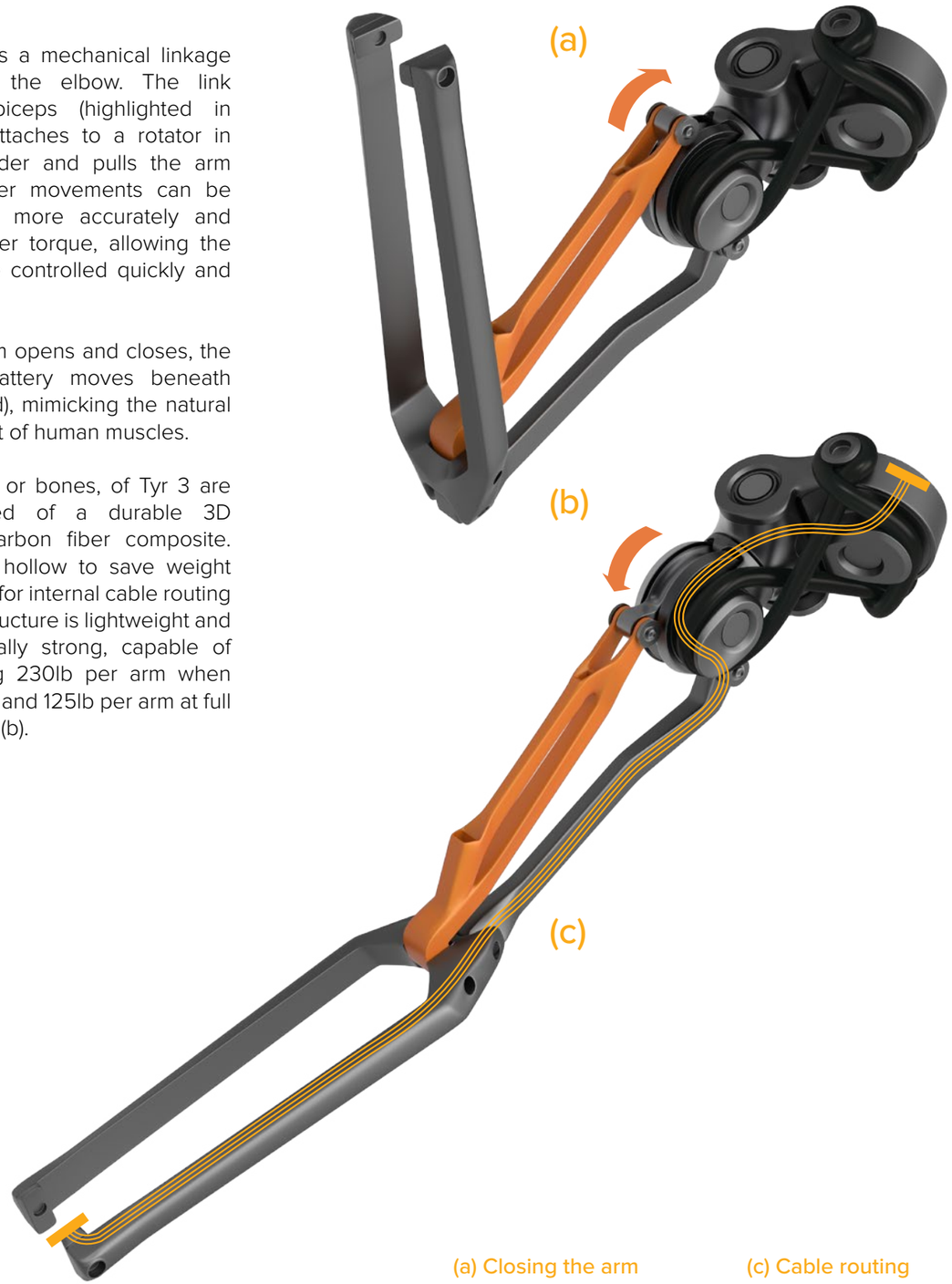
Instead, Tyr 3 uses self contained finger units that can be easily replaced. And unlike wired hands, Tyr 3 is compact enough to be worn by amputees with wrist disarticulation.

MOVEMENT

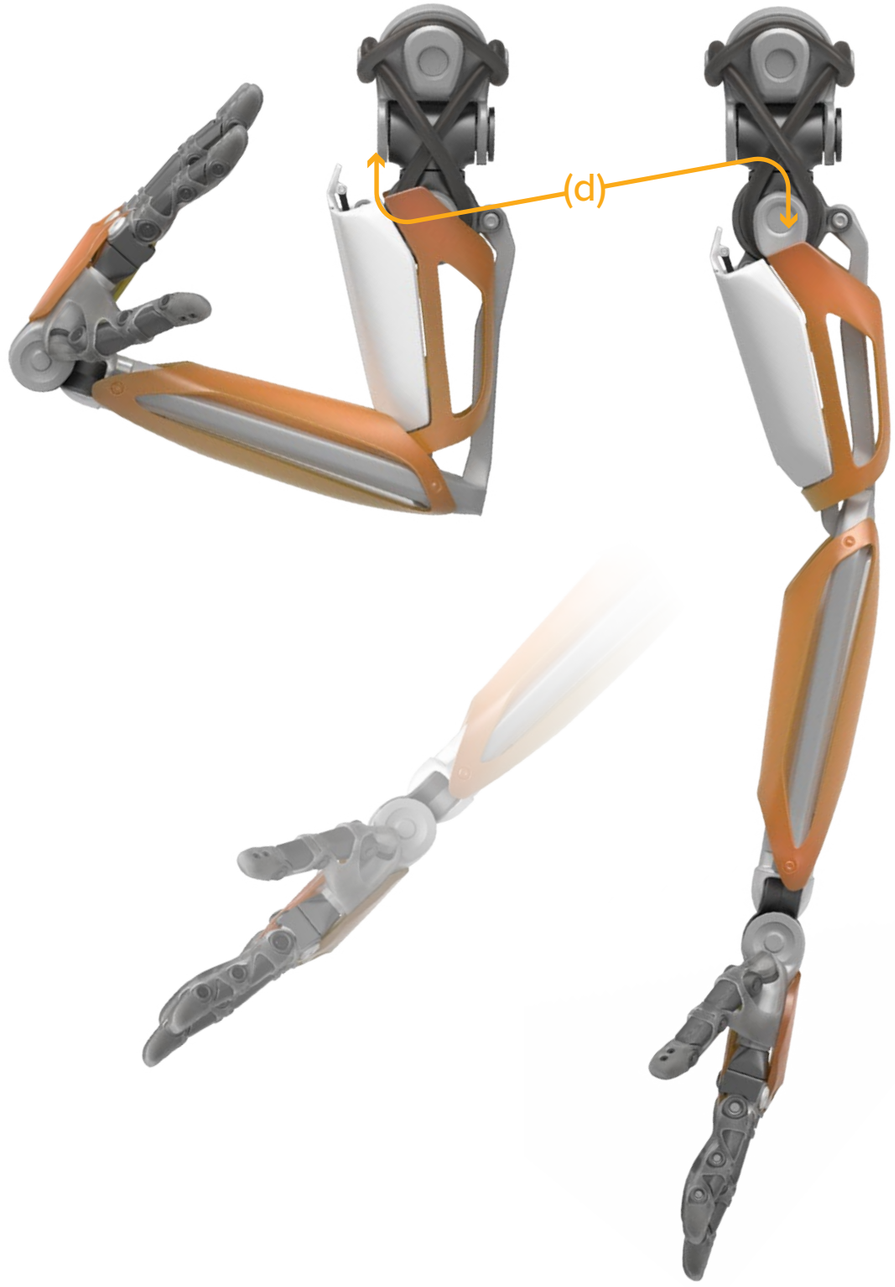
Tyr 3 uses a mechanical linkage to move the elbow. The link at the biceps (highlighted in orange) attaches to a rotator in the shoulder and pulls the arm up. Smaller movements can be controlled more accurately and offer higher torque, allowing the arm to be controlled quickly and precisely.

As the arm opens and closes, the biceps' battery moves beneath the skin (d), mimicking the natural movement of human muscles.

The links, or bones, of Tyr 3 are constructed of a durable 3D printed carbon fiber composite. They are hollow to save weight and allow for internal cable routing (c). The structure is lightweight and exceptionally strong, capable of supporting 230lb per arm when upright (a) and 125lb per arm at full extension (b).



(a) Closing the arm
(b) Opening the arm
(c) Cable routing
(d) Range of motion



By using linkages and moving most of the rotators to the shoulder (and closer to the body), the perceived weight of the arm is reduced.

