RIDE: Footwear for Astronauts Living and Exercising on the International Space Station

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Project Background

As we look to the stars and dream of the next frontier in space exploration, we must not forget the human element. Even with the most advanced tools and technology, long-distance exploration of our universe will not be possible until we find ways for the human body to better live and function in the harsh conditions of space. To find such solutions, scientists look to the International Space Station (ISS), where hundreds of astronauts have had the opportunity to live and work in a microgravity environment while orbiting around the Earth (Wild, 2020). Though humans have populated the space station for over twenty consecutive years, the longest consecutive stay of an individual human is only 355 days, which was completed by NASA astronaut Mark Vande Wei in 2021-2022 (Howell, 2022). Through studying astronauts on the ISS, researchers know that after prolonged periods of time in microgravity, human bodies undergo many changes which pose a danger to astronaut health and limits the amount of time humans can stay in space (Mars, 2022).

The muscles of the feet and legs are particularly impacted in a microgravity environment. Without the force of gravity to provide resistance, the muscles and bones in the back and lower limbs rapidly deteriorate. This leads to issues such as muscle weakness, bone loss, and balance problems. To counteract muscle atrophy and bone density loss, astronauts on the ISS dedicate two and a half hours to exercising each day to make up for the twenty-one and a half hours that their body is not experiencing physical activity. Astronauts follow personal workout regimen that is prescribed to them and monitored by a team back on Earth (Bowen, 2018). However, even with this meticulous effort to keep their muscles stimulated, astronauts still lose 1% of their bone density per month in space (Canadian Space Agency, 2019).

Another way that the feet are affected by microgravity is that the nerves of the feet become hyper-sensitive in space without the underfoot stimulation of standing and walking. While the bottom of the feet is under stimulated, the tops of the feet are being used in a completely new way on the space station. Astronauts hook their feet under metal rails to anchor themselves in one place or to get around the space station. The top of their feet gets sore and eventually callous over due to being used in a completely new way (Pomeroy, 2017). Because of this, astronauts can have foot pain that lasts for months after returning to Earth (Harrington, 2016). Mitigating these issues is paramount for astronaut health and the ability to plan future space travel. Surprisingly, despite the significant foot and leg issues that astronauts experience during and after their missions, there has not been much innovation regarding footwear to wear inside the space station that could help stimulate nerves, activate muscles, and protect the feet.

How Might We Statement

How might we create a footwear system that activates atrophying muscles and stimulates hypersensitive nerves while protecting the top of the feet to help mitigate the health issues and discomfort of astronauts living in the microgravity environment of The International Space Station?

History

History of the International Space Station

In October of 1957, humans made their first voyage into space with the Union of Soviet Socialist Republics Sputnik launch. This was during the Cold War, and it catalyzed the beginning of the space race, a year-long competition between the United States and Russia to send ICBM satellites into orbit (National Geographic Society, n.d.). In 1958, efforts in space exploration were grouped by the US government into a new agency, NASA. April 12, 1961, saw the launch of Soviet Cosmonaut Yuri Gagarin, making him the first human in space. Three years later, the U.S.S.R launched Vostok 6, making Valentina Tereshkova the first woman in space. In 1969, the United States launched Apollo 11, a mission famously known for bringing the first human, Neil Armstrong, to set foot on the moon (National Geographic Society, n.d.).

Armstrong's infamous steps on the moon drove a push toward longer missions into space. The United States sent the first space station, called SkyLab, into orbit on May 14, 1973. Over the course of the Skylab program, three crews of astronauts resided on the station and conducted investigations into how the human body is affected by space environments, as well as other research about space travel (Harland, 1998). Space agencies all over the world began to work together in 1984 to build an international collaborative space lab, later launching the International Space Station (ISS) component in 1998. Since the first crew arrived on the ISS, the space station has been continually inhabited (Howell, 2022).

Background of Exercise on the ISS

For the first human space launch of the 21st century, the space shuttle Atlantis delivered the Destiny Laboratory Module. Housed within the module was the first treadmill designed for astronauts to use. Today, the three machines that astronauts use to maintain muscle mass and bone density are the Advanced Resistive Exercise Device (ARED), the Cycle Ergometer with Vibration Isolation and Stabilization (CEVIS), and the T2 treadmill. Special sensors are installed over and inside of every piece of workout equipment so that NASA can collect data on how astronauts currently exercise and how this can improve in the future (Dunbar, 2009). The ARED is a fully equipped resistance training machine. Instead of using weight plates (or gravity), this machine gives resistance with vacuum tubes. This machine allows astronauts to do squats, presses, and lifts, building their bone density (Dunbar, 2009). Without room to walk around or gravity, the astronauts use a stationary ergometer bike. Without gravity, this bike does not need a seat. To save space in the small exercise pod, the bike also has no handlebars. Astronauts use handholds attached to the walls that can be found across the entire Space Station (Hicks, 2020).

Like the bike, the T2 treadmill provides necessary cardiovascular exercise to the astronauts but with added muscle activation. Combined with bungee cords, the T2 functions like any earthly treadmill but with added ‘gravitational’ resistance. Even with added resistance, NASA astronaut Jessica Meir said, “It’s pretty fun to run on T2. You get a little extra spring in your step” (Hicks, 2020). Each day, astronauts must stick to a strict workout regimen, with the most time being spent on the treadmill (Dunbar, 2009).

History of Shoes On the ISS

Since the beginning of orbital space stations, there have been accompanying footwear developments to assist astronauts in navigating microgravity environments. Astronauts on the initial Skylab missions had boots developed that would allow them to “lock” into place at various points on the ship. This provided those astronauts with the ability to be stationary in a weightless environment. These boots had triangular cleats that locked into corresponding triangular anchor points (Fig. 2) ("Shoes, Restraint, Skylab, Kerwin," n.d.).

Figure 1 Skylab locking boots ("Shoes, Restraint, Skylab, Kerwin", n.d.)

Following Skylab, astronauts on the crew for the initial launch of the International Space Station utilized simple nylon puff booties that gave them the ability to anchor themselves at various points around the station, such as in the tunnel hatchways (Fig. 1) (NASA Johnson, 2013). Members of the initial ISS crew were also photographed wearing normal sneakers, such as New Balances, during daily workout activities (Fig. 2) (NASA Johnson, 2013).

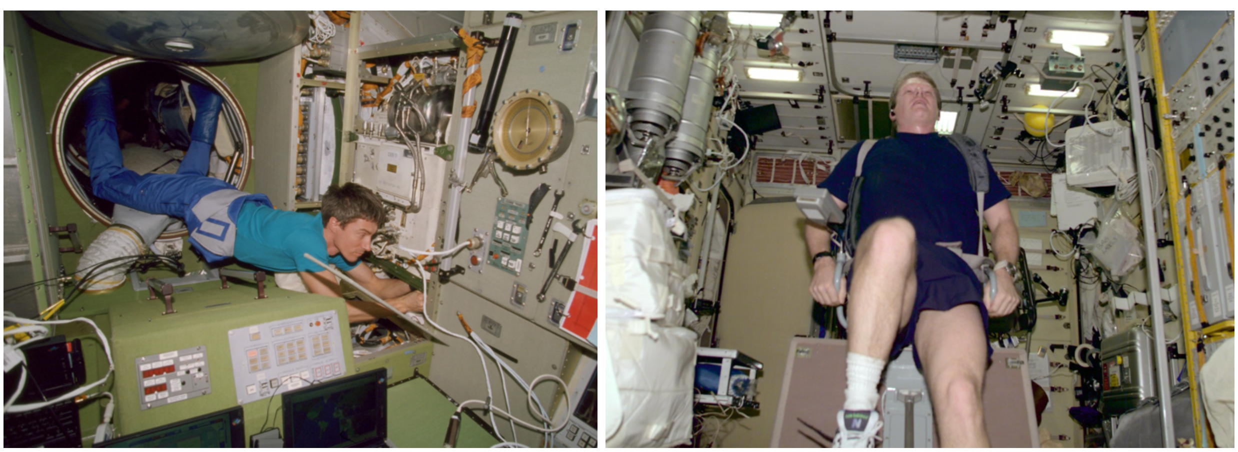


Figure 2 Booties and athletic footwear worn on ISS NASA (Johnson, 2013)

In 2014, NASA collaborated with a company called Xsens to develop a pair of shoes that had motion-measuring and data-collecting devices embedded inside. These shoes were made to be worn by multiple astronauts on the ISS during their daily workouts to better understand how the human body performs in microgravity environments so that their workout regimens could be optimized (Fig. 3) ("Xsens Technology Launched into Outer Space", n.d.).

Figure 3 Astronaut activity sensing shoes ("Xsens Technology Launched into Outer Space", n.d.)

Recently, a project involving Reebok and the International Space Station explored possible updates to the daily booties that astronauts wear while in Orbit. This project was completed in 2019 and sent to the International Space Station on the Boeing CST-100 Starliner. In an interview for Reebok, Kavya Manyapu stated "When you compare the boots to what we have now, they're just a notch up. They're literally Next Gen boots that we have" (Fig. 4) (Reebok, 2019).

Figure 4 Reebok Space Boots (Reebok, 2019)

User

Since the beginning of space travel, a total of 534 humans have gone to space. Of that group, 477 were men, and only 57 were women. From NASA, a total of 129 astronauts have gone to the International Space Station, 103 men and 26 women (NASA, 2022). Looking at gender representation in space exploration, women have been historically denied the same chance to participate as their male counterparts. This is not because women are less qualified but because societal norms have allowed this trend to continue. Though cultural tides are changing to allow more women to participate, in space, female astronauts face the challenge of maneuvering equipment and environments designed without their anatomy in mind. While the footwear solutions designed for this project will be beneficial to astronauts of either gender, this project will be designed around a female shoe last to pave the way to a more inclusive space product industry.

The target user for this project will be female astronauts on the ISS who are exercising daily to maintain muscle mass while in zero gravity. Currently, there are two women onboard the ISS, Nicole Mann, and Anna Kikina (NASA, 2022). Expeditions can last up to six months at a time, during which astronauts reside in orbit while conducting scientific experiments such as innovative cancer research or growing plants in space (Deiss, 2022). The ISS expedition crews usually have between two and seven astronauts (Harland, 2022). There are no age restrictions for astronauts on the ISS, but previous crews' ages ranged from 26-46 years old. Of the female astronauts who were stationed at the ISS between 1998 and 2003, the average age is 42.5 years old, making this the ideal age for the target user of the proposed footwear (Goel et. al, 2014).

While it is not a requirement, astronauts generally weigh between 110 and 209 pounds and measure between 5" and 6'3" tall. It is expected that astronauts have qualitative skills in leadership, teamwork, and communications. Other general requirements to become an astronaut for NASA are (Deiss, 2022):

1) Be a U.S. citizen
2) Possess a master's degree* in a STEM field, including engineering, biological science, physical science, computer science, or mathematics, from an accredited institution.
3) Have at least two years of related professional experience obtained after degree completion or at least 1,000 hours of pilot-in-command time on jet aircraft.
4) Be able to pass the NASA long-duration flight astronaut physical.

*The master's degree requirement can also be met by:

- Two years (36 semester hours or 54 quarter hours) of work toward a doctoral program in a related science, technology, engineering, or math field.
- A completed Doctor of Medicine or Doctor of Osteopathic Medicine degree.
- Completion (or current enrollment that will result in completion by June 2021) of a nationally recognized test pilot school program.

Environment

For this project, the environment is aboard the International Space Station (ISS). The station is in constant orbit around the Earth, averaging at an altitude of 248 miles above the ground and traveling at 17,500 mph. While traveling in orbit, both the ISS and the astronauts on it are in a constant state of freefall toward the earth. In this state, the astronauts experience what is called "microgravity." On the station, there is technically a gravitational force of 89% of what is felt on Earth. However, the relationship between the gravitational force, which is constantly pulling them ‘down to earth’, and the centrifugal force, which constantly pushes them ‘out’ in the circular motion, creates a sensation of weightlessness (“Microgravity: Living on the International Space Station”, n.d.). Microgravity allows astronauts to float around the spacecraft and move heavy objects with ease. According to NASA, astronauts can move objects that weigh hundreds of pounds with just their fingertips (“What Is Microgravity?”, 2017).

The International Space Station is the length of a football field and has a total mass of 925,335 lbs. It is made up of a series of modules that connect to form long pathways and rooms (Fig. 5). The living spaces inside the ship can be compared to a 6-bedroom, 2-bathroom house and has three gym facilities (Garcia, 2022).

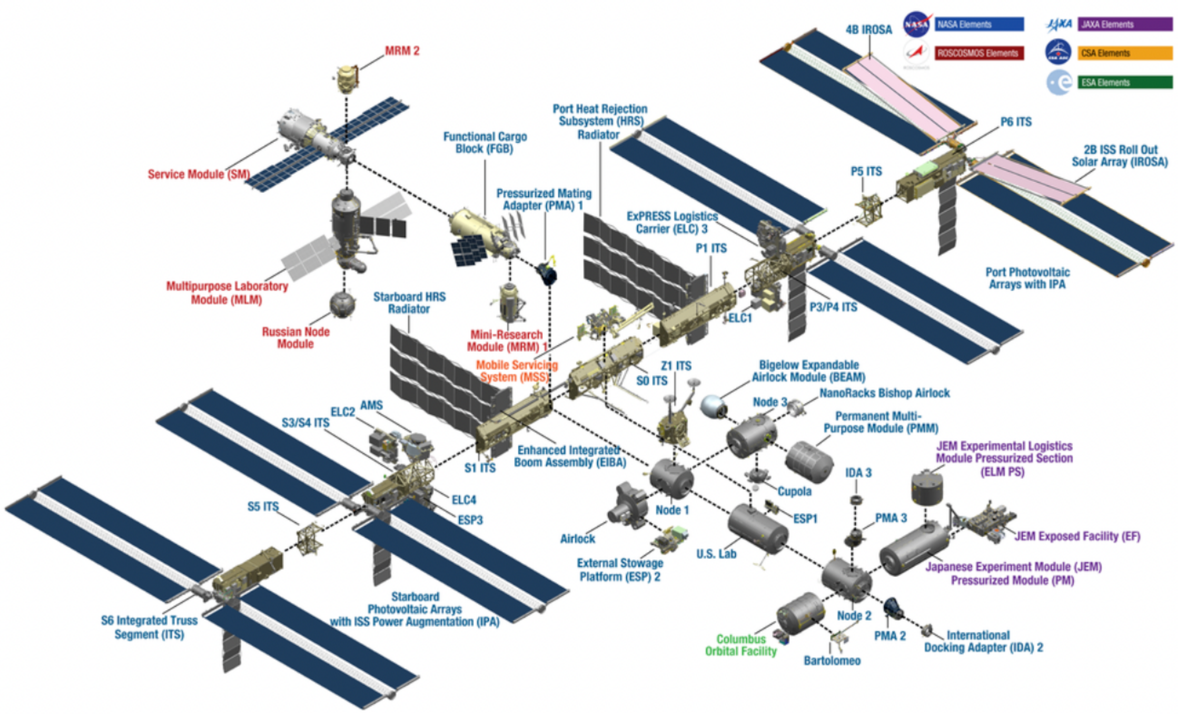


Figure 5 Modules on the ISS (Garcia, 2022)

The International Space Station has a thermal balance system that maintains the delicate balance between the freezing temperatures of space and the intense heat of the sun. Temperatures can vary from one location to another within the interior of the space station. The crew can adjust the temperature within the range of 65-to-80-degrees F. Humidity on board the ISS is kept at around 60% relative humidity. The humidity must be controlled in this environment to ensure that moisture does not build up inside the cabin. Moisture build-up can lead to the growth of microorganisms that could get astronauts sick if inhaled. The humidity system collects excess water to be reused, which is critical to the water supply of the ISS (Garcia, 2022).