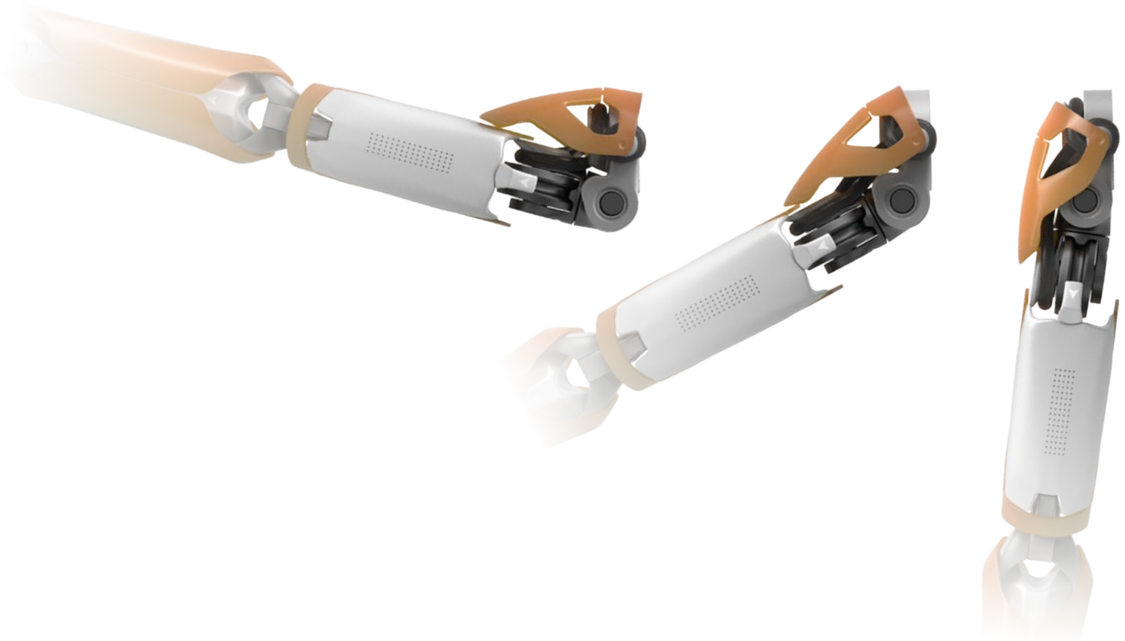
THE SHOULDER

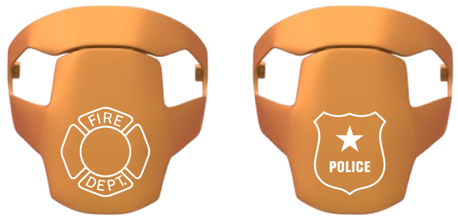
The shoulder assembly is the powerful engine that drives the arm for users with forequarter amputation and shoulder disarticulation.* It is a compact unit that offers four degrees of rotational freedom.

Consolidating the motors has a number of advantages, foremost being that it allows the size of the arm to be easily changed without needing to rearrange the motors. In practice, this means that all Tyr 3 arms use the same shoulder assembly with different links and fairings determining their size and shape.

A thick elastic loop is strategically wound around the shoulder. It serves to assist the rotators back to a neutral position and control the extent of their movement, in much the same way that human muscles stretch before reaching their limits.

This simple loop prevents the arm from coming to hard stops, reducing strain on the motors and giving the arm a smooth, realistic motion that more accurately mimics the human body.

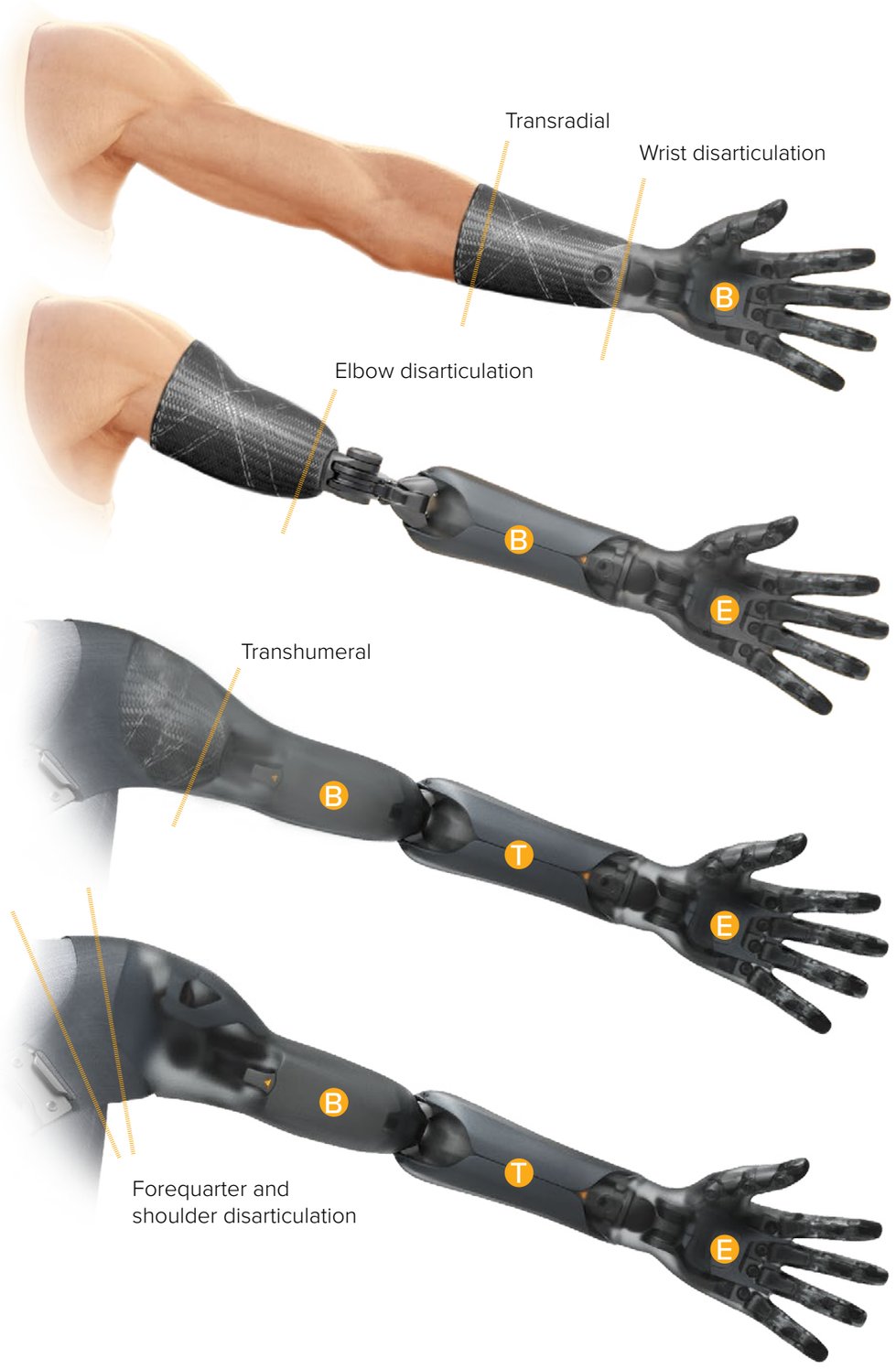




The assembly is protected by a soft rubber shoulder plate (orange) that shields it from impacts. The plate moves up and down with the arm, further adding to the natural movement. Cutouts in the sides prevent interference with the elastic loop and biceps battery at certain angles.

The shoulder plate was designed to be easily removed, allowing the user to put different badges or other identifiers on their shoulders. For autonomous robots, replaceable shoulder plates offer a cheaper and more flexible alternative for identification than paint or stickers.

*For transhumeral amputees, only the lower section (* , left) of the assembly is needed. This section is attached to a socket and allows extension and lateral rotation of the arm.



MODULARITY

As with other prosthetic arms, such as DARPA's MPL, Tyr 3 adapts to a range of amputation levels that include forequarter, shoulder and elbow disarticulation, transhumeral, transradial and wrist disarticulation. The location of the battery changes with these different levels, and additional tools and electronics are available in some configurations.

◀ The hand assembly is used for wrist disarticulation (shown left) up to transradial amputation. The socket is a braided sleeve of nylon, carbon fiber, and rubber over a cotton sock. Woven into the socket are sensors that read electrical signals from the arm's muscles and translate them into hand movements.

◀ For elbow disarticulation, the socket attaches to half of the shoulder assembly and uses shortened links to move the elbow. The battery is stored in the forearm. The hand stores a small electronic tool of the user's choice, such as a camera, light, or medical tool.

◀ Amputees transhumeral and above use a biceps battery and can store tools in the forearm and the palm. They can also wear Tyr 3's harness (without the chest socket) which allows them to wear the upper arm skin section while still retaining shoulder movement.

◀ Amputees with shoulder disarticulation and above use the complete shoulder assembly. The assembly connects to Tyr 3's segmented chest socket, which is held in place by the harness.

B *Batteries* S *Electronics* T *Tools*

LEMNOS

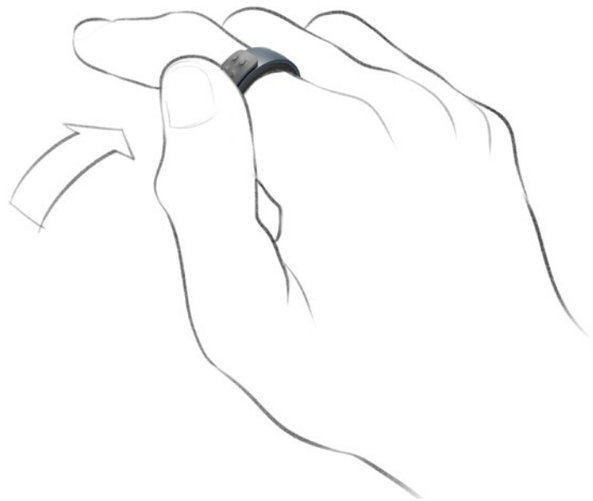
The capability and affordability of myoelectric* prostheses have been steadily improving for the last few decades, but they are still cost prohibitive for many amputees. In addition, they are too fragile for hard use and require extensive training.

Frustrated by uncomfortable and expensive myoelectric devices, many amputees turn to body powered** prostheses such as the split hook design which is reliable, affordable, and simple to use.

For single arm wrist disarticulation and transradial amputees, Tyr 3 offers LEMNOS, a versatile new split hook design that is operated remotely by a ring worn on the opposite hand. The ring offers quick and precise control using a four direction slider.

Since it doesn't rely on cables, the hook can be opened, closed, and rotated at any distance from the body, and will stay closed as it moves. The ring's position allows the hand to open and close while operating the hook, facilitating two handed tasks.

LEMNOS was created as an intermediate solution for those who cannot afford a myoelectric hand or who require something that can take a little more abuse.



The internal rubber lining prevents the ring from rotating and is replaceable for different finger sizes.

(a) Durable polymer is lightweight & strong.
(b) Interior rubber overmolding offers improved grip.
(c) A replaceable rubber band is used for cabled setups.
(d) A push rod interfaces with the standard cable mount.
(e) The wrist rotates 160 degrees before the rod stops.
(f) LEMNOS uses rechargeable high efficiency LiPo batteries.

* A myoelectric prosthesis is a type of bionic limb controlled via naturally occurring electrical signals from muscle movements in the amputees' limb.

** A body powered prosthesis is a harness with a tool, often a split hook, which can be opened and closed by pulling a cable connected to the amputee's back.

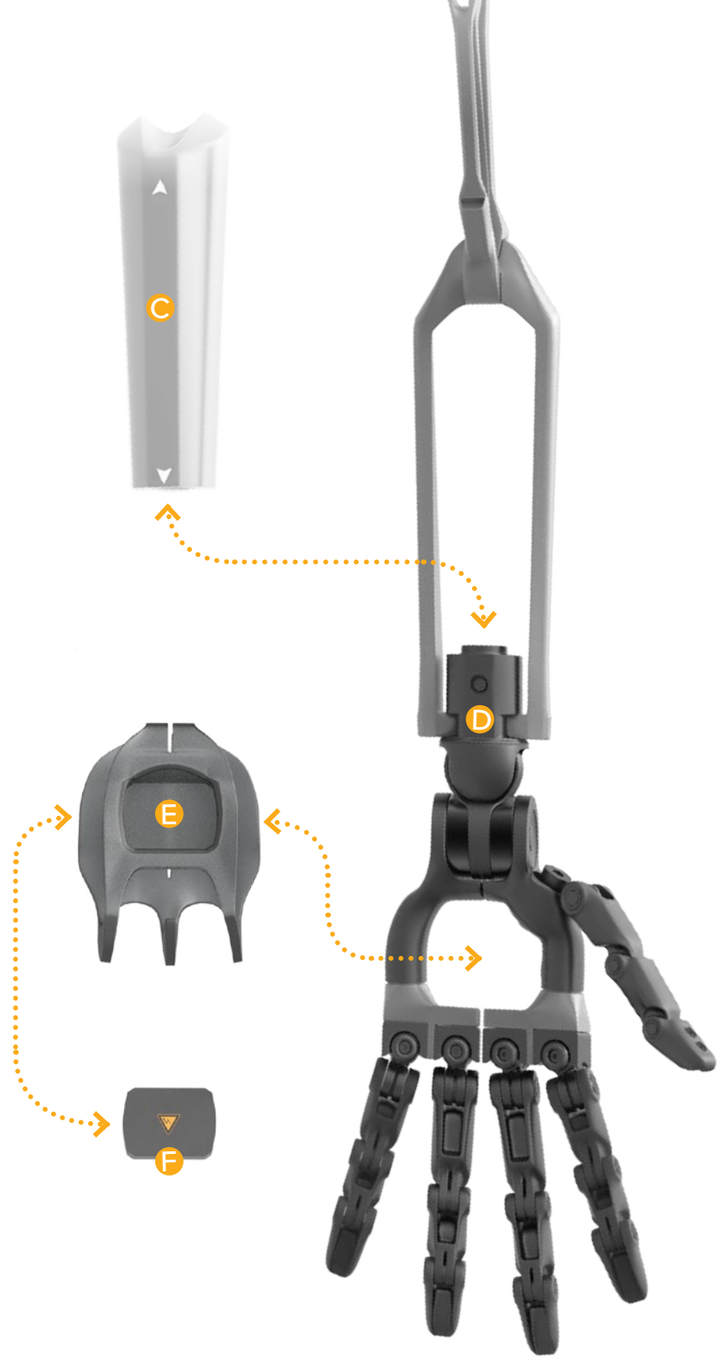
TOOL STORAGE

Tyr 3 was engineered to provide space in the forearm and palm for storing aftermarket attachments. Computers, power tools, lights, batteries, sensors, medical equipment, and much more can be stowed out of sight, protected beneath the rubber fairings and skin. The ability to interface with large tools means that Tyr 3 can be quickly outfitted for the different lifestyles and missions of amputees and humanoid robots.

For example, robots exploring hazardous environments can store lights and radios for communication, sawzalls and drills for entering buildings and collecting samples, or spray paint for marking zones and points of interest. Any number of mission critical components can be stored for immediate access in Tyr 3.

Amputees can store terabytes of information in mobile computers, charge other accessories such as phones and tablets, create wireless hotspots, or simply use it as a space for medication and other personal items. With customizable tool storage, each arm is as unique as its user.

The arm is hinged just above the wrist (A), allowing the contents of the forearm to swing backwards through the soft rubber fairings (orange) and through a split in the skin. If the arm ever runs out of power, the tool can be pulled out manually from the elbow (B) where the locking tab is.



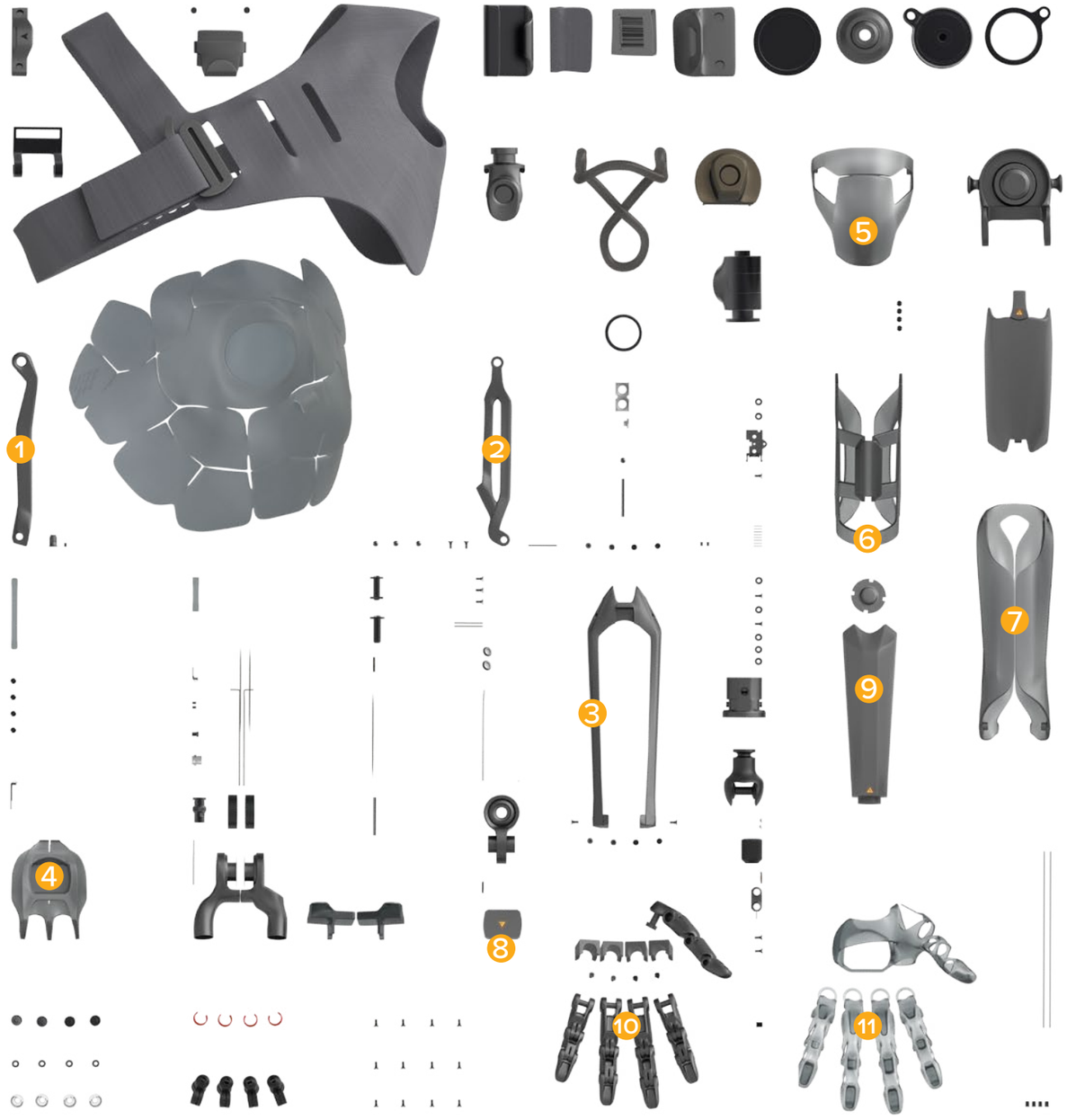
The forearm tool (C) locks into the wrist (D) which houses the arm's onboard computer. The rubber palm insert (E) houses a sensor (F). For wrist disarticulation and transradial amputees, it holds the hand's battery.

SKIN AND BONES

Tyr 3 is a modular system designed to be disassembled and upgraded over time. The arm balances simplicity and flexibility to achieve ease of use and personalization.

The physical shape of the arm is changed by swapping six key pieces. Length is determined by the bone structure (1,2,3). Shape is determined by the rubber fairings (4,5,6,7). Tools, sensors, and batteries can be easily changed without disassembly (8,9).

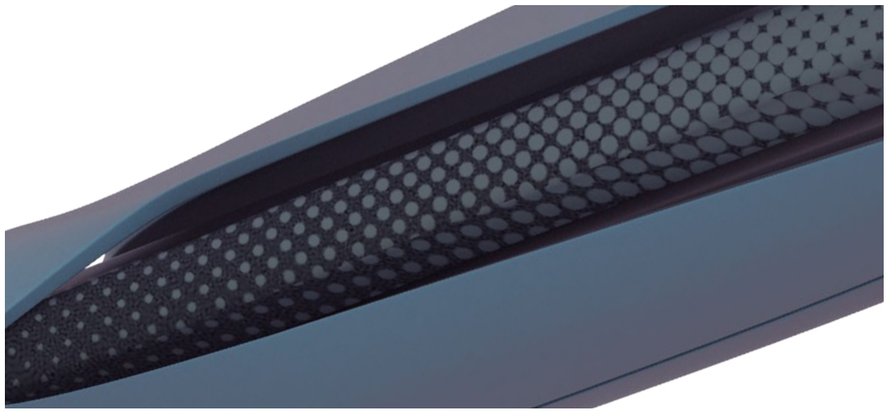
The hand comes in three standard sizes, and can be individually customized by replacing the fingers (10) with 3d printed parts. The standard elastic sleeves (11) stretch to accommodate most finger sizes. Every configuration of Tyr 3 uses the same standard motors, electronics, and fasteners regardless of the size.