The space station is equipped with three workout machines that are specifically designed for working out in the microgravity environment onboard. Astronauts use the treadmill, the stationary bicycle, and the weightlifting machine to complete the 2.5-hour daily workouts (Fig. 6) (Garcia, 2022).

Figure 6 T2 Treadmill on the ISS (NASA, n.d.)

Market

The ISS is the product of a partnership between five international space agencies and is operated by 15 different countries. As of September 12, 2021, 244 people have been to the ISS, and only 40 have been women (Garcia, 2016). At the time of writing this paper, in December 2022, two women are aboard the International Space Station, and NASA intends for this number to grow (NASA, 2022). With the expansion of the Chinese space program along with the rise of commercial space exploration companies such as SpaceX Crew Dragon, Virgin Galactic Unity, and Blue Origin New Shepard, the total number of humans traveling to space is increasing each year. Out of the increasing number of humans in space, trends show the proportion of women to be growing. In 2021, there were 24 human space travelers, a quarter of whom were female (Venckunas, 2021).

Each year, NASA spends approximately 30 billion dollars on furthering all areas of peaceful space exploration. This budget is broken down to support the 5 major program areas. At the top is budgetary allowance going towards human spaceflight (The Planetary Society, n.d.). Now that the ISS has full cargo transportation online and a commercial crew, the space station has more activity on board than ever before. With a higher onboard occupancy, approximately half of the budget allocated towards human spaceflight is going towards academic research and hundreds of experiments. Largely, the rest of NASA's human spaceflight research budget is going towards furthering technologies and product offerings that will be necessary to send the first person of color and the first woman to the moon within the next 10 years (Foust, 2022). NASA's 10-year mission plan, provided to Congress, outlined these five major mission goals (The Planetary Society, n.d.):

1. Enable deep space exploration
2. Conduct research to benefit humanity
3. Foster a U.S. commercial space
4. Lead and enable international collaboration

5. Inspire humankind

Within the goal to inspire humankind, NASA emphasized a need to broaden the audience that NASA reaches through connectedness with a younger audience. NASA believes that the future of their missions to the ISS and the moon is reliant on the younger generation. Through outreach and improving representation in all areas of STEM-related departments, NASA aims to create a more diverse population on the ISS (Foust, 2022).

Project Line Plan

This footwear line will include both a bootie and an exercise shoe for astronauts living on the International Space Station. The bootie is intended to be worn all day throughout the space station, during work, leisure, and navigation through the ship. The exercise shoe is intended to be worn throughout the daily 2.5 hours of exercise using the T2 treadmill and ARED workout machine (Garcia, 2022).

Jobs to Be Done

The footwear worn by astronauts on the International Space Station fits into two main functions: all-day wear and exercise. Typically, all-day wear consists of booties or socks worn by astronauts throughout the day in the station in place of regular shoes. The first task of the all-day bootie is to cover the entire foot, keeping the astronauts' feet warm. While working in an environment with microgravity, astronauts hook their feet around various rails and straps to anchor their bodies to prevent floating away. Because of this action, the second job to be done for the daily-use booties/socks is to provide adequate protection for the top of the foot to prevent callouses and blisters from forming. The bottoms of the feet must also be protected because the skin becomes sensitive and raw compared to when on Earth due to the lack of weight bearing on the sole (Petit, 2012). In microgravity, movements can be awkward, so it is also important that this footwear protect the toes in case of impact. The third job to be done for the booties is moisture management. Unlike on Earth, in microgravity environments, sweat from the body does not drip down and instead stays where it occurs (Wirth, 2016). Because of this, it is important that the booties can easily dry out or have a disposable sweat absorption component to prevent bacteria buildup which can be dangerous on the ship.

The first job to be done for an astronaut exercise shoe is to provide the feet with protection while using the T2 treadmill and the ARED workout machine on the ship. The second job to be done is to support feet with cushion and stability throughout the workout activities such as jogging, squats, and lifting weights. The third job to be done is to increase muscle activation during workouts to counteract the atrophy of muscles and joints while in space ("Exercising in Space", n.d.). The fourth job to be done is moisture management, for the same reasons mentioned for the bootie. However, the exercise shoe is not thrown out after two days of wear, so moisture management is even more important here. The fifth job to be done for the workout shoe is to provide an effortless donning and doffing experience for astronauts in a microgravity environment.

Product Rules

The only time that astronauts on the International Space Station wear traditional athletic shoes is during their daily workout sessions to assist with foot cushion and stability while using the machines. Otherwise, there are no rules about what footwear can be worn throughout the ship. Shoes are not necessary for a micro-gravity environment because the feet do not interact with the ground as they do on Earth. Most crew members simply wear socks for comfort and warmth as they float around the cabins. Some semi-structured sock booties have been constructed to provide some traction; however, many astronauts just opt for their regular socks (Fig. 7) ("Socks, Slipper, Shuttle", n.d.).

Figure 7 Booties worn inside the ISS ("Socks, Slipper, Shuttle", n.d.)

When astronauts are using the gym and machines on the ship, there do not appear to be any regulations regarding what specific shoes to wear. From images collected so far, it appears that normal athletic running or training shoes with a thick midsole are ideal because they support and cushion the foot for a long period of time ("Socks, Slipper, Shuttle", n.d.). While there does not seem to be any footwear-specific regulations for astronauts on the ISS, there are safety guidelines for materials for apparel on the ISS. When proposing new designs specifically for use on the space station it will be beneficial to utilize the materials that are safer for this environment, rather than just the materials that are typically used in athletic footwear. Due to fire concerns onboard the ship, clothes for astronauts on the ISS must be made of fibers that char rather than melt-and-drip. While cotton has been the material most used for crew clothing, lint creates problems with the onboard air filters. Because of this, yarns made of multifilament fibers are preferable. For safety precautions, cotton that is used on the ISS must be treated with flame-resistant compounds that have been developed by Nasa and Cotton Inc. (Wirth, 2016).

Product Anatomy

Sock/Bootie Anatomy

A sock is made from interconnecting loops that are knit together. Socks provide warmth to the foot, to absorb perspiration, provide cushion, and protection against the interior of the shoe. Socks that have an extra layer of protection or traction on the sole of the foot are sometimes referred to as booties. The knit construction allows socks to stretch around the foot and hug the skin without any type of binding or lace (Fig. 8) (Lovegrove, 2019).

Figure 8 Sock Anatomy

Athletic Shoe Anatomy

Athletic shoes are made up of three main component groups: the upper, the midsole, and the outsole. Each of these component groups can be broken down further into individual performance pieces, each with its own role in supporting the foot throughout the movements of a run or a workout.

The Upper

The upper (Fig. 9-a) is what holds your foot into the shoe. The construction of the upper pieces can play a huge role in thermoregulation, protection, and security of the feet. Elements of the running shoe upper include heel counter, heel tab, collar, toe box, quarter panel, tongue, lacing system, and strobel (Loda, 2018). The heel counter is a formed piece that hugs the back of the foot, stabilizing the rearfoot and protecting the Achilles tendon. The heel tab is a loop that sits on top of the heel counter and helps with donning and doffing of the shoe. The collar adds padding and comfort around the ankle. The toe box is a molded part of the upper at the very front that provides room and protection for your toes. The quarter panel connects with the toe box and is the stretch of material that covers the medial and lateral mid-foot section of the shoe. Together, the toe box and the quarter panel are sometimes referred to as the vamp. The lacing system is made up of laces, eyelets, and/or a quarter-panel cage. Combined, these lacing system elements work together to secure the foot inside the shoe and allow for a good fit. The tongue is sewn or knit onto the upper and aids in protecting the top of the foot from the pressure of the laces. Finally, the strobel is a structured piece of material that the upper is sewn onto and to the bottom of which the midsole is glued (Runkeeper, 2017) (Loda, 2018).

Depending on the shoe, elements of the upper could be combined or knit into the same piece to minimize shoe parts and overall weight. Most of the running shoes on the market today have uppers that are made up of breathable mesh fabric, synthetic knits or wovens, or other cut &

sewn performance fabrics. Overlays can also be added to the upper to hold pieces together without stitching, add aesthetic designs, and add structure or weatherproofing (Runkeeper, 2017).

The Midsole

The midsole sits just below and is glued to the upper at the strobel. The role of the midsole is to provide cushion underneath the foot. The components and construction of a midsole are what dictate how the shoe feels as we carry our feet across the ground. The midsole itself is made up of a few main parts: the insole or sockliner (Fig. 9-b) (which technically sits inside the upper but is part of the underfoot cushioning system), the energy plate (Fig. 9-c), cushion unit (Fig. 9-d), main midsole unit (Fig. 9-f), stability unit (medial post) (Fig. 9-e), and the shank (Fig. 9-g).

The insole is a removeable component that sits inside the upper but plays a huge role in foot comfort. This piece sits closest to the foot and is usually constructed of molded EVA foam that gives support in key foot areas like the arch. Because this component is removable, athletes can swap in different insoles to customize the shoe feel or provide extra foot support. Laminated fabric on the insole additionally absorbs moisture from the foot (Loda, 2018). What the energy plate is made of, shaped like, or whether it exists at all in the shoe varies between different brands and styles of shoe. Plates are rigid-formed parts that sit within the main midsole unit and can assist with the energy return and the forward propulsion of the shoe. Extra cushion units are usually propitiatory technology systems, such as encapsulated air or gel, to enhance underfoot comfort during a workout. The main midsole unit of most shoes is made with closed-cell EVA foam and usually runs across the entire length of the shoe, with the extra stability and cushion element embedded within or attached to it ("Footwear - Running Shoe Anatomy", n.d.). The stability units, such as a medial post, help to prevent the excessive pronation of the foot that would lead to injury. These units are made of foam that is denser than the rest of the midsole to add stability to an otherwise cushioned part of the shoe. Lastly, the shank is a part of the midsole that stiffens the area of the shoe around the arch to restrict flexion or torsion. The shank ensures that the foot bends at the toes instead of under the arch ("Footwear - Running Shoe Anatomy", n.d.).

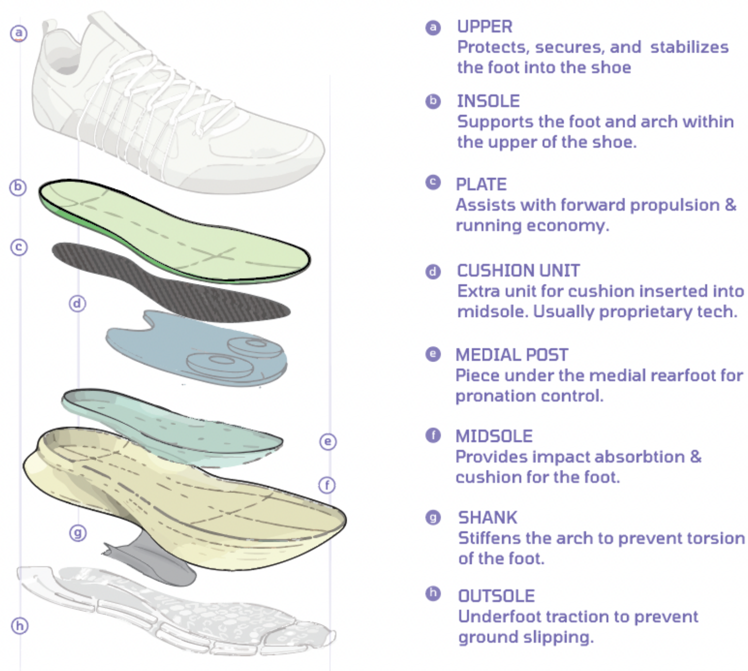


Figure 9 Athletic Shoe Anatomy

The Outsole

The outsole (Fig. 9-h) is a separate piece that is attached to the bottom of the midsole, forming the bottom of the shoe that touches the ground. Outsole pieces are formed into lugs made of a dense rubber that grips onto the ground, providing underfoot traction and protection on uneven terrains (Furrer, 2021).

State-of-the-Art Products

For this project, state-of-the-art products can be categorized into two areas: athletic shoes used for workouts on the ISS and booties developed for daily life on the ISS. This section of the paper will analyze the features and benefits of the best-in-class products for each of these categories to inform the design and innovation directions for the proposed footwear. For the athletic shoes, the Asics Gel-Kayano and the Brooks Adrenaline GTS 20 will be analyzed because they have been identified as the shoe choices of female astronauts in photographs taken on the ISS. Along with those workout shoes, the Acorn Original Sock Slipper will be analyzed because it was worn by astronauts on the ISS during their daily activities, in place of normal socks (Phillips, 2020). Finally, the Reebok Floatride Space Boot SB-01 will be analyzed because it is the most recent development in footwear for astronaut daily use on the ISS (Estiler, 2017).

Athletic Workout Shoes

The Asics Gel-Kayano retails for $150. This is a running shoe that has added stability technology within its design that is effective in protecting the user's joints and reinforcing proper running gait cycle. The supportive insoles of this shoe make it a great option for those who have low arches, flat feet or are prone to overpronation. The outsole of this shoe utilizes high abrasion resistant rubber, which is a durable material placed in key areas where the sole wear is likely to occur. The outsole resists damage brought about by friction and continued use, making it a very good option for astronauts who need to use

Figure 10 Astronaut wearing Asics to workout (CBS News, 2010)

this shoe on a treadmill every day (Anderson, 2016). This shoe is pictured above in use by astronaut Nicole Stott, a flight engineer who was part of the crew during a 2009 space station mission (Fig. 10) (CBS News, 2010).