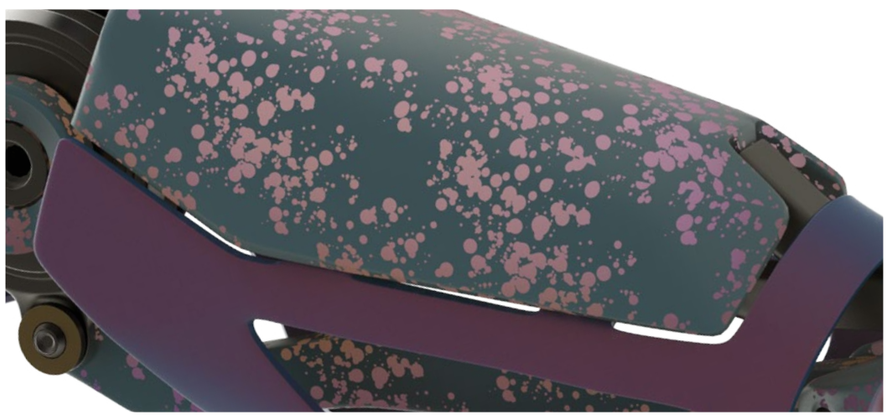


The skin is separated into three sections to accommodate different amputation levels and make fitting simpler. The separate sections facilitate drainage and can be removed and cleaned independently.

Despite being a highly sophisticated electromechanical tool, Tyr 3 is constructed of less than 300 individual parts. (Internal wires, circuit boards and other small electronic components are not shown).

STYLE





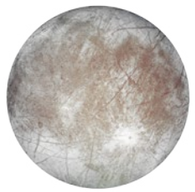
Above all, Tyr 3 was designed to be an object of beauty. It is a project driven by a single idea: that the human arm is an exquisite tool and any substitute must be dedicated to recapturing that beauty. Technology alone will not heal us. Pure engineering is apt to be rejected for its harshness. Design is the field that reaches beyond math and science to find and fulfill the *emotional needs* of human beings.

Tyr 3 is based on the premise that one of the primary emotional needs is *beauty*, defined as: a sense of harmony in which all parts of a whole exist in unity and without conflict. To create a beautiful arm, the outside must be in harmony with the inside. It must be an integrated solution where all parts exist as one.

The design of Tyr 3 was influenced by the Japanese concept of Wabi-sabi, the acceptance of imperfection, impermanence, and incompletion. Through subtlety, richness is achieved. Patterns ebb and flow and colors mingle.

Ganymede

Callisto



Europa

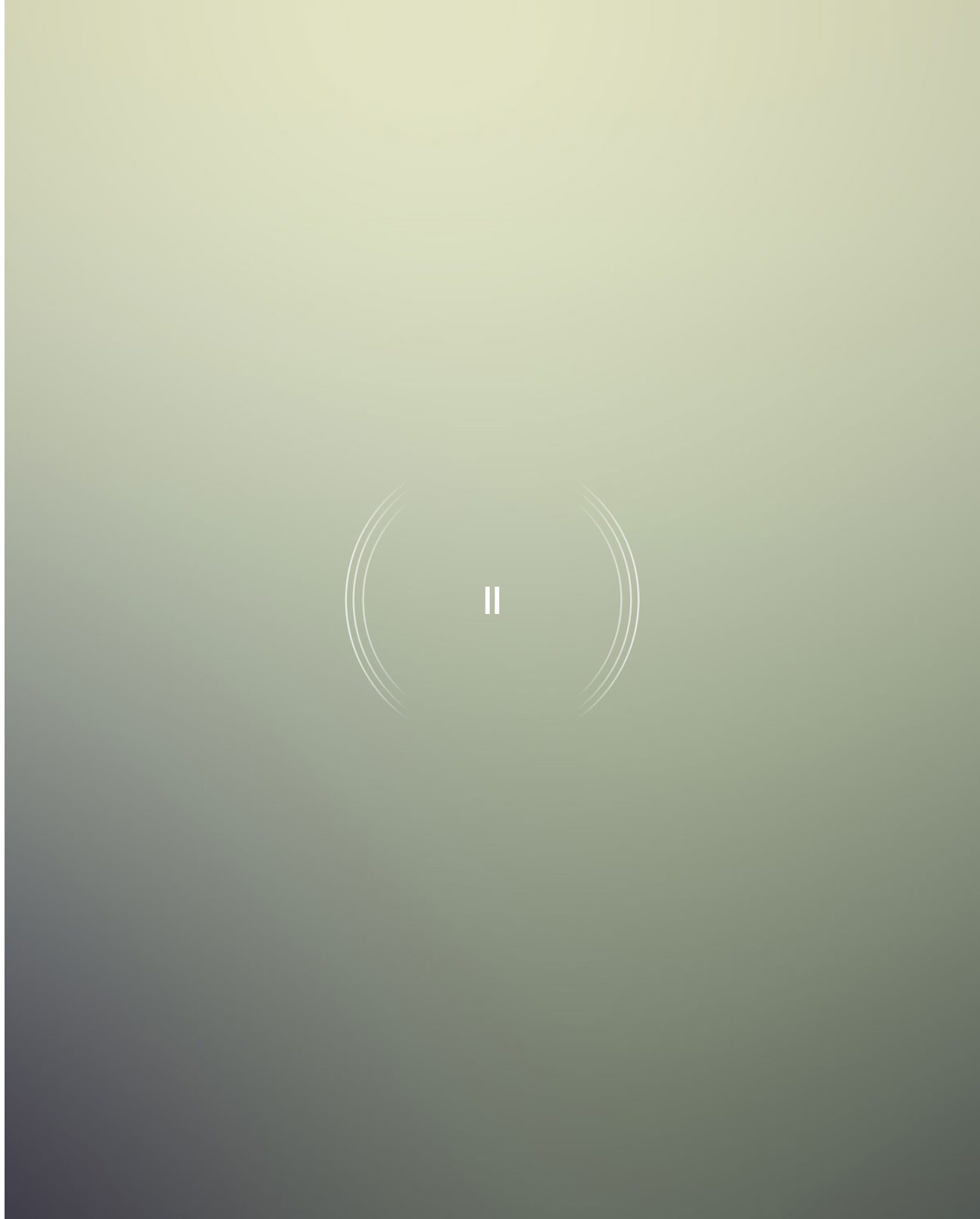
Io

The colorways of Tyr 3 were inspired by the scarred surfaces of Jupiter's satellites.

Patterns of textured rubber on the plastic surfaces grip the interior of the skin.

WHO IS IT FOR?

Tyr 3 was designed to be a comprehensive solution for today's amputees and tomorrow's robotic systems. It is a flexible platform built for customization.



EQUALITY

Today, prosthetics is a male dominated industry. Only 3% of veteran amputees are women* and while statistics from industrial accidents and diseases are a little more even (around a 70/30 male/female split), the unfortunate truth is that the majority of prosthetic devices are designed for the male body. For the female population of amputees, finding a properly sized prosthesis can be quite difficult.

With the number of women veterans growing and jobs becoming less divided by gender, it is crucial that we make prostheses that fit women as well. Tyr 3's system of replaceable rubber fairings were designed specifically with this in mind. The ability to easily change the shape of the arm makes accommodating different body sizes a much simpler process.

* Based on a 2013 study of service of members from Operation Iraqi Freedom/Operation Enduring Freedom by the U.S. Department of Veterans Affairs *http://www.rehab.research.va.gov/jour/2013/502/page173.html*

WORKWEAR

Tyr 3 was built for an active lifestyle. It is a power tool, built to resist water and impact, swap batteries quickly, and work reliably for years.

Maintenance is simple: wash the skin weekly, and swap the battery every two or three days. Working out? Tyr 3's biceps battery comes in three sizes to accommodate different activity levels. No matter what the task, Tyr 3 is ready for anything you throw at it -- or with it.

Rotating parts and ports are o-ring sealed to protect from rain and brief submersion. The harness uses antimicrobial fabrics that wick away moisture and the socket is built with segmented plates that flex with the chest as it moves.

(Above) To remove the battery, lift the tab (a) and pull forward, lifting the battery up and out of the plug (b).

(Below) Battery packs come in three sizes, each with a different shape and output level to match the user's physique. Replacement is fast and can be done with one hand: place the battery into the plug and rock it back until the locking tab clicks.

FASHION

What could be more personal? Prostheses offer a platform for creative expression, blurring the line between clothing and the human body. Rarely has design been so intimate and so apparent.

Today, men and women customize their prostheses to match their unique identities. Tyr 3 predicts a future where prostheses are fashion statements, objects of desire that enhance the user's appearance.

PROTECTION

Rescue

Fire fighting is dangerous work. There is serious risk of injury or death from burns, smoke inhalation, daily exposure to carcinogens from machinery exhaust and chemicals, extreme physical exertion, and the dangers of collapsing structures. Human piloted robots using Tyr 3 arms can help to mitigate many of the dangers of fire fighting.

Military/LEO

Clearing buildings is one of the most dangerous jobs of a military or law enforcement officer. While there are times when the risks of a quick entry into a hostile and unknown environment are necessary, there are many occasions when sending piloted robots to spearhead entry teams could save lives. Humanoid robots could also assist negotiators when a prolonged interaction with hostile or volatile parties is necessary.

Explore

Environments containing extreme temperatures and pressures, radiation, or dangerous chemicals can be more safely navigated by humanoid robots. In addition to safety, it is often more cost effective to explore with robots, especially during space missions.

(Above) Covered in a fireproof fabric and equipped to see through smoke, piloted robots can carry more equipment, go further into dangerous buildings, and stay longer while searching for victims.

(Above) A piloted robot leads a SWAT team with a ballistic shield, entering quickly, identifying threats, and providing protection from fire. The robot is outfitted with thermal imaging to identify threats and bright strobe lights to blind and disorient targets. Even a few seconds of advanced warning can save the lives of SWAT members and suspects in these dangerous environments.

ROBOTIC WARFARE

As technology advances, we rely more and more on robotic systems to enhance our productivity, and save us from human error. Today, automated trading systems manage hundreds of billions of dollars. The same technologies that create wealth today will save lives tomorrow.

War is changing. Soon, soldiers will work alongside robots that carry supplies, identify threats, and warn of potential dangers. These robotic systems will assist our warfighters by communicating more efficiently and strategizing many moves ahead of their human counterparts. But strategy is only half the battle. To operate within a human environment, opening doors, pushing buttons, and lifting equipment, robots need arms. We will use these robots to clear buildings and safely dispose of IEDs, chemical weapons, radioactive materials, and hazardous waste.

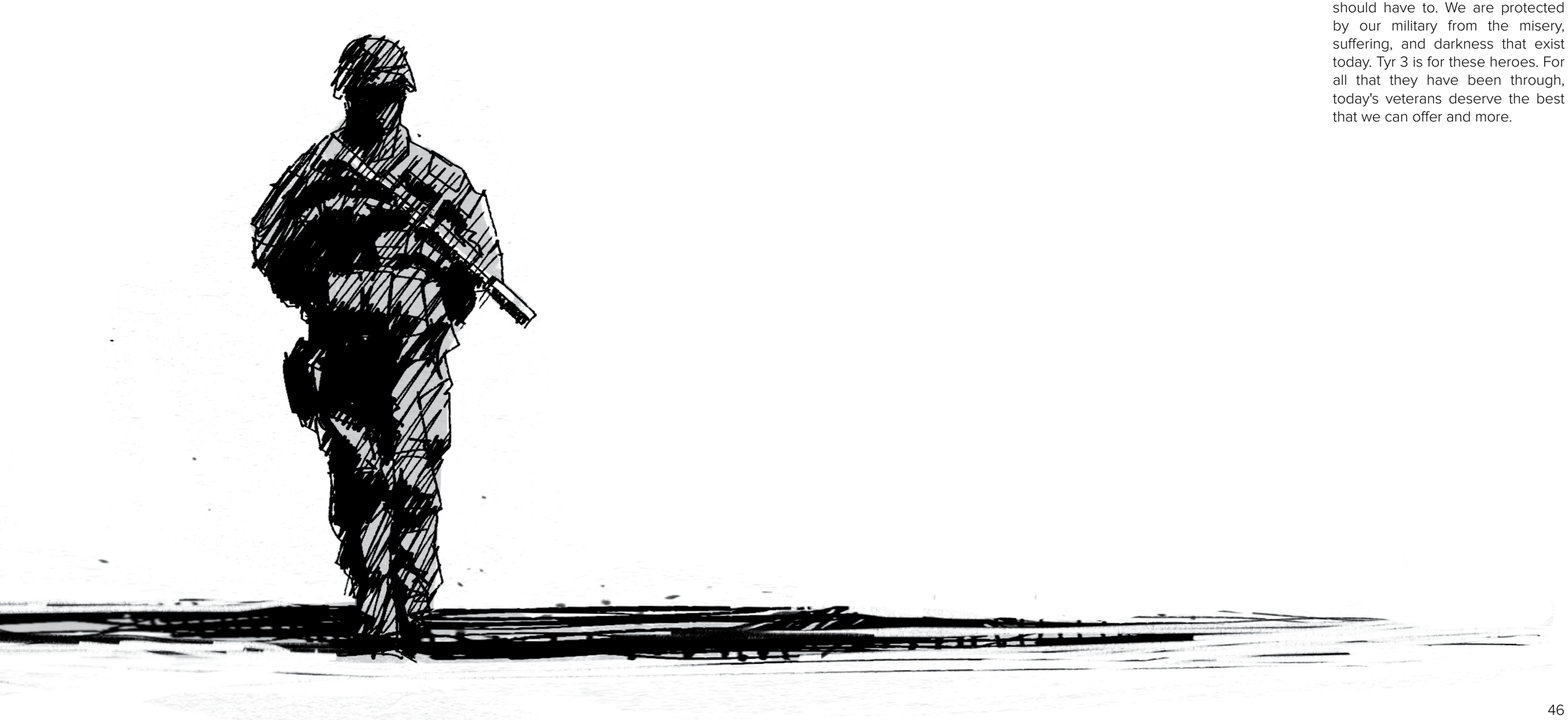
Eventually, these humanoid robots will be used to find and eliminate designated targets. In the future, soldiers will no longer have to risk their lives to achieve their goals. Today's unmanned aircraft and ships have proven successful. The next goal is the creation of remotely operated ground assets. Tyr 3 is part of this effort to replace ground soldiers with surrogates so that one day, bionic arms will be put on robots, not veterans.

A new generation of robots inspired by Boston Dynamic's BigDog will work quickly alongside soldiers, offering moving cover, advanced threat detection, and heavy weapons support. One day, the solider will be a robot too.

HONOR

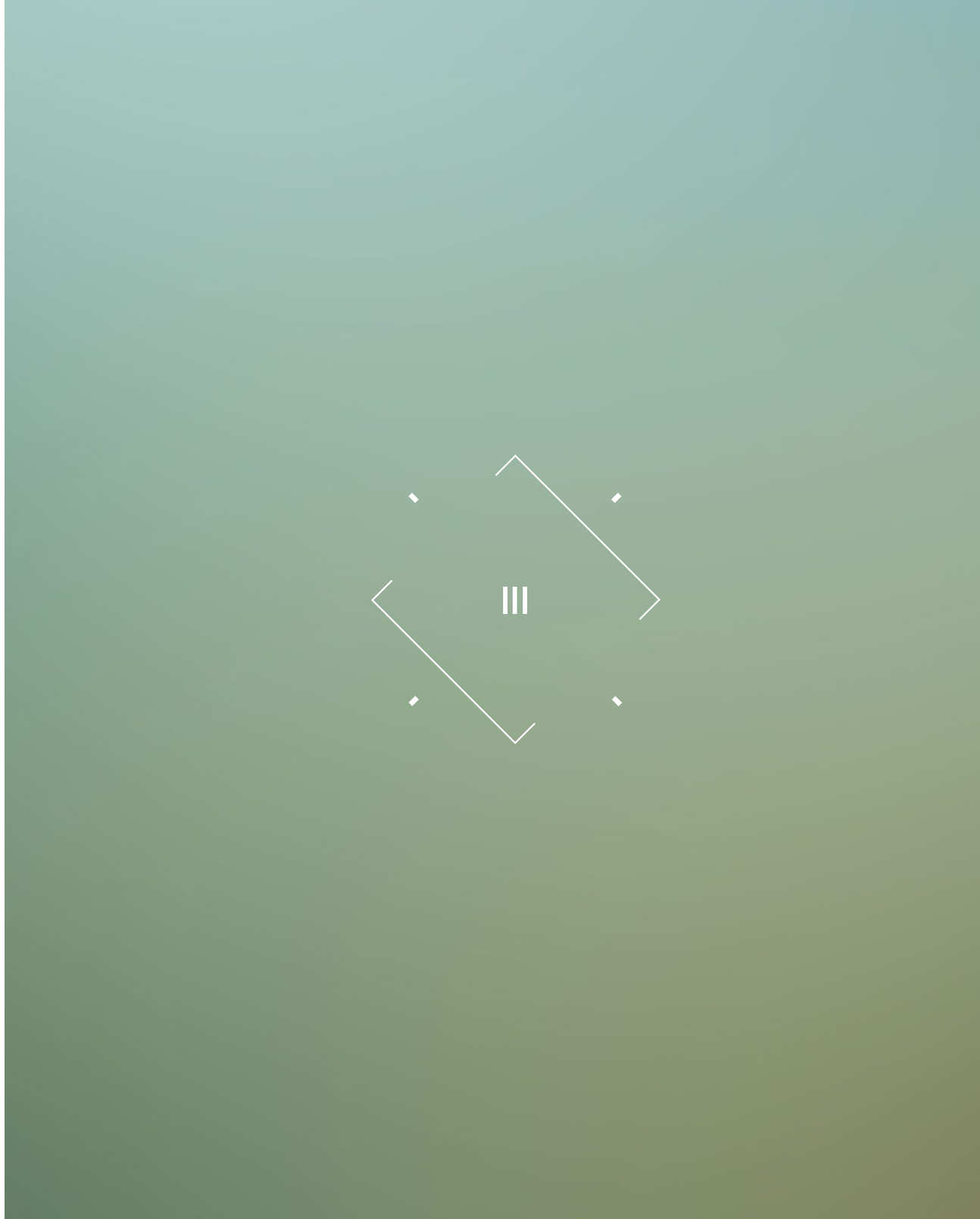
Tyr 3 was born out of a deep respect for the men and women who are returning from overseas missing limbs. They have given more than anyone could ask in protection of our rights.

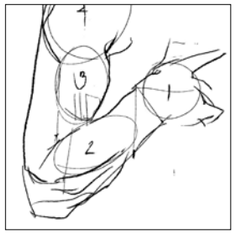
There is evil in this world, more than the innocent would care to see -- or should have to. We are protected by our military from the misery, suffering, and darkness that exist today. Tyr 3 is for these heroes. For all that they have been through, today's veterans deserve the best that we can offer and more.