The Brooks Adrenaline GTS 20 retails for $129. It is also a good general purpose workout shoe that has added stability technology that helps align the hips, knees and ankles of the person wearing them while they run. This shoe has an engineered upper with extra padding in the heel and tongue. The foam is lightweight but not overly squishy, giving it a structured yet comfortable feel. The shoe is pictured below by flight engineer and European Space Agency (ESA) astronaut, Samantha Cristoforetti, while she exercises on the ARED in the Tranquility Node 3 (Fig. 11) (Johnson, 2020).

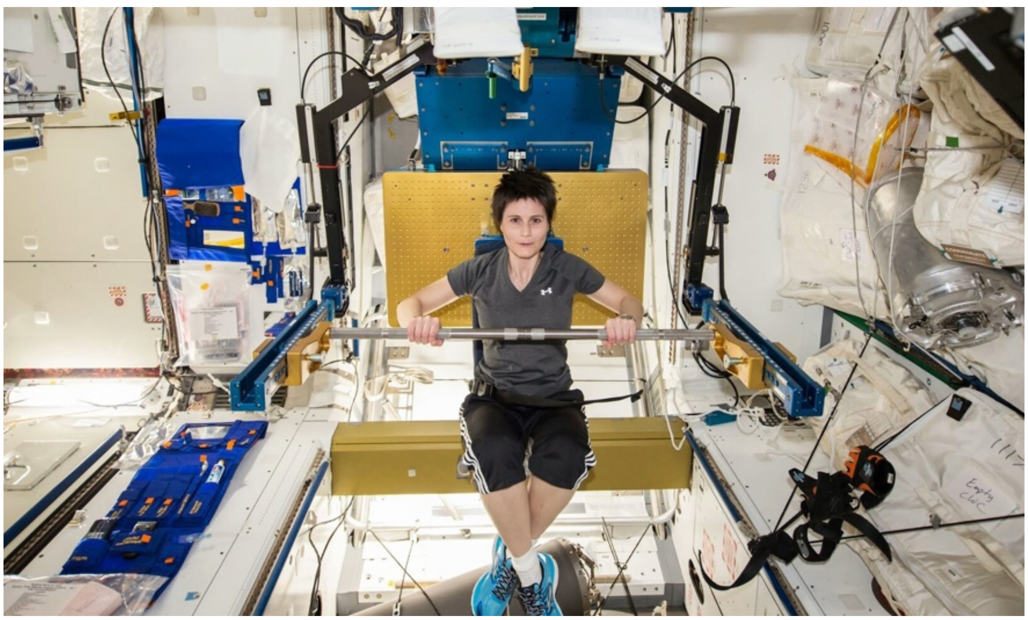


Figure 11 Astronaut wearing Brooks to workout (Johnson, 2020)

Footwear for ISS Daily Activities

Because astronauts on the International Space Station do not have to walk around, and instead float around the ship, they usually opt to not wear shoes. Generally, astronauts wear normal ankle socks that are disposed of once they have been worn numerous times. However, in 1982, astronauts on the ISS opted to switch out their normal socks in place of the Acorn slipper socks (Fig. 12). These socks are made of 85% Ragg Wool which has anti-microbial properties and is also thick and soft to keep their feet cozy and warm. These slipper socks also have an internal footbed that cradles the feed and adds extra cushion. The leather bottom of the slipper provides some adequate traction and protection while onboard the ISS. These sock slippers are pictured above in use on the ISS (Phillips, 2020).

Figure 12 Astronaut in Acorn Slippers (Phillips, 2020)

The Floatride Space Boot SB-01 (Fig. 13) was developed with Reebok in partnership with the David Clark Company in 2017 to serve as the "first evolution in space footwear in the last 50 years" The boot was designed to be worn with the outfits that the astronauts will wear while on the Boeing's new vessel CT-100 Starliner, which will be transporting astronauts to and from the International Space Station in future missions (Estiler, 2017).

Figure 13 Reebok Space Boots (Reebok, 2019)

The boot design is reminiscent of the classic tall leather boots that have traditionally been worn by astronauts but feature high-performance sneaker innovations. One of the innovations of the boot is the use of Reebok's Floatride foam, which is a consistent cell structure that serves to deliver better cushion and responsiveness than ever before. Matt Montross of the Reebok Innovation team summarized the importance of this material used in the design, commenting that "weight is a huge factor in space travel with just a single pound having big financial implications, traditional space boots were made of rigid leather with firm soles and were not integrated into the actual space suit. Reebok Floatride foam introduced three revolutionary elements to the space boot; it decreased the overall weight significantly; it brought the added comfort in a space boot and support that you would expect in a running shoe, and it delivered a new level of sleekness and style" (Neira, 2018). The midsole design also boasts an enhanced foam rim "bumper" that stabilizes astronauts' center of balance and the foot through the gait cycle in zero-gravity environments. The internal layer of the upper consists of a seam-free ultra-knit, which was engineered to provide better breathability and comfort in strategic places. The outer layer of the upper zips up to lock the boot to the leg up to the mid-calf ("The Reebok Space Boot Is Preparing for Launch", 2019).

State-of-the-Art Materials & Manufacturing

This section of this essay will overview the best materials and manufacturing techniques used in state-of-the-art running and training shoes so that this knowledge can be used or improved upon for the proposed footwear products.

Athletic Shoe State-of-the-Art Materials & Manufacturing

Uppers on athletic shoes have a wide range of potential materials but are usually constructed as an engineered knit mesh with polyester or nylon fibers. Knit fabrics are constructed with a systematic linked loop system that allows the material to be stretched in different directions. These engineered meshes and knits provide the close-to-foot, sock-like feel needed for flexibility and comfort in athletic shoes (Furrer, 2021). These materials are constructed using a flatbed or warp-knit knitting machine that knits the upper together in one piece. Woven materials and synthetic leathers are also sometimes used to add structure to the upper. These materials would be die-cut and stitched together.

Some upper parts, such as the collar, are made from open-cell polyurethane (PU) foam that is die-cut, heat-pressed, and then stitched onto the main upper part. Overlays are generally made from thermoplastic polyurethane (TPU) films that are heat transferred or high frequency welded to bond them to the fabrics. Some running shoe uppers will utilize durable water repellent (DWR) treatments to prevent external moisture to be let in. The heel counter and other rigid pieces are either made from TPU that is injected molded or die-cut, formed to shape, then glued onto the upper. Non-woven polyester fibers are used to create the rigid strobel material, which is then stitched to the rest of the upper using a special machine specifically for this sewing step. EVA foam, or ethyl-vinyl-acetate, is die-cut and formed to create the insole for the shoe. This part is laminated together with a woven polyester top cloth. Given that this part absorbs sweat and moisture from inside the shoe, state-of-the-art insoles have an anti-odor treatment (Motawi, 2017).

The midsole unit and embedded technology sit just below the strobel. In state-of-the-art products, injection-molded EVA foam (Fig. 14-a) has been the standard since the 1970s due to the material's softness, flexibility, and low cost. Other potential midsole materials include PU (Fig. 14-b), which is not as temperature sensitive as EVA but is about 50% heavier. Formed TPU (Fig. 14-c) is also used on some midsoles, such as the Adidas Ultraboost, where small TPU beads are pressed and fused to create a more durable, bouncy midsole. For high-performance shoes like the Nike Vaporfly, 4%, Pebax (Fig. 14-d) is the material used for the midsole. Pebax is a Polyether block amide that is known to be a very responsive material that is 20% lighter than TPU (Furrer, 2021). Within the midsole, there are needed recesses to fit any additional stability or cushion units which are made with materials such as encapsulated air or gel. Medial posts and shanks are made of injection-molded foam, like the main midsole unit, but they must be denser than the rest of the midsole to create stability within the shoe. Pieces of the outsole are injection molded or die-cut from textured rubber or TPU. All the pieces from the midsole and the outsole are aligned, layered together, and cemented to the upper ("How Running

Figure 14 Midsole Material Options (Furrer, 2021)

Shoe Is Made - Material, Manufacture, Used, Parts, Components, Machine, Raw Materials", n.d.).

Bootie/Sock Materials & Manufacturing

Booties or socks that are worn by astronauts on the ISS are made of the same materials and constructed the same way as booties or socks on Earth. Athletic socks can be made from a material such as cotton, polyester, spandex and wool. Material fibers spun into yarns which can then be industrially knit into the sock form. The machines take the yarns and patterns that are generated by a computer and circularly knit the material into sock form (Patterson, 2022). Booties are just socks with extra structure or traction that are sewn or molded onto the knit sock to give form.

Competitor SWOT Analysis

A SWOT analysis was conducted for the competitor product landscape for this project to understand the strengths, weaknesses, opportunities, and successes of the booties and athletic shoe options are currently available to astronauts on the International Space Station. To understand the products from a holistic standpoint, the analysis of each shoe is broken down into its performance components: the upper, the laces, the midsole, and the outsole if applicable. The SWOT information is a compilation of insights gathered from company websites, customer reviews, and close studying of the product.

SWOT 1: ISS All-day bootie/sock

Bulk mid-height white socks

Retail Price: ~$2 per pair

	STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
UPPER	• Soft • Easy to layer • Disposable • Easy donning/doffing • Absorbs sweat • Cheap	• Astronauts have to layer two pairs if they get cold • Bacterial growth	• Top of foot protection • More breathable • Strategic padding/support • Antimicrobial material • Split toe for dexterity	• Changes in astronauts feet might cause hot-spots in weird places • Bacteria growth
LACES	• N/A	• N/A	• Loops down toe and heel to ease donning & doffing	• Tall socks are hard to put on in microgravity • Fit
MIDSOLE	• N/A	• No cushion or support	• Arch or ankle support	• N/A
OUTSOLE	• N/A	• No traction • Wear quickly •	• Grippy traction • Protection against stubbed toes	• Wearing out with daily use • Dexterity of feet


(Petit, 2012) (24 Pairs Cotton Crew Socks, 2020)

SWOT 2: ISS All-day bootie/sock

Acorn Original Sock Slipper

Retail price: $52

SWOT 3: Updated ISS All-day bootie/sock

	STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
UPPER	• Thick material for warmth • Tall ankle, good for tucking pants in	• Not as disposable • Bacterial build up • More expensive • No top-foot protection	• Top of foot protection • More breathable • Antimicrobial material • Split toe for dexterity	• Changes in astronauts feet might cause hot-spots in weird places • Bacteria growth • Thick material causing excess sweat
LACES	• N/A	• N/A	• Loops down toe and heel to ease donning & doffing • High and low styles	• Tall socks are hard to put on in microgravity • Fit
MIDSOLE	• Premium, multi-layer Cloud Cushion™ footbed	• N/A	• Arch or ankle support • Interchangeable disposable footbed	• Sweat build up in footbed
OUTSOLE	• Durable leather sidewall repels stains and water • Genuine suede sole for traction and insulation •	• Leather is not breathable • Minimal toe protection	• Grippy traction • Protection against stubbed toes	• Dexterity of feet


(Phillips, 2020) (Phillips, 2020)

Reebok Floatride SB-01 Boot

Retail price: Unlisted

	STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
UPPER	◦ Design matches the outfits/space ship ◦ Two layer system ◦ Seamless, engineered knit liner ◦ Zipper closure for secure fit ◦ Seamless look	◦ Interior layers could get pretty dirty when worn for extended periods of time ◦ High boot design could get hot/irritate the legs	◦ Outer layer could zip all the way off ◦ Boot top could separate or roll down	◦ Many parts that could get damaged on long missions ◦ Issues with calf tightness ◦ Multi-step donning and doffing
LACES	◦ Lightweight interior lacing system ◦ Dynamic eyelet placement for extra ankle security	◦ Laces could get caught in zipper ◦ Eyelets are placed on a loose mesh layer	◦ Laces could wrap all the way around the ankle ◦ Pull-tight lace system instead of traditional lacing	◦ Interior layer could get caught in zipper ◦ Annoying to lace all the way
MIDSOLE	◦ Made with Reebok's lightweight Floatride foam ◦ 30% Lighter than traditional EVA ◦ Cushioned, flexible, light	◦ Does not look particularly innovative ◦ Base looks narrow, like it might be easy to roll ankle	◦ More visual draw to the midsole technology ◦ Mid foot stability units	◦ Boring apperance ◦ Performance in zero-gravity environments ◦ Over pronation
OUTSOLE	◦ Full foot outsole pattern for enhanced traction ◦ Outsole wraps toe for protection	◦ Lug design looks heavier than it needs to be inside a space ship ◦ Overly simple ◦ No flex grooves	◦ Create visual appeal with interesting pattern ◦ Remove excess weight with cut-outs and grooves in rubber	◦ Looks like it could be the outsole of any old shoe ◦ Too much traction on floors in an anti-gravity environment could impede movement

(Neira, 2018)

(Neira, 2018)

SWOT 4: ISS Daily workout shoes

Asics Gel-Kayano

Retail price: $150

	STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
UPPER	◦ Glove like fit ◦ Secure foot-lockdown ◦ Moisture-wicking sockliner ◦ Open mesh	◦ Thick material ◦ Not very breathable ◦ Lots of heavy pieces/overlays ◦ Not engineered knit	◦ Minimizing parts ◦ More breathable material, use of engineered knit or mesh ◦ Heel and tongue loops	◦ Changes in astronauts feet might cause hot-spots in weird places ◦ Bacteria growth on non-breathable upper ◦ Tight toe box
LACES	◦ Durable ◦ Smooth ◦ Ridges help instopping unlacing ◦ Reinforced lacing system	◦ Circular laces come untied easily	◦ Toggle lock-down instead of standard lace ◦ Lighter weight laces ◦ Flat shape laces	◦ Lacing in micro gravity could be challenging ◦ Breakage in space
MIDSOLE	◦ Efficient shock absorption ◦ Practical stability mechanism ◦ Good cushioned ◦ Shank	◦ Heavy for long runs ◦ No energy plate ◦ Can feel stiffer than most workout shoes ◦ Heavy gel	◦ More of a heel-toe drop ◦ Less gel to decrease weight ◦ Lighterweight foam	◦ Too rigid ◦ More of a lifestyle shoe
OUTSOLE	◦ Durable outsole	◦ Slippage for use on treadmill	◦ More dynamic tread pattern ◦ Higher treads for traction	◦ Wearing out with daily use

(Andersen, 2016)

(Johnson, 2020)

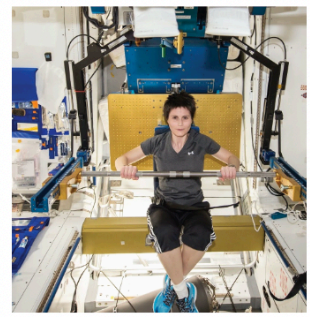
SWOT 5: ISS Daily workout shoes

Brooks Adrenaline GTS 20

Retail price: $12

	STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
UPPER	• Highly durable • True-to-size • Great heel lock-down • Cushioned Achilles area • Many color options • Wide options available	• Regular fit is narrow for wide feet • Plush tongue can rub ankle • Not the most breathable, can run kind of hot	• Lighter weight material • More open mesh • Cage for mid-foot support • Heel and tongue tab for donning and doffing	• Changes in astronauts feet might cause hot-spots in weird places • Bacteria growth
LACES	• Durable • Smooth • Stay laced	• Laces sit high on the foot, can cause blistering • Eyelets are reinforced hot-melt, could wear out	• Laces could sit lower on the foot, enhancing forefoot lock-down • Toggle lock-down instead of standard lace	• Lacing in micro gravity could be challenging • Breakage in space
MIDSOLE	• Aligns the knee/hips/ankle • Thick midsole cushion • Lightweight for everyday • Stabilizing base • DNA LOFT soft foam	• Heavy for long runs • Foam can feel a little firm • No energy plate, shank • Minimal technology	• More contoured shaping • More interesting form • Added shank for torsion control	• Over-pronation
OUTSOLE	• Good traction for indoor or outdoor terrain • Foot never sticks during gait cycle	• Could down quickly with daily treadmill use	• Thicker outsole • Deeper treads • More interesting tread pattern	• Wearing out with daily use • Slippage on a treadmill

(Holbert, 2019)



(Johnson, 2020)

Possible Intellectual Property and Patent Infringement Risks

Relevant intellectual property to this research includes patents that currently exist pertaining footwear with enhanced muscle activation technology, patents for weight reduction innovations in materials, and patents that pertain to sock insoles and traction technology.

Training Footwear

U.S Patent No. US8713817B2 describes an article of footwear that is used to enhance training. This article of footwear includes a forefoot bulge and a heel bulge that create multidirectional micro-instabilities, or “controlled instabilities” underfoot, thereby increasing muscle activation in the legs (Fig. 15). This contributes to dynamic conditioning of the wearer’s muscles during the gait cycle because the user is forced to use muscles for stability that would not normally be targeted by a workout in normal shoes (Litchfield & McInnis, 2013).

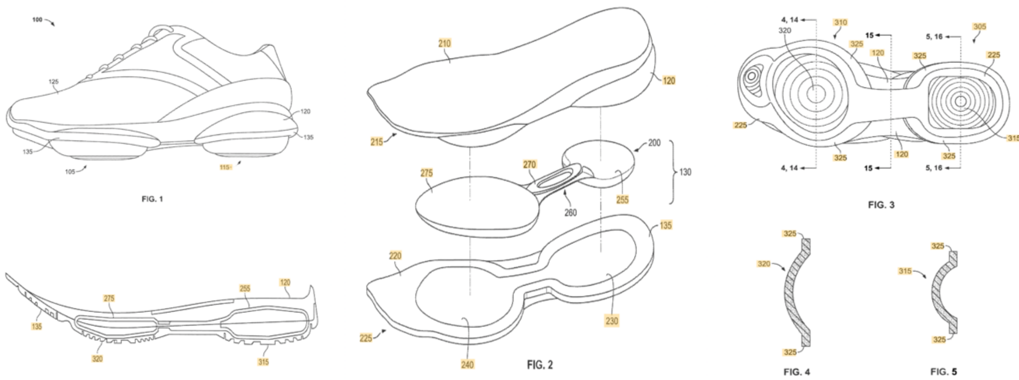


Figure 15 Training Footwear (Litchfield & McInnis, 2013)

Footwear Midsole with Lattice Structure Formed Between Platforms

U.S Patent No. 10702012B2 describes an article of footwear that has a midsole made from a series of lattice structures that is formed between two platforms. The lattice is formed from a network of laths extending from a user-facing side to a ground-facing side, that are interconnected at a plurality of nodes with voids. Included in this patent is also the method of manufacturing for this midsole. The midsole lattice structure is printed and integrally formed into the upper of the shoe (Fig. 16) (Guyan, n.d.).

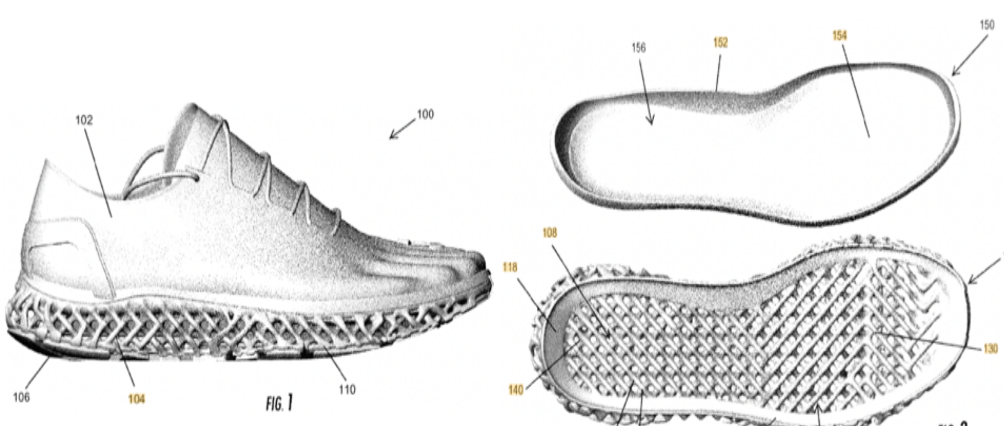


Figure 16 Lattice Structure Midsole (Guyan, n.d.)

3D Arch Sock Pad

TW108213007U describes a patent for a sock with 3D arch support embedded on the interior part of the sock. This patent includes the main sock material and two 3D molded comfort pads, one for the arch of the foot and one for the ball of the foot. The 3D arch support is combined with a surface of the bottom layer of the sock facing upward, towards the user's bottom of the foot. These 3D pads are used to enhance support for the arch and joints of the foot while wearing the socks inside of shoes (Fig. 17) (Chengmin, 2019).

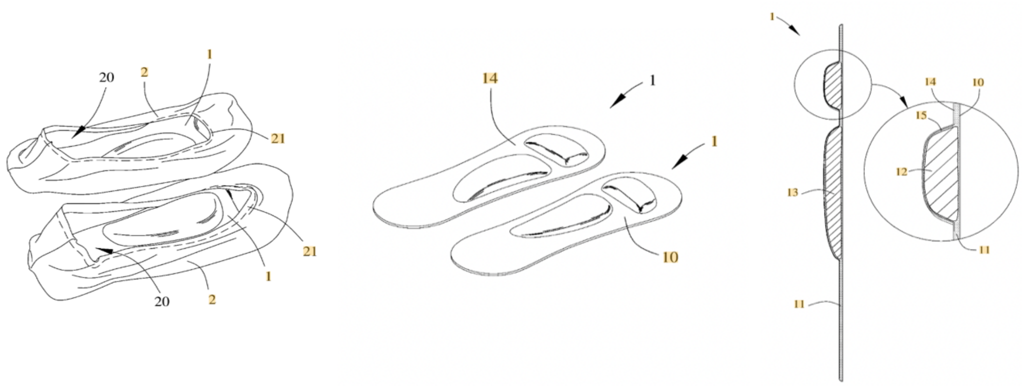


Figure 17 3D Arch Support Diagrams (Chengmin, 2019)

Augmented Footwear for Gripping and Holding in Micro-gravity Environments

U. S. No. Patent 20110296715A1 describes an article of footwear that is designed for human spaceflight to enable the use of the feet as gripping appendages. This is achieved by molded extensions that protrude under the toes and ball of the foot which creates additional leverage and ability to extend the toes (Fig. 18) (Howell, 2016).

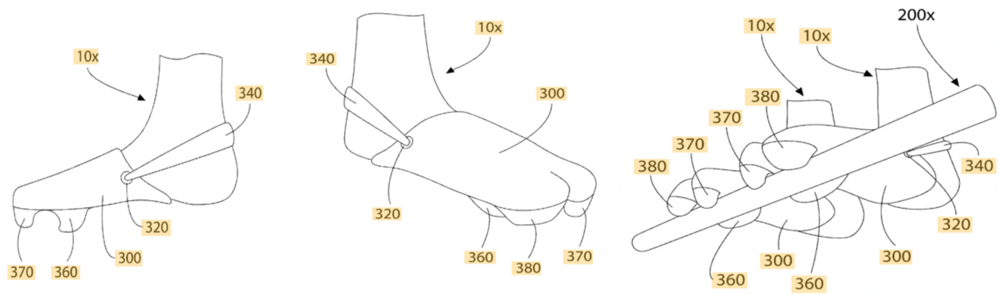


Figure 18 Microgravity gripping shoes (Howell, 2016)

Current and Future Trends

Current Color Trends

The current color trends in the athletic apparel and footwear space reflect a juxtaposition of vibrancy and calm (Fig. 19) and "bring together our competing desires for comforting familiarity and joyful adventure," according to Leatrice Eiseman, director of the Pantone Color Institute (Ator & Rodenberg, 2022). When looking at the current footwear product colors coming directly from the space industry, they are almost all hues of blue. For example, both the Reebok Floatride Space Boot SB-01 (Fig. 22) (Estiler, 2017) and the space suit and boots from Under Amour and Virgin Galactic (Fig. 23) (Chochrek, 2019) are both dominated with blue, which matches the new Boeing CST-100 Starliner spaceship ("The Reebok Space Boot Is Preparing for Launch", 2019).

Figure 19 Active Color Palette A/W 2024/5 (WGSN, 2022)

Figure 22 Floatride Space Boot SB-01 (Estiler, 2017)

Figure 23 Under Armour x Virgin Galactic Space Boot (Chochrek, 2019)

Future Color Trends

According to the Active Color Forecast for the autumn and winter seasons of 2024 and 2025 from WGSN, future consumers will be looking for more emotive colors than before. Important color themes will include "energizing brights, grounding mid-tones, tranquil pastels, and subversive tinted darks" (Fig. 24) (WGSN Color Forecasting Team & Yvonne Kostiak, 2022).

Looking even further into the future, in their Advanced Color Forecast for 2027, WGSN notes the industry's move toward more natural and sustainable dyes will have a large impact on color trends. The look of eco-dyes will be contrasted with the digital hues of expanding metaverse and AI technologies (Morrison et al., 2022). The color palette chosen for this project seeks to captivate future running shoe consumers by blending dream-like, nature-inspired colors with digital, oversaturated tones.

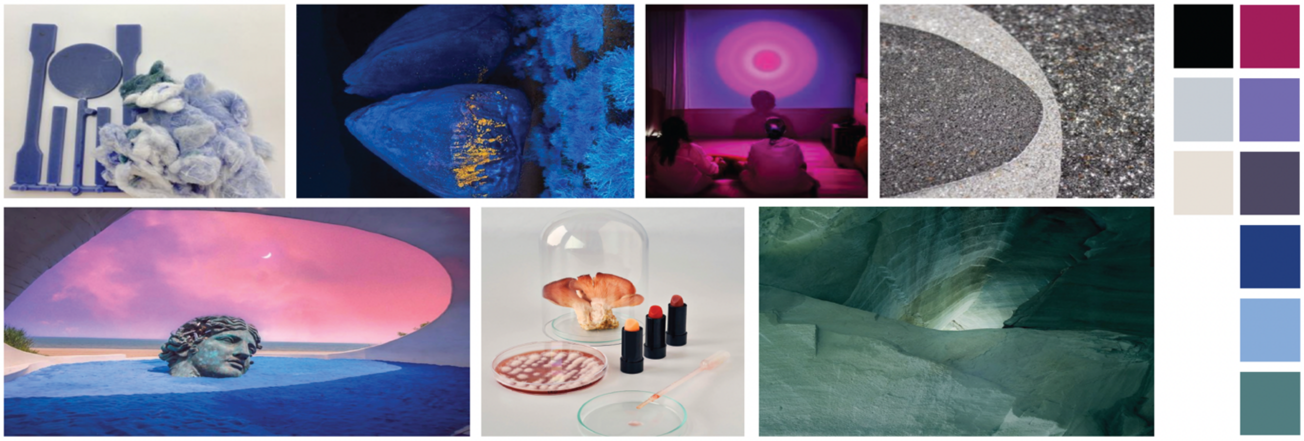


Figure 24 Future Running Shoe Color Strategy

Current Graphic Trends

The current graphic trends for women's running shoes serve to imply athletic performance. Though many athletic shoes do not have an obvious printed graphic, patterns in the knits, overlays, midsole textures, and color blocking tend to evoke quick speeds and explosive velocities. For example, the blurring and gradient color on the Nike Alphafly Zoom X evokes the feeling of something flying by so fast that it is a blur (Fig. 25). The Nike swoosh logo is also moved from the traditional lateral placement to crossing the length of the foot, which adds to the feeling that the graphics are being warped by the speed of the runner. Patterns that imply motion are consistent across brands from the low to high end, with fading striations or splatter textures that appear to fall off the back of the shoes.

Other graphic trends on many running shoes highlight innovations and technology in the shoe through hyper-technical materials and finishes. For example, the semi-translucent upper on the Adidas Adizero Adios Pro 3 reveals internal layers and functional constructions below the surface (Fig. 26). The over-stitching and quarter panel lamination on the Nike React Escape Run call to attention the reinforced stability and support around the arch of the shoe (Fig. 27).

Figure 25 Nike Air Zoom Alpha Fly (Nike, 2022)

Figure 26 Adidas Adizero Adios (Adidas, 2022)

Figure 27 Nike React Escape Run (Nike, 2022)

Future Graphic Trends

According to WGSN, the future graphic trends in running shoes will be largely influenced by shifts towards more sustainable materials. The color flecks that occur when recycling materials will be played up to call it to attention. In their sneaker materials forecast for Spring/Summer 2024, WGSN outlines a future footwear space with exaggerated 3D surface textures that are exaggerated and playful takes on patterns that exist in nature (Fig. 28).