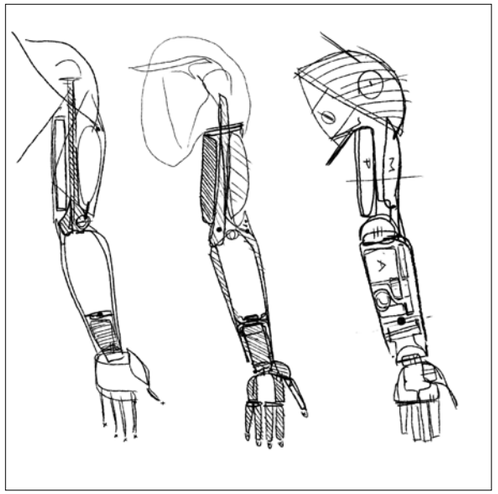


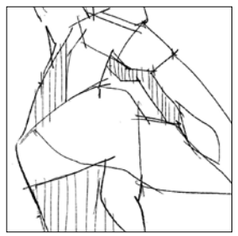
PROCESS

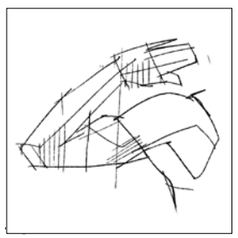
Tyr 3 was developed over the course of six months. After interviewing prosthetists and upper limb amputees, market research was done to determine the end user and product requirements. Sketches and moodboards were developed to help determine the aesthetic style. Paper and clay models were made before beginning the final computer model in Modo. Scale parts testing and further research was done. Lastly, final product renders were produced, a full scale model was 3D printed, and this book was laid out.







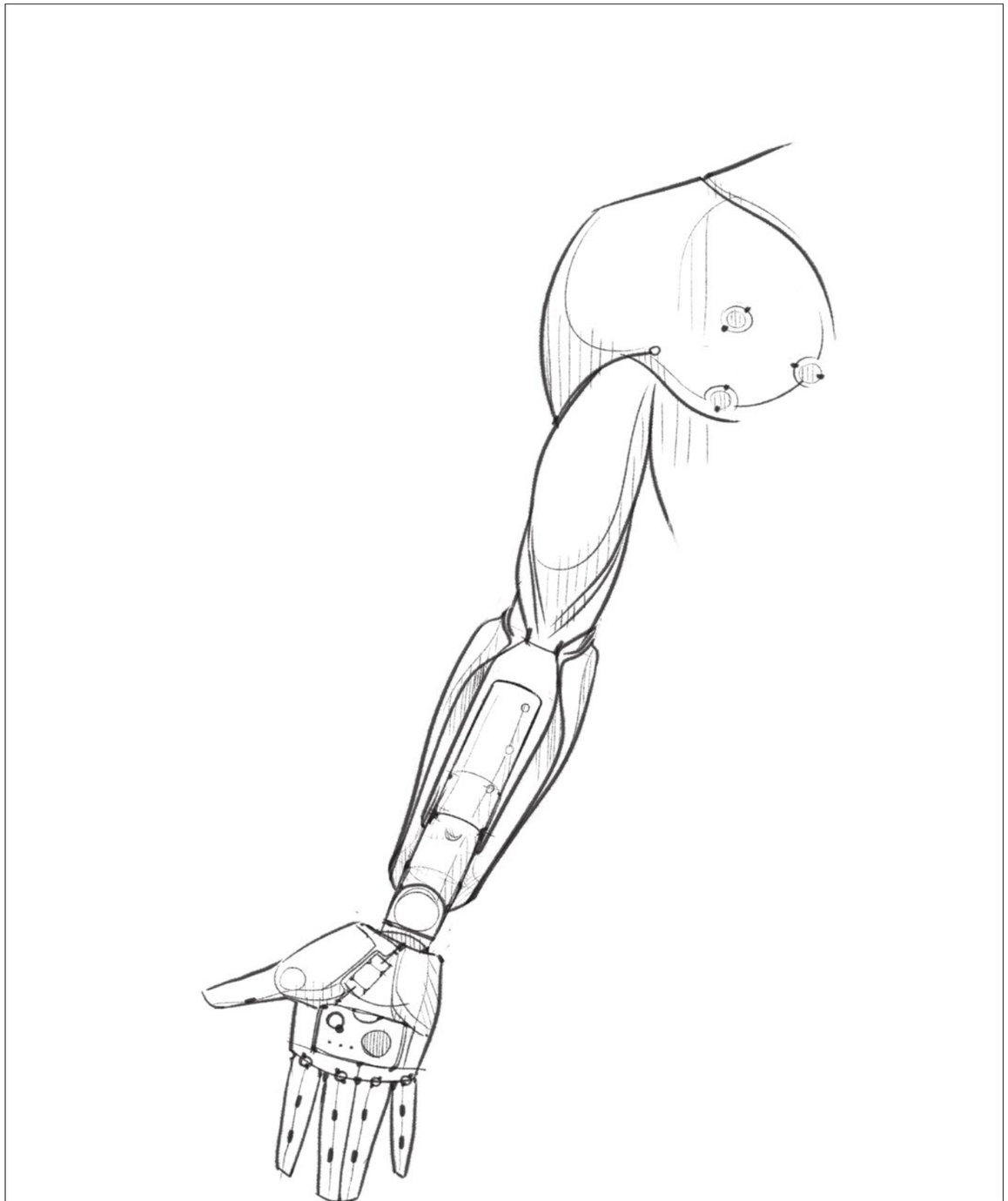




SKETCHES

Tyr 3 went through an extensive sketch development phase. Hundreds of ideas were scribbled and thrown out. It was in these early stages that the idea of a hollow forearm, a biceps battery and a modular hand were formed.

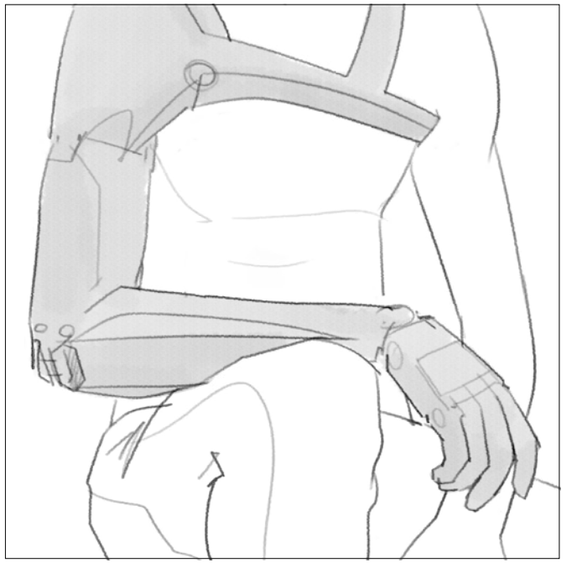
Studying anatomy was critical in understanding the shapes that make the human arm both functional and beautiful. Later on, these drawings were used to develop the shape of the modular rubber fairings.

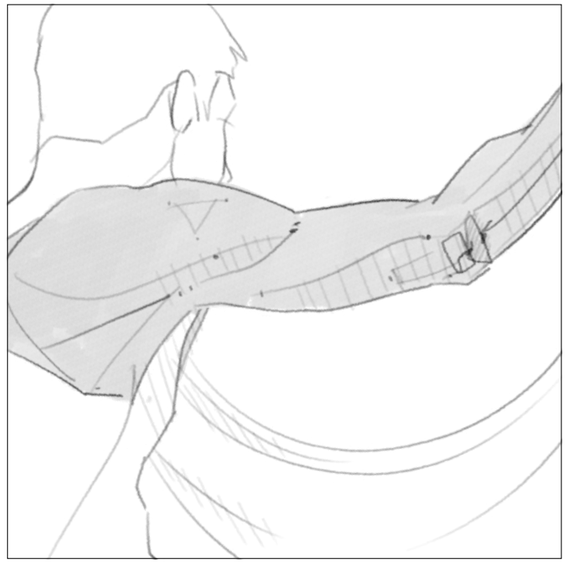


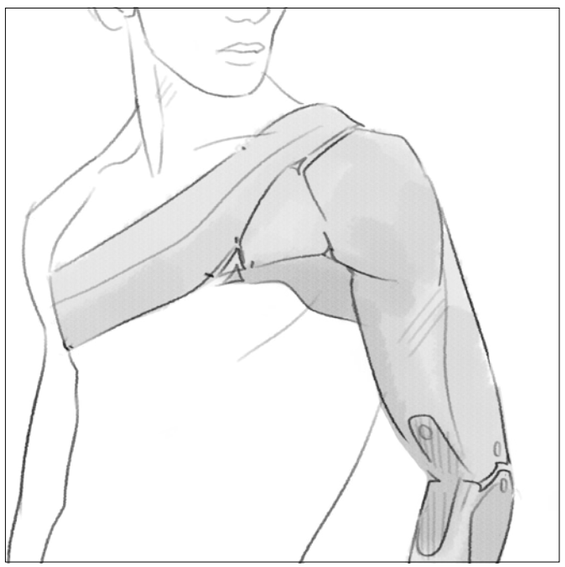
SCOPE

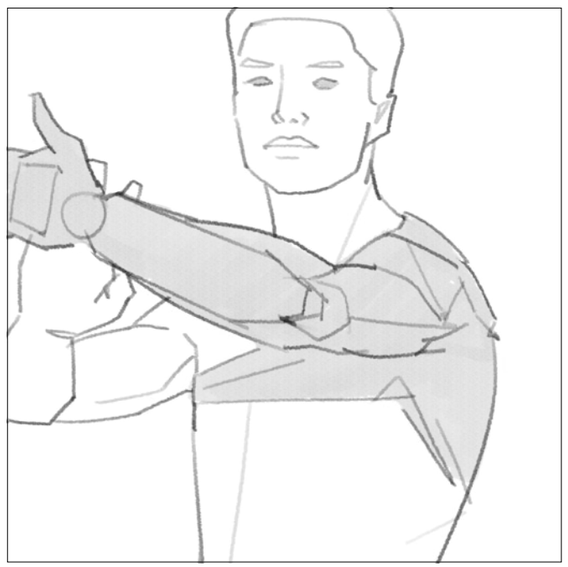
Amputees are frequently frustrated by high tech concepts that are too expensive for their immediate needs. Tyr 3's design is intended to allow gradual improvement in the arm over time as finances and technology grow.