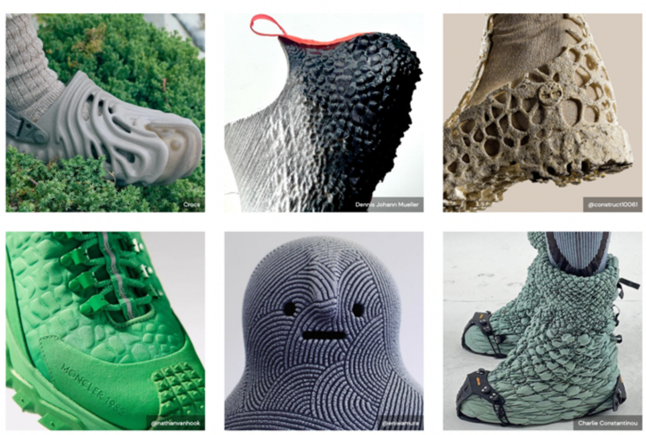


Figure 28 Future Graphics (WGSN, 2022)

The graphic language used in this project will play off these natural patterns and 3D textures to highlight unique designs. Organic, nature-inspired patterns can be transformed through a digital lens to encapsulate future shifts toward AI and computerized imagery (Fig. 29). Graphics such as soft, glowing gradients could also be used to emote lively and energized feelings to consumers. The specific graphic strategy will develop as design forms are explored and will serve as a complementary element, emphasizing the sensations evoked by the geometry.

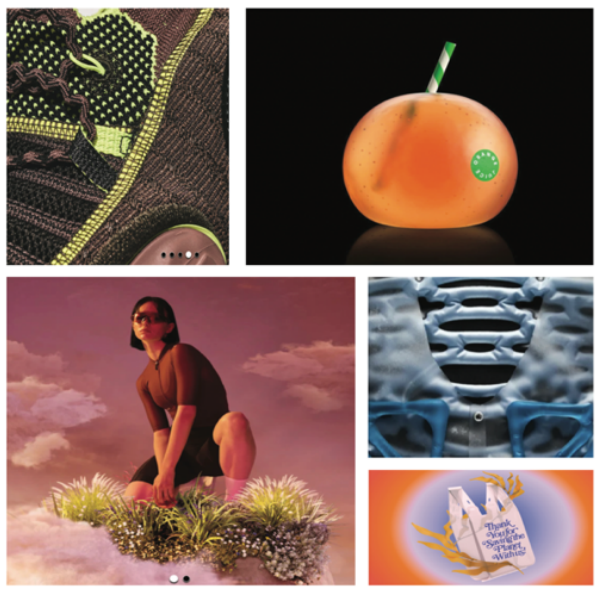


Figure 29 Future Product Graphics

Branding

Current Branding Trends

Current branding in the athletic product space is typically about pitching a particular lifestyle or athletic achievement. Companies use their overall brand language to tell product stories that resonate emotionally with their consumers. For example, the “Just do it” tagline from Nike is a simple call-to-action that can be understood by athletes of all levels (Restrepo, 2022).

The phrase is meant to inspire consumers to push toward their maximum potential. Adidas has a similar tagline, “impossible is nothing,” which means that anything is possible and is meant to push athletes to shoot for the stars (Ameen, 2021). Outdoor Voices use the tagline “Doing things” to inspire the world to get moving by freeing fitness from performance and emphasizing fun instead of competition (Tolentino, 2019).

While these company slogans help communicate brand missions and values, on-product marketing is currently limited. The real estate on running shoes is small, so logos and branding are pared down to the most essential elements. Successful companies have clear logos that are distinct and recognizable from a distance, even on someone’s shoes. Running shoes generally have similar logo placements: one large logo on the quarter panel, one small logo on the tongue tab, and one logo on the outsole. Specific cushion technology is occasionally printed on the midsole; for example, the Adidas Adizero Adios Pro shoe has a lateral midsole printed logo calling out the “Lightstrike Pro +” foam that is used on that specific shoe.

Future Branding Trends

According to WGSN, future consumers will connect to brands that are more empathetic to user emotions and that conjure up positive feelings and create a sense of community.

> “[One] strategy to build cultural relevance is to create consumer experiences that are emotion-centric, as a way to help customers overcome negative emotions while harnessing positive ones” (Rocca, 2022).

The branding language for this project will seek to connect with users empathetically by rejecting the notion that running is all about competition (i.e., being the best, pushing your own limits, etc.) Pulling inspiration from Nike ISPA collections, the branding of this project will be disruptive to the perfection-focused athletic norms. For example, this could be achieved with a “disrupted tech-pack” design style, where technical-feeling, clean page layouts are contrasted with playful elements (Fig. 30).

Figure 30 Future Branding

Research Studies

Physiological Research Related to Product Space

Physiology of Running in Orbit:

Understanding the preservation of the health and fitness of crew members aboard the international space station for long periods of time is a major objective for space travel researchers. The first exercise program implemented in space was during the Skylab missions in the 1970s. The data from those missions showed Skylab crew members generally maintained cardiovascular capacity but did show muscle atrophy in the lower legs. Since then, the available data from astronauts who have flown in space for 6 months or longer indicates that muscle mass and performance are negatively impacted while in orbit over time, even with the exercise countermeasures (Trappe et al., 2009).

A 2009 study from the Journal of Applied Physiology studied the effectiveness of the current workout requirements in preserving skeletal muscle size and function of astronauts on the ISS for extended periods of time. Researchers analyzed the muscle volume, muscle performance, and fiber type profile of nine ISS crew members. The calf muscles were the focus of this study because they have been shown to atrophy more than other leg and upper body muscles. Before and after spaceflight, calf muscle volume was measured using an MRI machine. Static and dynamic calf muscle performance was also recorded. While on the ISS, crew members performed daily personalized workout routines on a running treadmill, cycle ergometer, and resistance exercise machine (Trappe et al., 2009).

The researchers found that the exercise program implemented at the time was not enough to fully protect astronauts from lower leg muscle atrophy. They found significant decreases in muscle mass in the gastrocnemius and soleus muscle (Fig. 31). This study did find a positive correlation between the time spent on the treadmill and protection against muscle atrophy (Fig. 32), suggesting that the treadmill running exercises should be increased on future missions to better protect astronaut health (Trappe et al., 2009).

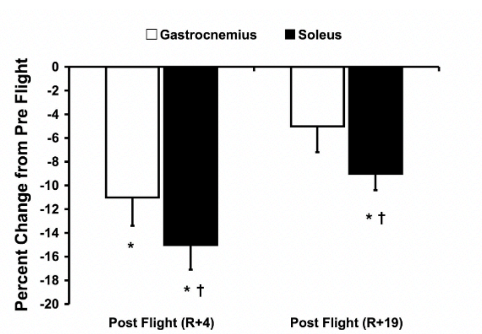


Fig. 1. Percent change in gastrocnemius and soleus muscle volume from preflight to postflight recovery *days 4* (R+4) and *19* (R+19). *$P < 0.05$ vs. preflight. †$P < 0.05$ vs. gastrocnemius.

Figure 31 Muscle Atrophy on ISS (Trappe et al., 2009)

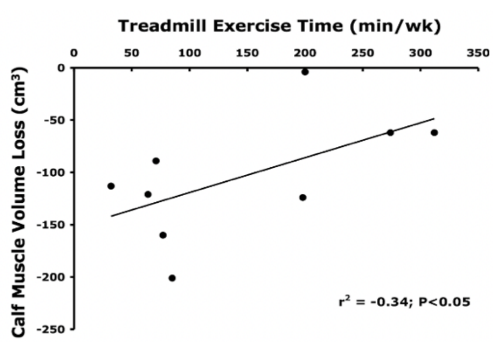


Fig. 5. Correlation between treadmill exercise time (min/wk) while on the International Space Station and calf muscle volume loss (cm^3) with spaceflight.

Figure 32 Correlation between treadmill & calf muscle volume (Trappe et al., 2009)

Microgravity environments affect the musculoskeletal system because the way we hold our bodies and can move around is completely different. While in space, our brain is trying to process a completely new environment while experiencing extreme changes to the systems in the body. A study conducted in 2021 by Johnson Space Center and KBR Houston looked at possible countermeasures to mitigate some of the postural and locomotor control deficits that occur during long-duration space flight.

One finding of this research is that on Earth, upright posture is organized by a combination of joint angles and body segment positions. In space, astronauts' posture shifts forward with more extreme flexion in the ankles, knees, and hips. Because of the forward translation of the foot in microgravity, the stretch reflex at the ankle joint triggers the Tibialis anterior muscle in the front of the leg unexpectedly. With this finding, the researchers suggest that any interventions to help train more upright posture astronauts should allow for increased multi-joint extensions that may occur. This finding is important for the purpose of this project because it suggests that the ankle joints, ligaments, and muscles function differently in microgravity and that allowing more ankle torsion could be beneficial to the locomotive control system (Macaulay et al., 2021).

This study also found that the unloading of body weight decreases the proprioceptive input to our brain through our lower limbs, which causes the balance dysfunction experienced by astronauts. The lack of this proprioceptive input from the feet can even affect an astronaut's ability to raise their arms normally. The research of this study found that the feet are an important balance organ and that changes in the tactile input in the feet have a significant effect on post-flight balance. One way that this study suggests mitigating the decrease in proprioceptive input is to simply provide astronauts with textured insoles (Macaulay et al., 2021). This finding is an example of a direct way that footwear can help prevent the negative effects of microgravity on the body in a simple yet significant way.

General Running Physiology:

When tasked with running for a long distance, the human body uses physiological systems that work together to supply cells with needed energy and allow muscles to contact. Certain physiological characteristics of a particular athlete may largely affect their ability to perform. The three key physiological demands of long-distance running are as follows: the maximal oxygen uptake (VO2 max), the lactate threshold, and running economy (RE). The VO2 max represents the amount of oxygen that the body can utilize during an exercise. When the intensity of a run increases, the demands of the body require a higher volume of oxygen to keep up performance. Therefore, runners that have higher VO2 max values may have faster running speeds. The lactate threshold is the level of intensity at which the body switches over from using aerobic energy to anaerobic energy to power the movements. The running economy is the amount of oxygen that it costs the body to be able to generate a given running speed (Samuels, 2018). These internal physiological measurements are a measure of athletic ability and can help understand the key elements an athlete may need to target in training to enhance performance.

Other factors that influence running performance are external, like the environment or weather. In a 2021 review by Daniel Tang Kuok Ho at the University of Arizona, the association between environmental factors and athletic performance was analyzed. This research found that when running in environments with higher temperatures, athletes' core body temperatures rose. This causes an increase in perspiration and dehydration, leading to overall poorer athletic abilities. The study found that higher environmental temperatures lead to a potential 2-3%

decrease in performance times because more energy is expended by trying to prevent exceeding critical bodily temperature (Kuok Ho, 2021).

A 2015 systematic review looked at the effect of footwear on running performance and running economy in distance runners. After reviewing 19 research studies on the matter, this review found that lighter-weight shoes have significant small beneficial effects on running economy when compared to heavier running shoes (Fig. 33) because less mass carried means less energy expended. The study also found that when the mass of the shoe was controlled for, the shoes with minimalist midsoles produced significantly better running economy than conventional running shoes. When it comes to the density of the cushion elements, this review concluded that there is no real difference in running economy when comparing soft and hard shoes controlled for the same mass (Fuller et al., 2014).

For this research, these studies provide ample background to understand the internal and external factors that affect running physiology. When designing new cushion solutions for running shoes, the tradeoff between cushion needs and overall shoe mass is valuable based on the direct effect it has on running economy.

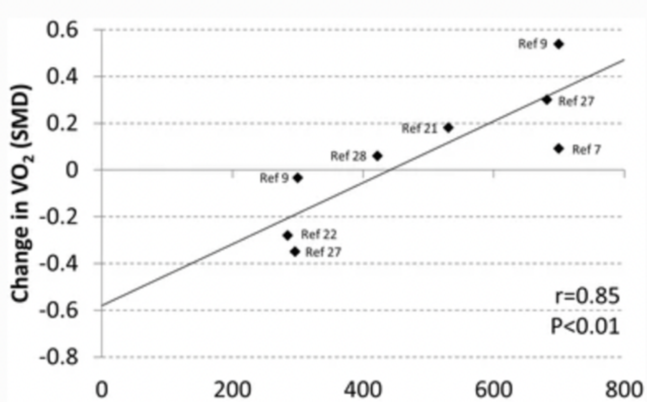


Figure 33 Shoe Mass vs. Change in Vo2 (Fuller et al., 2014)

Biomechanical Research Related to Product Space

Biomechanics of Running in Space:

A study that was published by NASA in 2014 researched the locomotive biomechanics similarities and differences between treadmill exercises of International Space Station crew members in both normal gravity and weightless environments. The study looked at changes in bone density, fracture risk, muscle mass, strength, and endurance of ISS crew members in both environments. Data was collected from 7 astronauts before the flight and during their ISS missions. Before launch, participants performed a single data collection session at the NASA Johnson Space Center. During the flight, each crew member completed up to 6 data collection sessions spread across their missions, where they performed their normal exercise prescription for the test day. Tape markers were placed on the feet, legs, and neck to capture 3D motion data with an HD video camera. Kinematic data was pulled from 129 recorded workouts and was analyzed to determine the range of motion of different parts of the body while exercising in zero gravity (DeWitt et al., 2014).

Cross-correlation analyses between gravitational conditions revealed that there were consistent movement patterns at each joint and little to no lag in movement timing. Motion patterns in weightless environments were consistent at a given speed with those occurring in 1G, showing that despite differing sensory input, astronauts can maintain normal running kinematics. The study showed that individuals are capable of compensating for the loss of limb weight when creating movement strategies (DeWitt et al., 2014). These findings are important when creating workout regimens for crew members and designing athletic footwear for missions on the space station because it shows that normal exercise form can be maintained even in a weightless environment.

General Running Biomechanics:

The biomechanical relationship between foot and shoe while running was investigated in a study from the Biomechanics Laboratory of the Swiss Federal Institute of Technology, Zurich. In the study, researchers examined torsion and rearfoot motions in running. The goal of the research was to see if there was any variation in the angles of pronation and torsion when running with track spikes, running shoes, or bare feet (Stacoff et al., 1991).