Tyr 3 is a guideline for a new generation of prosthetics offering a range of solutions that can be configured to meet the individual’s needs, one person at a time.







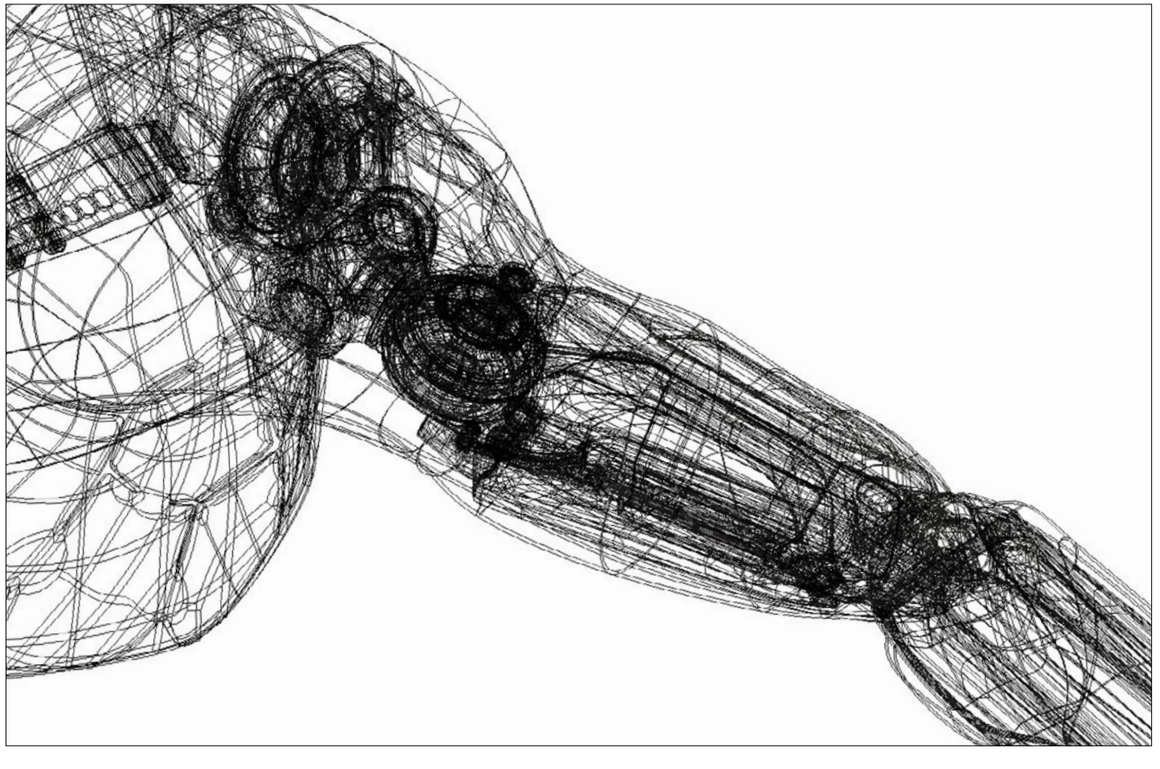


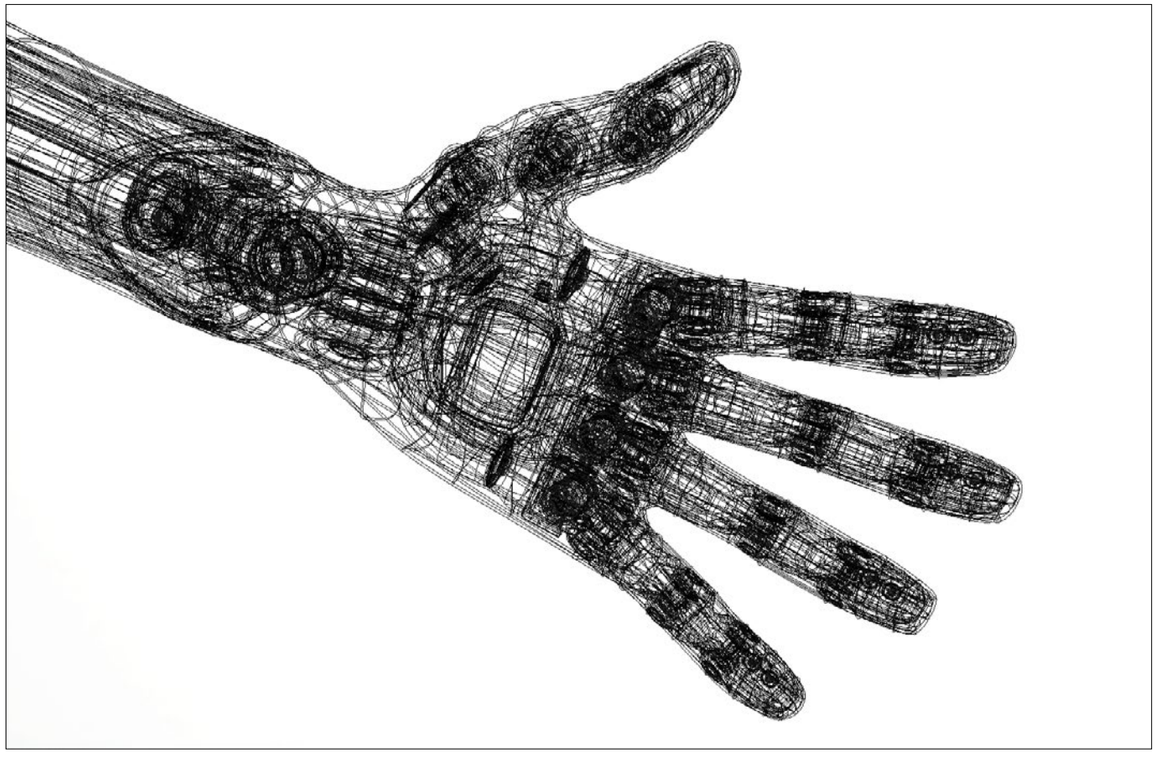
MODELING

A new generation of modeling programs and a revolution in affordable 3D printing is changing the way designers explore ideas. The speed and accuracy with which new products can be tested is accelerating productivity across industries.

In the space of just thirteen weeks, Tyr 3 was designed and modeled in Modo. After well over fifty iterations, four major redesigns, and 241 separate files, Tyr 3 was ready to be shared with the world.

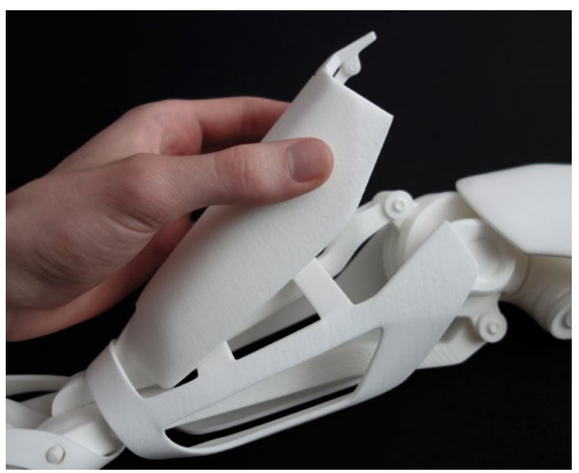
This project could not have existed a decade ago. Today's inventor now has access to a wealth of powerful new tools that redefine the limits of what one individual can do.