The two types of shoes have very different constructions and performance properties. Spikes are made to be as lightweight as possible, with minimal sole and stabilizing components, because they are usually only worn during a race. They also have arch cut-outs that allow the shoes to be more torsionally flexible. In contrast, running shoes have enhanced cushion and more rearfoot stabilization, which makes them highly stiff in comparison to spikes but allows them to support feet for long distances. The researchers found that previous literature on this topic cites weak heel counters and high torsional stiffness to be the reason for overpronation and injury in running. At the time of the study, the effects that the different types of shoes might have on the foot were not yet documented. The researchers hypothesized that there would be notable differences in each running scenario and that these findings could help athletes better understand the varying risk of injury between shoe types. This data was collected through timed running trials of nine middle-distance runners on an indoor track at a set pace. Visual markers were placed on the legs and the shoes of participants, allowing the filmed runs to be analyzed accurately to measure the kinematics of the feet (Stacoff et al., 1991).

The study found that running barefoot produces running movements with the most torsion and least pronation. They also found that the stiffness of the shoe plays an important role in running when the foot touches down on the ground. They concluded that running shoes could be improved to allow better and more natural torsional movements to prevent injuries and overpronation (Stacoff et al., 1991).

The study was valuable for proving that footwear choice does have implications for running performance. However, the findings were lacking in depth because they analyzed two completely different types of shoes. For the purposes of this research, the testing parameters could be reused but with a more directed scope: comparing the different midsole cushioning systems specifically within running shoes.

The ideal thickness for midsole cushion in running shoes is a topic that is highly debated. Recently, trends have leaned towards shoes with larger midsoles. Maximal midsoles (MAX) give runners a comfortable, bouncy running sensation by reducing ground reaction force felt while running. One downside of MAX shoes is that the added height can cause balance and stability issues, leading to possible injuries. On the other hand, some argue that running shoes with minimalist midsoles (MIN) prevent injuries in the long run. The reduced cushion in minimalist midsoles provides a more natural, “barefoot” running sensation. More of the ground reaction force is felt, so feet and leg muscles work harder and strengthen over time (Ogston, 2019).

One study conducted by Jena Kay Ogston in the Department of Physical Therapy at the College of St. Scholastica compares the biomechanical responses to minimalist and maximalist cushions in running shoes. The research compared the in-shoe plantar loading forces of two completely different types of shoes; the Hoka and the Arc’teryx Norvan. Ogston studied 15 participants who are recreational runners that wear MAX running shoes. Participants ran for a full minute on a treadmill in both shoes, and PEDARVR insoles collected data for plantar loading force on the total foot, forefoot, midfoot, and rearfoot during key moments: contact time (CT), maximum mean pressure (MMP), peak pressure (PP), pressure time integral (PTI) and force time integral (FTI) (Ogston, 2019).

The test showed a significant decrease in all plantar loading variables for total foot and forefoot when wearing the maximalist shoe. There was more of a difference in the results when looking at the forefoot compared to the rearfoot. Ogston concluded that maximalist running shoes may be a better option for runners who are aiming to reduce force and pressure under the foot during activities (Ogston, 2019). For the purposes of this paper, Ogston's research can inform the product needs and testing methods by providing a framework on how to analyze steps by breaking the movements down into key stance moments.

Psychological Research Related to Product Space

Psychology of Living in Space

Douglas A. Vakoch discusses the psychology of space exploration in his 2011 research paper, *Psychology of Space Exploration Contemporary Research in Historical Perspective*. In this paper, Vakoch explains that astronauts can experience anxiety or stress for many reasons while on a space expedition, including, "riding atop a rocket; rapid changes in acceleration and deceleration; primitive and compact living conditions; isolation from family and friends; close confinement with other people; and the ever-present specter of a collision, system failure, or other disaster" (Vakoch, 2018).

According to an article published by NASA, *Understanding the Psychological Hazards of Spaceflight on the Space Station*, physical isolation plays a huge role on the astronaut's psyche while on a space expedition. The healthy dynamics between crew members are foundational to their ability to perform mission tasks. The success of any space trip relies on individual team members having good mental health and high morale. One of the ways that the mental health of astronauts can stay on track is by creating normal routines. The workout regimen required on the ISS is not only a very important aspect of the physiological health of astronauts, but it is also critical to the daily routine because exercise releases mood-lifting endorphins (Guzman, 2022).

General Running Psychology

In the last few decades, there have been many studies regarding injury prevention in running. While biomechanical and physiological studies can provide a lot of insights, there are also psychological factors that shape athletes' experiences and can influence injuries. In a 2022 study from the Otago Polytechnic Institute of Sport, Exercise, and Health and the Centre for Health, Activity and Rehabilitation Research, School of Physiotherapy at the University of Otago, researchers studied the factors influencing runners' choices of footwear. The study investigated the empirical evidence to back the idea that footwear choice is a risk factor for running-related injuries (Ramsey et al., 2022).

The participants consisted of twelve runners who were a mixture of recreational and competitive runners, both male and female. A series of interviews with these athletes were transcribed and thematically analyzed. The study found that there are fifteen unique factors within three main theme categories that lead to decisions to buy one pair of shoes over another. The three main factors that emerged were: economics, external social influence, and personal shoe characteristic preferences. Economic factors include subthemes such as the cost and durability of the shoes, the availability to purchase, and considerations regarding sustainability. Social influence factors included: opinions of other runners, media posts and product reviews, and conversations with salespeople inside stores. Personal characteristic preferences were the opinion of the brand and model, specific style and specifications of the product, the feeling of comfort and performance when on foot, whether the shoes encouraged proper gait and posture, and if the shoe filled a void in their current footwear rotation (Ramsey et al., 2022).

The conclusion that was drawn from this study was that runners are mainly influenced by the opinions of people that they trust and admire and their own personal experiences. The researchers acknowledged that more studies need to be done to determine whether athlete perception of their footwear contributes to impact injury rates. For this paper, the general themes and considerations of consumers serve a good backdrop for designing future products that resonate well with the target athlete.

User Research

Day in the Life Analysis

A Day in the Life Analysis was preformed to create a general daily schedule of an astronaut stationed on the ISS. The information has been synthesized from NASA ISS Daily Log posts, interviews with astronauts, and informational articles (Fig. 34).

Astronauts on the International Space Station typically work 5.5 days per week and have 1.5 days off for leisure time. A daily schedule is made for each crew member and planned out down to 5-minute increments (Volz, 2020). The specific research activities and timing of tasks may vary between crew members, but a typical daily schedule for an astronaut on the International Space Station (ISS) looks like the following:

1. Wake up: The astronaut's sleep schedule is adjusted to align with the mission's requirements and the ISS's orbit around the Earth. Time is allotted to get dressed and clean their area (May, 2021).

2. Exercise: Astronauts have 2.5 hours of time scheduled for their daily workout. The exercise may include activities such as running on a treadmill, lifting weights, or performing resistance exercises. Time allotted also includes the time it takes to get changed and set up the equipment (Bowen, 2018).
3. Hygiene: Astronauts brush their teeth, shave, and take care of other personal hygiene tasks as needed using special equipment for microgravity. They use “rinse-less” shampoo with a small amount of water to clean their hair (Volz, 2020).
4. Breakfast: The astronaut may have a variety of food options to choose from, including pre-packaged and freeze-dried meals. A special machine dispenses the correct amount of water needed to rehydrate each pouch (May, 2018).
5. Work: The astronaut's workday is scheduled to be 6.5 hours long and may include a variety of tasks, such as conducting experiments, performing maintenance on the ISS, participating in spacewalks, and communicating with Mission Control (Volz, 2020).
6. Lunch: Like breakfast, lunch is chosen from pre-packaged and freeze-dried meal options that are rehydrated. Occasionally there will be fresh fruits and food items that came in a supply shipment that is enjoyed (Mars, 2020).
7. Afternoon: Workday continues throughout the afternoon.
8. Dinner: Evening meal is eaten together as a crew around a large table. This tradition was created to support the emotional wellbeing of the astronauts and make the station feel like a home. Food pouches are secured to the table with Velcro and the crew gets to know each other as they eat (Mars, 2020).
9. Leisure time: The astronaut may have some free time to relax, watch movies, listen to music, or communicate with friends and family on Earth (Volz, 2020).

10. Sleep: Astronauts have 8.5 hours of scheduled sleep time each day. They must strap themselves into position, so they do not float around or bump into anything (May, 2015) (Volz, 2020).

Figure 34 Daily life of astronauts on the ISS (Mars, 2020)

(Student Project: Imagine You're an Astronaut, 2020)

Astronaut Personal Inventory

On current missions to the International Space Station, astronauts are allowed 3.3 lbs. (1.5 kg.) for personal preference items. This is a considerable upgrade compared to previous space missions like Apollo, Gemini, and Mercury, when the weight of personal items a bigger issue due to the size limitations of the rockets. Astronauts take items of personal value that remind them of home and give them joy (Patrinos, 2020). The following is a typical packing list for missions to the ISS (Petty, 2013):

Personal items:

- Toiletries (e.g., toothbrush, comb, deodorant)
- Photos and other personal mementos
- Books, magazines, and other forms of entertainment
- Musical instruments (Fig. 35)

- Journals
- Cameras

Clothing (Fig. 36):

- Flight suits (worn during launch and landing)
- Training suits (worn during training and preflight activities)
- Coveralls (worn during maintenance and repair tasks)
- Shirts, pants, and other casual clothing
- Daily undergarments and socks (disposed of when dirty)
- Exercise shoes
- Sleepwear
- Thermal underwear (worn under the space suit to provide additional warmth)

Figure 35 Saxophone onboard the International Space Station (Patrinos, 2020)

Figure 36 NASA Astronaut Cady Coleman with some personal items (Lockman, 2022)

Expert Interviews

To gain further user experience research for this project, conversations with experts working in the space industry provided valuable insights into the process of creating successful products for astronauts on the International Space Station (ISS) and other human spaceflight expeditions. The following experts shared their knowledge and experiences designing space products:

- Dan Klopp, previously the Director of Marketing & Business Development at ILC Dover's Space Systems Division designs and manufactures EVA and LEA Spacesuits, Inflatable Space Habitats, and Spacecraft landing systems
- Terrick Eto, Soft Goods Designer and Sewist at Axiom Space
- Cathy Lewis, curator of the space suit collection at the Smithsonian National Space & Air Museum
- David Gabriel, Senior Industrial Designer at Sierra Space, formerly a Human Factors Industrial Design intern at NASA
- Danica Remy, president of B612 Foundation

Interviews with these experts were mostly open discussions that began with the following questions:

1. What are the main guidelines and regulations for soft-good materials for space travel or inside space stations?
2. What are the most important considerations when developing products for space?
3. How do microgravity influence apparel and footwear design for space? Do the changes to the body in microgravity affect the fit or feel of footwear/apparel?

4. Are there any common pain points with apparel or footwear for astronauts in microgravity environments?
5. Do muscle atrophy and bone density loss come into play when designing products for astronauts?

Expert Interview Findings:

The most mentioned consideration from these industry experts when designing products that will be used by astronauts is the microgravity experience. The absence of gravity in space requires designers to think about how products will function differently than when on earth and consider the experience that someone would have in a confined, weightless environment. For example, designers must think about how objects will behave when released and how they can be secured to prevent them from floating away. David Gabriel shared that astronauts are often exhausted after dealing with the physical and mental stress of adjusting to microgravity. Gabriel pointed out, "the extremely high cost of space travel makes time an incredibly valuable thing [to crew members]. Meaning that products need to help save time and energy, not make the day-to-day more complicated."

Following microgravity, human empathy for the astronauts is also important. The physical and psychological well-being of astronauts depends on products that are ergonomic, comfortable, reduce stress, and strengthen health.

Other main considerations that these experts pointed out include:

- Limited resources: The ISS has limited space and resources, so designers must create products that are compact, lightweight, and efficient.

- Safety: The safety of astronauts is of the utmost importance, so designers must ensure that their products do not introduce any additional hazards or risks, especially in terms of fire and bacteria growth.
- Maintenance and durability: The ability to maintain products and for them to stay useable is crucial, as it is not feasible to bring replacement parts or tools from Earth on every mission. Designers must create products that are easy to maintain and repair using the resources available on the ISS.
- Compatibility with other systems: The ISS is a complex system with many different subsystems and components, so designers must ensure that their products are compatible with these systems and do not interfere with their operation.

Astronaut Interviews

Space Explorers: The Infinite is an immersive and interactive augmented reality experience that walks participants through an actual full-scale 3D model of the International Space Station. This experience was made in collaboration with NASA and TIMES Studios and is the largest production ever filmed in space. This AR experience was attended in Richmond, California to gain further user research for this project. In the interior of each module of the ISS, astronauts explained their personal experiences in space while they unfolded in real time. These interviews revealed some of the challenges and demands that astronauts face while adjusting to life in microgravity, as well as the strategies that they use to cope with these challenges. It is one thing to see photos or watch videos of astronauts, but the Infinite Experience showed how the human body fits and floats inside the confines of the station, offering information on the placement and use of navigational foot rails, hoops, and straps throughout each module of the ship. For this project, the module with the most important information was the exercise room.

This module provided an interactive, 360 ° tour of the workout area, the special equipment that is used, and astronaut experiences while getting ready and completing their exercise (Fig. 37) (Felix & Paul Studios, 2022).

Figure 37 Photos from the Infinite Augmented Reality Experience in Richmond, CA (Felix & Paul Studios, 2022)

Key Quotes from Space Explorers: The Infinite

“Adapting to live in space has been a process. [I] Got here initially and I was crashing everywhere. I was losing everything because everything floats away from you if you don’t put it in your pocket or use Velcro to tie [it] down… or maybe an elastic bungee. I was looking at our colleagues who had been here for several months already and I was wondering how can they be so efficient and so in control of their movements? Well, lo and behold, after a couple of weeks I found myself, surprisingly, to be very efficient moving around.” – David Saint-Jacques, NASA astronaut of the class of 2013 (Felix & Paul Studios, 2020)

“One of the things that I think about is that it’s not that I am one of the first women to be *able* to do this, that I am simply one of the first *allowed* to do so.” – Anne McClain, NASA astronaut of the class of 2013 (Felix & Paul Studios, 2021)

"The closer we get to making space more accessible to everybody, the closer we get to being a truly space-faring species." – Anne McClain, NASA astronaut of the class of 2013 (Felix & Paul Studios, 2022)

"I think it is incredibly important that the crew members connect with each other and function well with together, because as you can see right here (Fig. 38), we are constantly working right on top of each other." - Christina Koch, NASA astronaut of the class of 2013 (Felix & Paul Studios, 2021)

Figure 38 Astronauts working on top of each other on the ISS (Felix & Paul Studios, 2021)

Astronaut Feedback

It can be difficult to get in direct contact with astronauts for a variety of reasons. Astronauts are often busy with their training and missions and there are so few of them, so they may not have time to respond to individual requests for feedback.