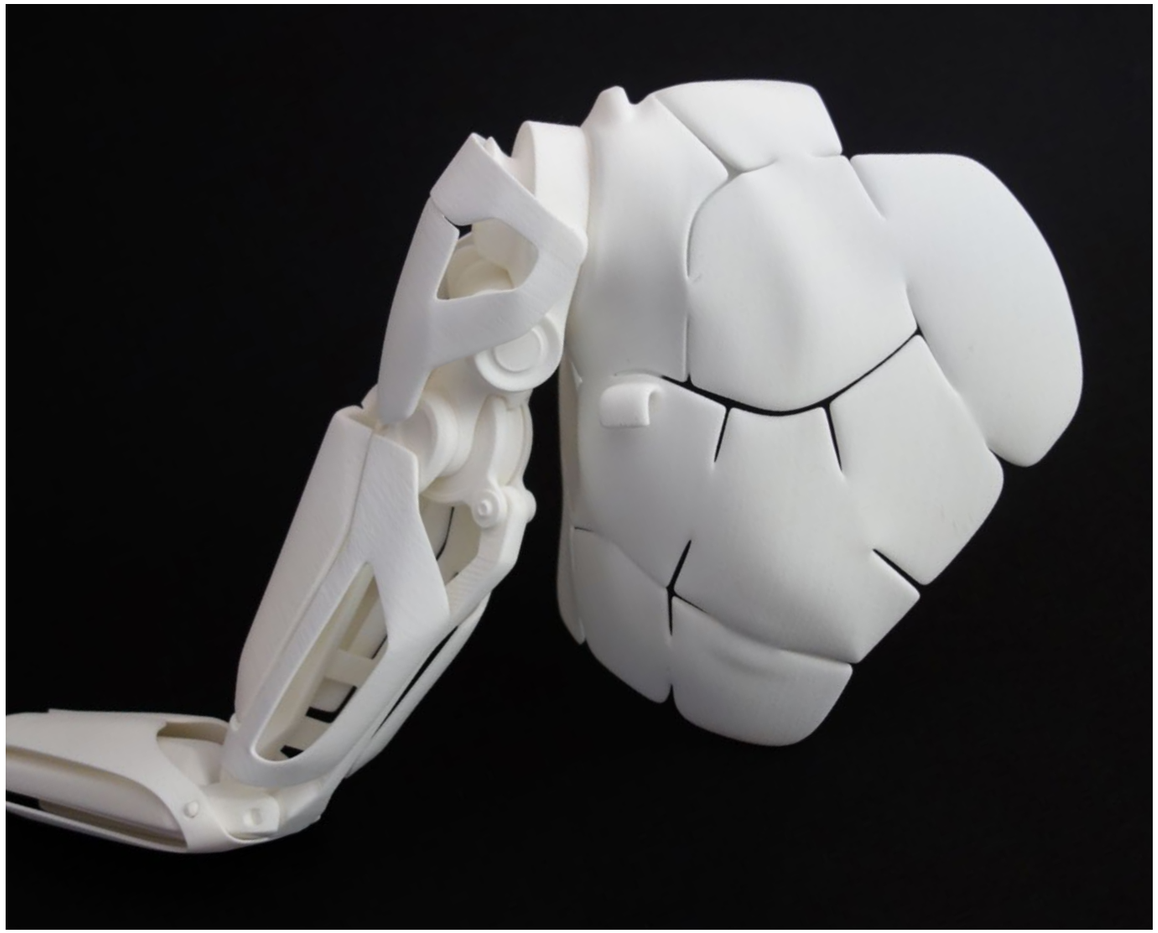


PROTOTYPING

A 1:1 scale model was 3D printed over the course of two weeks and assembled in a single day. The shoulder, elbow, and wrist exhibit 7 degrees of freedom. A second hand was printed without the elastic sleeves to illustrate its 24 degrees of freedom.



The arm as shown (without the socket) weighs just 3.5 pounds, despite being sized for a 6 foot tall 160 pound man. With motors, electronics, and metal components it will still weight under the 8.5 pound limit for this size.

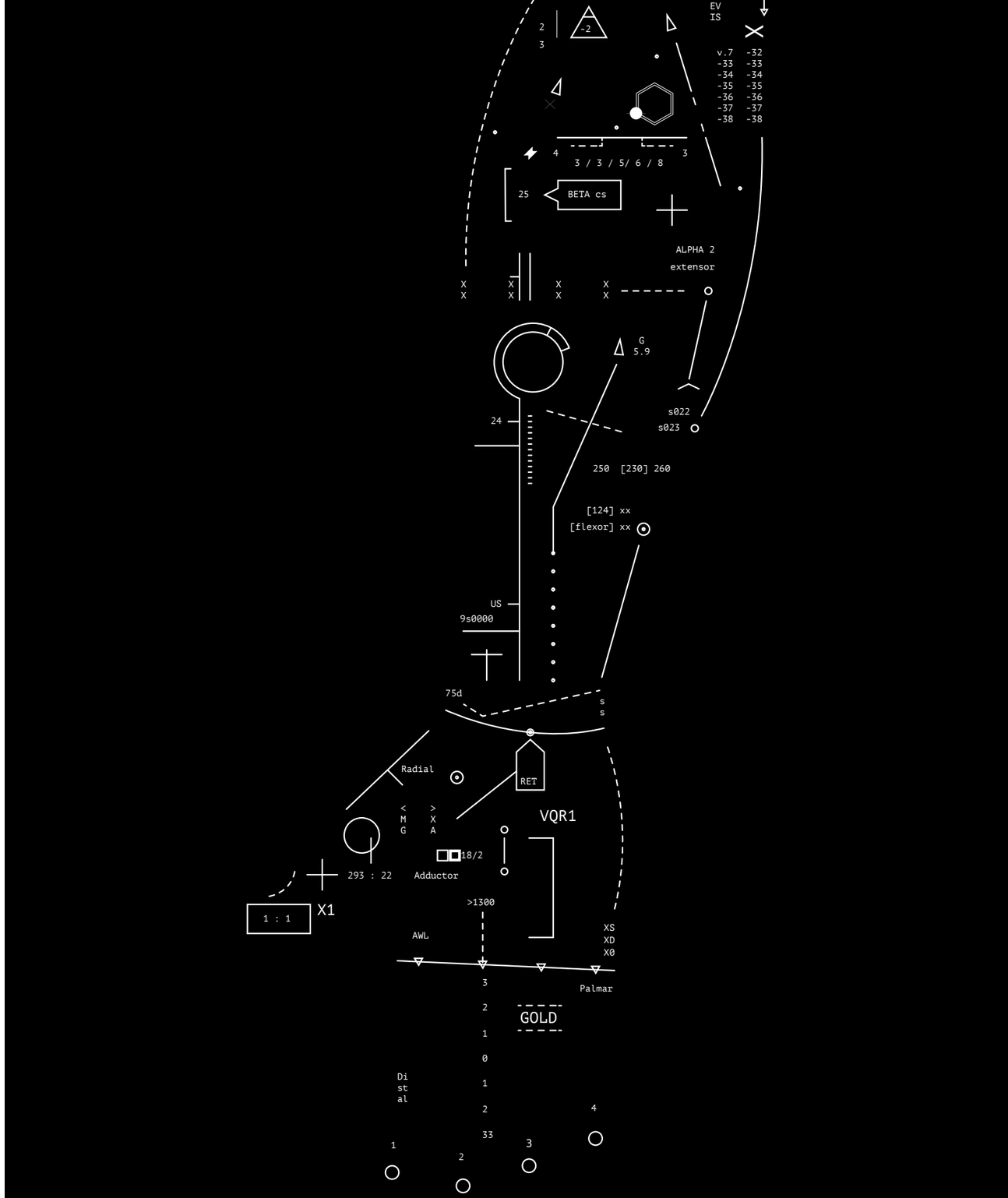


AFTERWARD

We are quickly converging on a single point, where governments, companies, and individuals are competing to re-engineer the human body. It isn't a question of whether this technology will be made, but rather when and by whom.

WHOLE NUMBERS

At its core, bionics is the process of rebuilding nature with numbers. Biology, chemistry, and physics ultimately reduce to mathematics; when we understand a system we can predict and control it. When the body is reduced to numbers, we can make it whole again. The arm is a machine, and today's machine language is binary. Thanks to the electronics revolution, in the past 30 years the prosthetics industry has made more progress then in the last 3000, and in the coming decades we will see many more truly incredible advances.



PROSTHETICS AS SCULPTURE

Rebuilding the human body brings with it aesthetic questions: Should we strictly imitate the human form or enhance it? What are the implications of defining a new physical standard of beauty? The answers to these questions are best left to the individual. To this end, Tyr 3 was created as an arm whose appearance is easily personalized. Prosthetic limbs are a unique blend art and technology. They are scientific achievements that challenge our conventional understanding of beauty.

POINT BLANK

In many respects, our history as a species has been an arms race, and in the 21st century, there will be new revolutions in the production of piloted and autonomous robots, as well as in our ability to augment the human body chemically and mechanically.

Today, advances in prosthetic arms are largely military funded. How will this affect the way they are developed and used in the future? Tyr 3 offers modular tool storage, a feature that could easily be weaponized. The aim of Tyr 3 is to highlight all that bionics has to offer, because ultimately, the nature of technology is a function of its application.

TOMORROW

Eventually, prosthetics will be obsolete. Humanity will posses the technology to regrow human tissue and use nanotechnology to rebuild our organic bodies from the inside out. The technology we developed for human prostheses will be used to equip robots to live in a human world.

We are accelerating towards a technologically and culturally unknowable future. Tyr 3 exists within two worlds, a stepping stone between the organic and the synthetic that speaks to the possibilities of tomorrow.

“I invented nothing new. I simply assembled the discoveries of other men behind whom were centuries of work. ... So it is with every new thing. Progress happens when all the factors that make for it are ready, and then it is inevitable.”

– Henry Ford

Acknowledgments

Family

To my family, thank you for your support: Mom, Dad, Liberty, Mona, Dan, and little E. None of this would be possible without your love and guidance. Thank you for your moral support -- I am so fortunate to have such rational and reliable role models.

Mentors

To my program director, Mike Glaser, thank you for encouraging me these past four years to think deeply, take on more, trust my own judgment, and find my own value.

To my classmates, thank you: Jemma, Candace, Tony, Danielle, Hanya, Zidu, Tim.

To my interviewees and friends, thank you for your time and assistance: Lisa Serpico, Sarah Dierck, Michelle Zatta, Mark & Verena Hjetlness, Sam Fox, Eric Sundquist, Jason Kirk, Deepak Siromani, Taffy Bowman, Richard Vallett, Dr. Kim, H.H., Dr. Ilya Rybak, Dr. Mushahwar, Dr. Voskuhl, Jay Hardman, Emily Bryan, Jes Koepfler, Mike Jou, Amy Stoltzfus, Lewis Colburn, RJ Wafer, Eric Stephans, Sam Garret, Ian Preschel, Zach Thomas, Cole Gindhart, Johanna Taylor, Carla Diana, Longo, and Charles Anderson.

To those who trained me, Julie Hetzel, Donald Strum, Yuka Midorikawa, Rob Van Varick, Dodie Colavecchio, Vladimir Anokhin, Matt Schmitt, Bill Parcells, Jaeho Seo, Jenn Lydell, Vijay Chakravarthy, Jessica Hurwit, Abby Smith, and all of the lovely people at MG.

Support

Special thanks to the Foundry for including properly scaled human assets in Modo 901. to Hugh Herr, Aimee Mullins, and Jerod Bradford for their inspirational examples, to Makerbot for their (mostly) reliable 3D printers, and to Keyshot for a great render engine.