One way to overcome these challenges is to seek the feedback and product reviews of the industry experts who work in the space industry and design for astronauts. For example, industry contacts at Sierra Space and Axiom have agreed to give product advice from their perspective as this project develops. They are also willing to pass along quick surveys to astronauts and facilitate communication in some other ways if schedules allow it.

It's worth noting that getting feedback from astronauts can be very valuable, as they have unique insights and experience with microgravity that could help inform the design of astronaut shoes. However, it's important to be realistic about the challenges and limitations of getting in touch with astronauts directly and consider alternative ways of getting their feedback or advice. By working with industry experts and leveraging their connections and expertise, the project can receive the successful insights needed to improve footwear designs.

Design Process

The key product features and functions were decided after synthesizing the above research and analysis of the competitor products and then ideating upon possible solutions. From there, new product technologies were developed, prototyped, and tested. The following sections will provide readers with the steps to create the final workalike models for the RIDE product line.

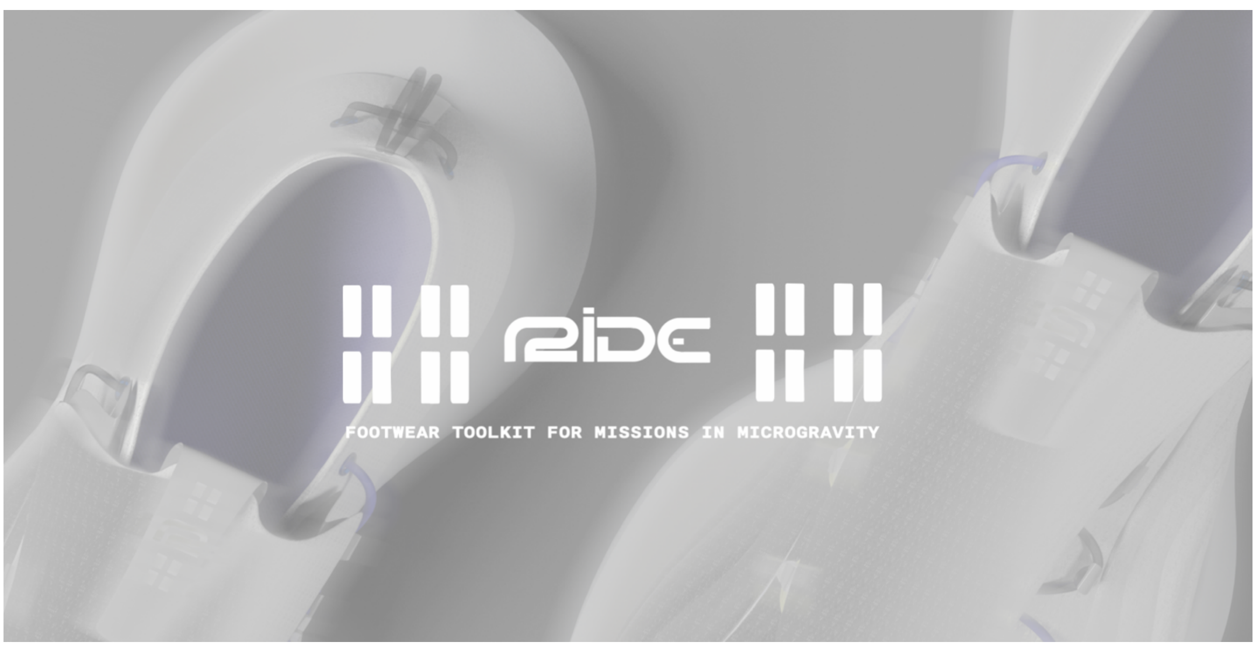


Figure 39 Ride Footwear Logo

Summary of Environmental Constraints

There are four key lifestyle factors that shape the daily lives of astronauts on the International Space Station and that will influence the design of any product created for use on the space station. The microgravity environment changes how people and objects interact around the station and how the human body functions. The cost of sending one pound of cargo to the ISS is $10,000 meaning that everything must have a significant purpose to the mission and be worth taking (Brian Dunbar, n.d.). Water consumption is limited on the ISS due to the cost of bringing it. Moisture is pulled from the air and processed to generate drinking water while on a mission (O'Callaghan, 2020). The research that astronauts do on the ISS takes up most of their day. They work at different lab areas located around the space station performing tests and research on a plethora of topics (Dunbar, 2023)

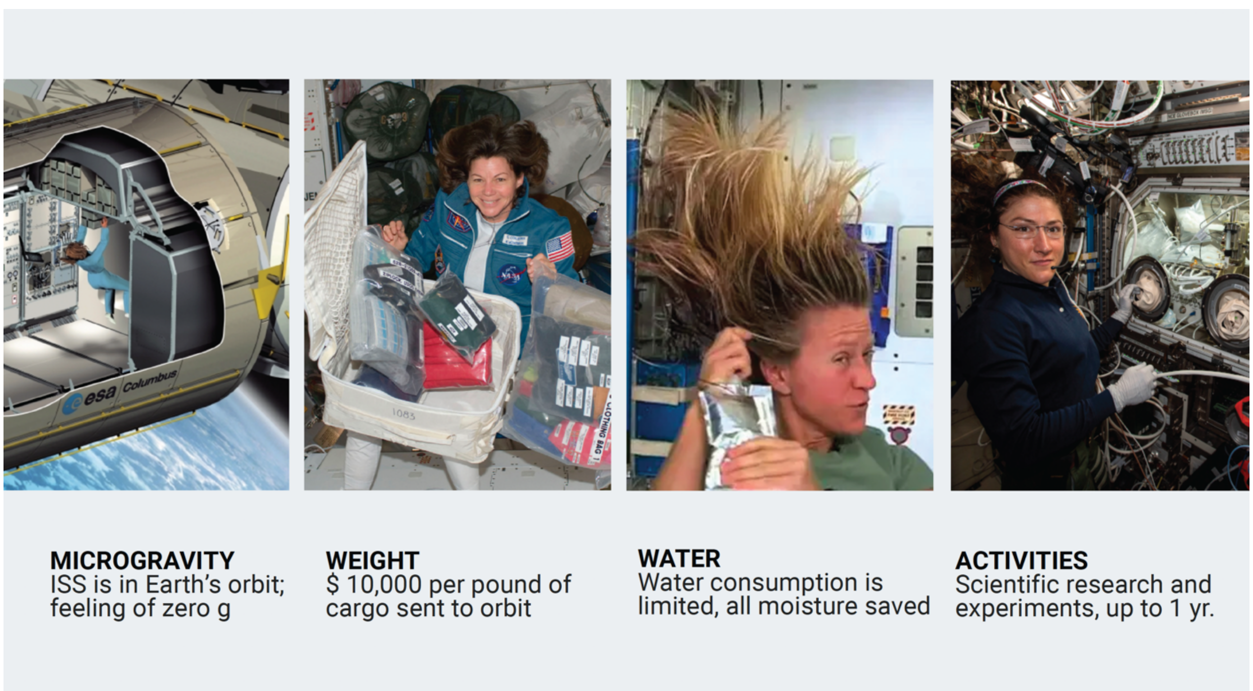


Figure 39 Key Lifestyle Factors on the International Space Station

Summary of Bodily Changes in Space

For this project, there are five main changes to the body in a microgravity environment. Fluids sit higher up inside the body without gravity pulling them downward (Mars, 2022). Because of this, the face tends to swell while the legs and feet shrink. Similarly, sweat is affected by the lack of gravity. Instead of moving down to our feet, sweat pools at the glands and stays put (Greenfieldboyce, 2022). The lack of gravity means that there is no loading force to keep our muscles activated while keeping our bodies upright. Because of this, the muscles of the body are significantly atrophied after just a short while in microgravity. In space, astronauts do not flex their foot in the way that we do while standing and walking on Earth. In microgravity, the feet stay relaxed with toes pointed downwards most of the time, which neglects to activate the calf muscles leading to even more muscle atrophy in that area (Macaulay et al., 2021). The top of the feet become chaffed and hardened with callouses due to the constant rubbing against foot rails used to navigate around the ISS (Pomeroy, 2017). Lastly, the feet become hypersensitive due to the lack of underfoot stimulation, which causes balance issues and foot pain when returning to Earth (Macaulay et al., 2021).

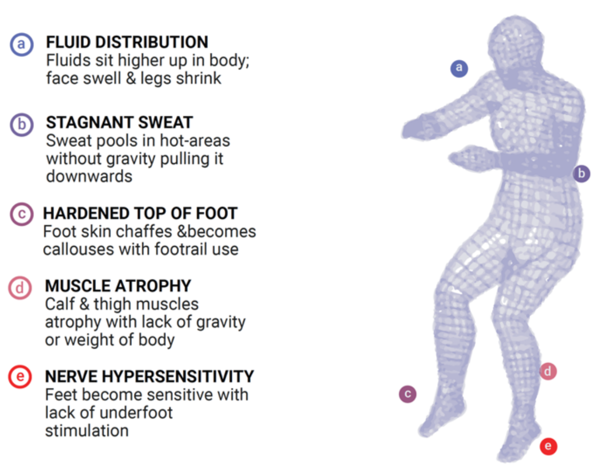


Figure 40 Changes to the Body from Microgravity

SWOT Synthesis

After analyzing the main competitor products for footwear worn on the ISS key strengths and weaknesses surfaced. Astronauts generally just wear ankle socks around the space station to keep their feet warm. The strength of this product is that ankle socks are cheap to buy in bulk and easy to dispose of after use. However, they do not provide adequate protection for the top of the feet of astronauts. The competitor product for the workout shoe, the Asics Gel Kayano, is a basic running shoe that has a very secure upper with leather quarter panel pieces to for a stable lockdown. However, in the context of space travel, these shoes are very heavy with a chunky midsole and an upper with many thick layers.

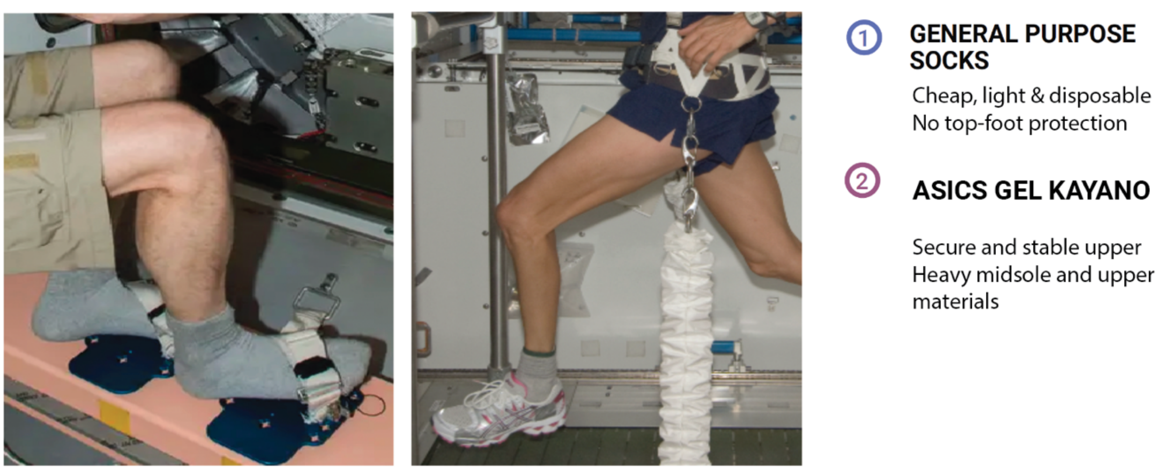


Figure 41 SWOT Summary

RIDE Line Plan

The product line plan for RIDE includes the Tranquility Runner and the Harmony Bootie, which are named after nodes on the ISS. The Harmony Bootie is a sock-like bootie for all-day wear around the space station that provides underfoot stimulation, top-of-foot protection, and activates the muscles in the arch of the foot. The Tranquility runner is an exercise shoe specifically designed running on the T2 treadmill and weightlifting on the ARED machine on the ISS. It features lacing system for better donning and doffing in microgravity, a midsole that promotes a mid-foot strike and a natural ankle torsion, and enhanced airflow through the midsole and upper for moisture management.

Figure 42 RIDE line Plan and Product Goals

Aesthetic Direction

The refined visual aesthetic direction for the RIDE product line is futuristic and clean. While the forms and embellishments are largely influenced by space products, the use of textured materials creates a unique tactile experience. The color palate blends traditional space with saturated pop colors used sparingly to emphasize product features.

Figure 43 Aesthetic Direction

Sketching & Initial Ideation

The intial sketch phase explored differnet patterning options of the upper of both the bootie and athletic shoe, considering different closure mechanisms, protection elements, and structural pieces. A general sweat map of a foot was used to explore material use, airflow, and vents throughout the shoe.

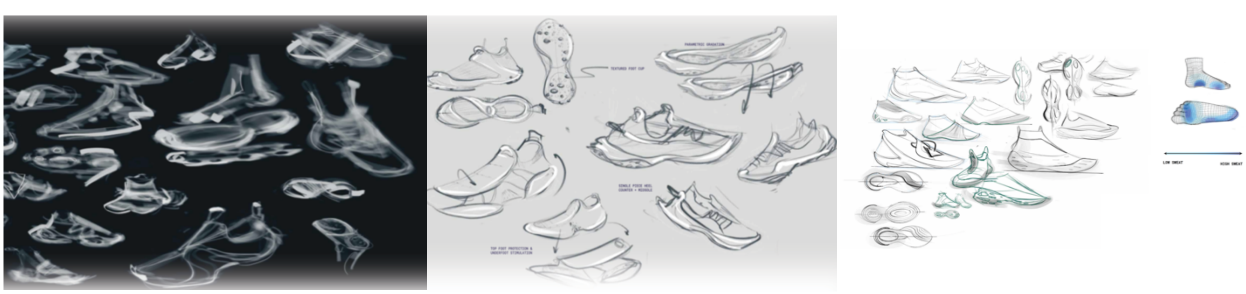


Figure 44 Initial Sketches

Prototyping

The prototyping phase of this project started with rapid prototypes that explored bootie construction and patterning through sock teardowns. The next phase explored placement and material choice for the top-of-foot reinforcement for the bootie. The third phase of prototyping included extensive tape-up prototypes with semi-functional elements to refine the lacing system and upper components. Next, 3D modeling of the midsole explored various shapes and proportions of the midsole as well as different parametric patterns that could be utilized in a 3D print to create more airflow and a lighter-weight product. After the 3D model was developed, 3D prints were executed on both an FDM printer using a flexible TPU filament and a SUNLU printer with a nylon-like filament. From there, the 3D models were used to make silicone molds to cast the midsole in foam.

Figure 45 Prototyping Phases

Testing

Material Timed-Dry Test

To determine if the material selection for the Harmony bootie and the Tranquility Runner upper were better at managing moisture than the baseline products, a timed dry test was performed. Swatches weighing exactly 1.5 grams were cut from both the new and the baseline products. Each swatch was then placed in a water dish for five seconds, weighed, then set aside. Each swatch was weighed again after 10, 15, 20, 25, and 30 minutes to see how fast the moisture was evaporating from the material. The findings from this test proved that the proposed materials for both the TerraTech Bootie and the G0 Runner preformed slightly better than the baseline. These results are promising but alternative material exploration should be done to maximize the moisture management capabilities of each shoe.

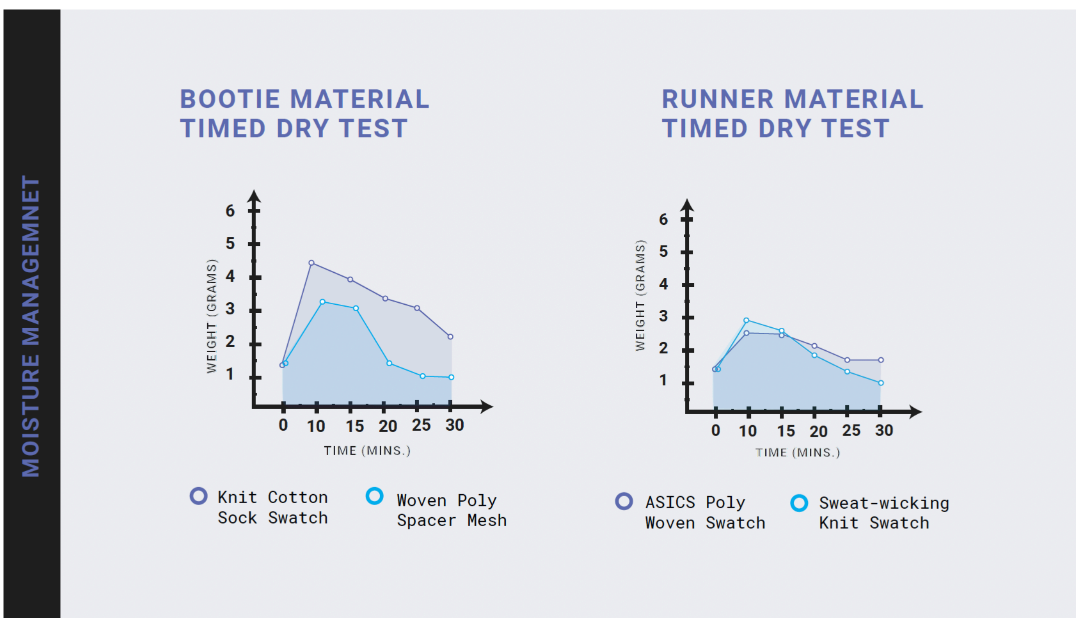


Figure 45 Dry Time Test

Donning and Doffing Test

A timed donning and doffing test were used to determine if the new lacing system of the Tranquility Runner might aid in putting on the shoe quicker and easier in a microgravity environment. For this test, three participants sat on a stool with their legs extended in the air. The first timed test recorded how fast the participant could untie the Tranquility Runner shoe, put it on their foot, and lace it tightly, without putting the foot or shoe on the ground for leverage. This test was repeated with the baseline Asics running shoe. The results showed that in general, the Tranquility Runner system resulted in faster donning times, though there was a notable learning curve because the laces in unusual places.

The second test recorded the amount of time it took for the participant to unlace the shoe and remove it from their foot entirely. This was repeated for both the baseline and the Tranquility Runner. The results showed that the Tranquility runner was quicker to get off the foot.

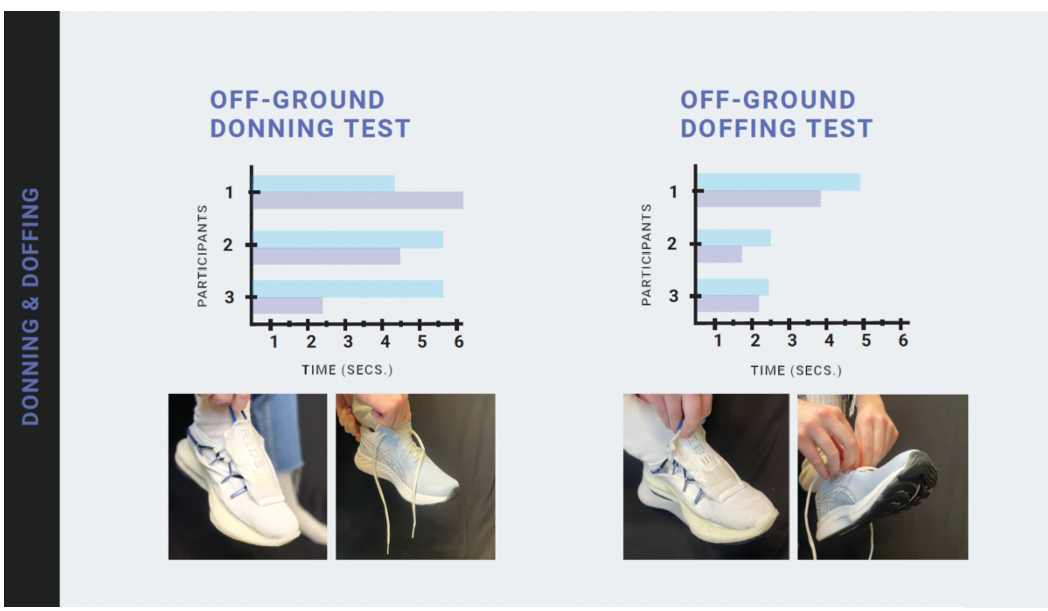


Figure 46 Donning & Doffing Test

Top of Foot Protection Test

A miniature footrail was constructed out of PVC pipes in order to conduct tests to see what specific areas of the top of the foot are affected by the footrail use. In this test, the rail was coated in chalk and then a participant studied videos of the foot movements of astronauts on the ISS. Then, the participant acted out each of the different foot movements under the rail. The chalk indicated where the foot was rubbed by the bar the most and where the bootie needed to protect the foot. A follow-up test was conducted to ensure that the final bootie prototype protected the foot in the proper areas. This test showed that there needs to be more protection on the vamp of the foot. The TPU overlay might also function better as protection if there was a layer of foam padding underneath.

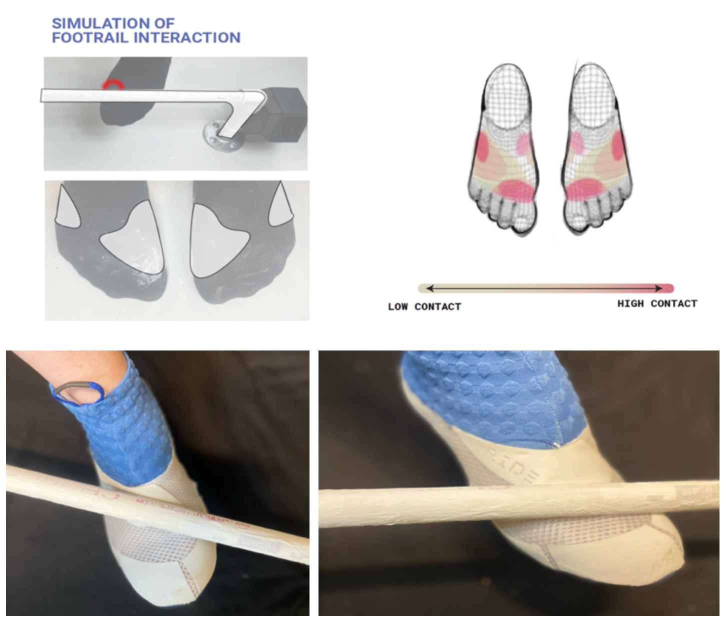


Figure 47 Top-of-Foot Protection Test

Gait Analysis Testing with RunScribe Sensor

The testing protocol for evaluating the design of the Tranquility Runner required the use of an AlterG treadmill to simulate the microgravity environment of the International Space Station. The protocol consisted of two 5-minute runs, during which the subjects wore the new design shoe as well as a control shoe. To gather data on gait and ground reaction forces, RunScribe sensors were attached to both shoes. During each 5-minute run, the subjects' gait data was collected using the RunScribe sensors. The sensors captured various biomechanical metrics such as cadence, ground contact time, foot strike type, and pronation excursion. This data provided insights into the subjects' running form and allowed for a comparison between the control shoe and the new design.

The sensors measured metrics related to shock and impact forces, including vertical oscillation, impact G's, and braking G's. Overall, this testing protocol provided a systematic approach to evaluate the new running shoe's performance in a microgravity-like environment. The results showed that compared to the control shoe, the final design of the Tranquility Runner did change the testing subject's gait in the intended ways. In the control shoe on the Alter-G treadmill, the sensors revealed a fore-foot strike pattern. Once the new design was tested, the gait changed to a heel-strike pattern. This will be beneficial to astronauts on the space station because a ground-strike pattern that further back on the foot activates the calf muscles and ligaments in the lower limbs more than with a toe-strike gait (Cavanagh, 2015).

Figure 48 Testing on Alter-G Treadmill with RunScribe sensor

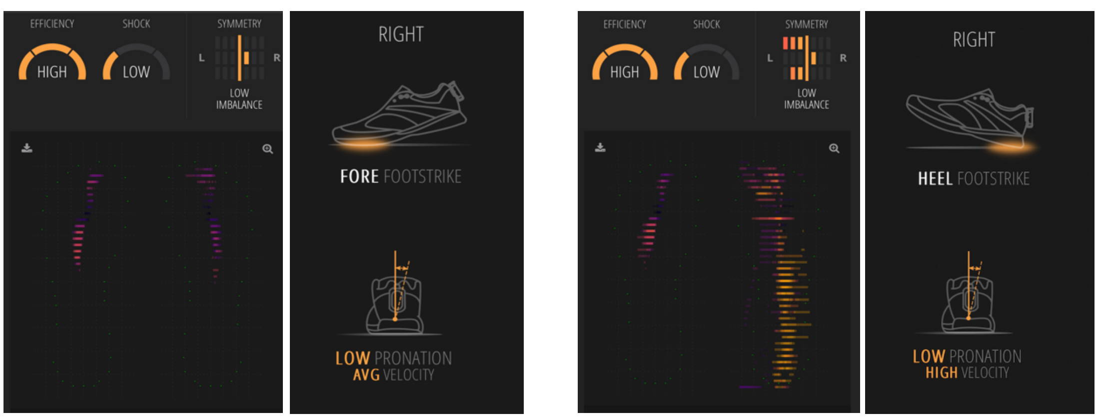
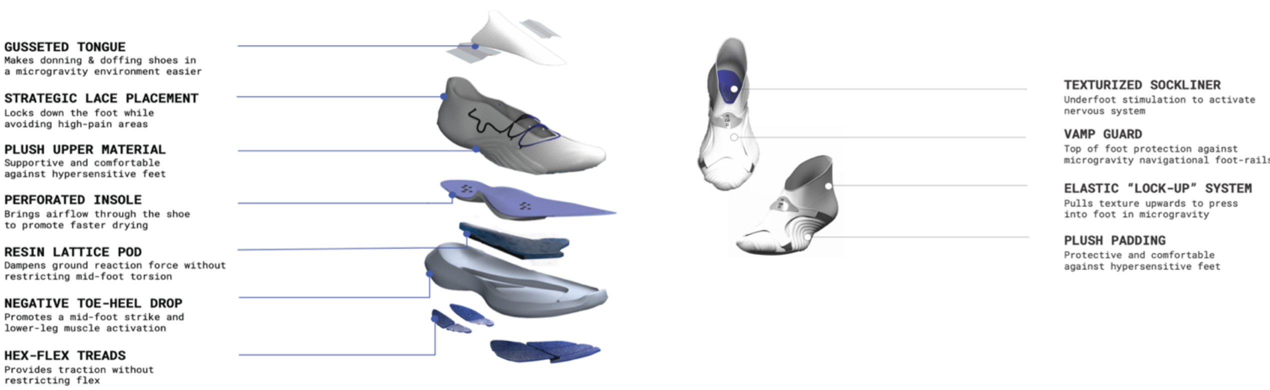


Figure 49 RunScribe data for Asics Gel Kayano (left) & Tranquility Runner (right)

Final Models

Features & Benefits



Final Prototypes

Designer Introduction

Kat Hazen received her bachelor's degree in industrial design from the University of Washington in 2019. During her undergrad, she worked as a Textile Design Intern at Knoll Furniture and attended a footwear design program at Pensole Academy, focused on colors, materials, and finish. Following her undergrad, Kat was an associate footwear designer at Crocs, focusing on in-line classics and international collaborations. Kat is now pursuing her master's degree at the University of Oregon in Sports Product Design to play in the project space where performance and innovation coalesce. Her first-year projects explored areas including space boots for future Mars astronauts and injury prevention for lateral ankle-rolls in women's soccer. This summer, she interned with Kik Laboratory, a local footwear innovation studio, where she created new tooling, redesigned uppers, and developed color stories for multiple companies. Following graduation, Kat aspires to work as a footwear designer focusing on innovation and technology.

Personal Strengths

The Clifton Strengthsfinder assessment is a survey that guides the discovery of one's individual strengths. The survey analyzes personal patterns of thinking, feeling, and behaving to determine someone's strongest talent areas (Rath, 2017). Based on their assessment, my top five strengths are:

1. <u>Futuristic</u>: People exceptionally talented in the Futuristic theme are inspired by the future and what could be. They energize others with their visions of the future.

2. Adaptability: People exceptionally talented in the Adaptability theme prefer to go with the flow. They tend to be "now" people who take things as they come and discover the future one day at a time.
3. Ideation: People exceptionally talented in the Ideation theme are fascinated by ideas. They can find connections between seemingly disparate phenomena.
4. Empathy: People exceptionally talented in the Empathy theme can sense other people's feelings by imagining themselves in others' lives or situations.
5. Strategic: People exceptionally talented in the Strategic theme create alternative ways to proceed. Faced with any given scenario, they can quickly spot the relevant patterns and issues.

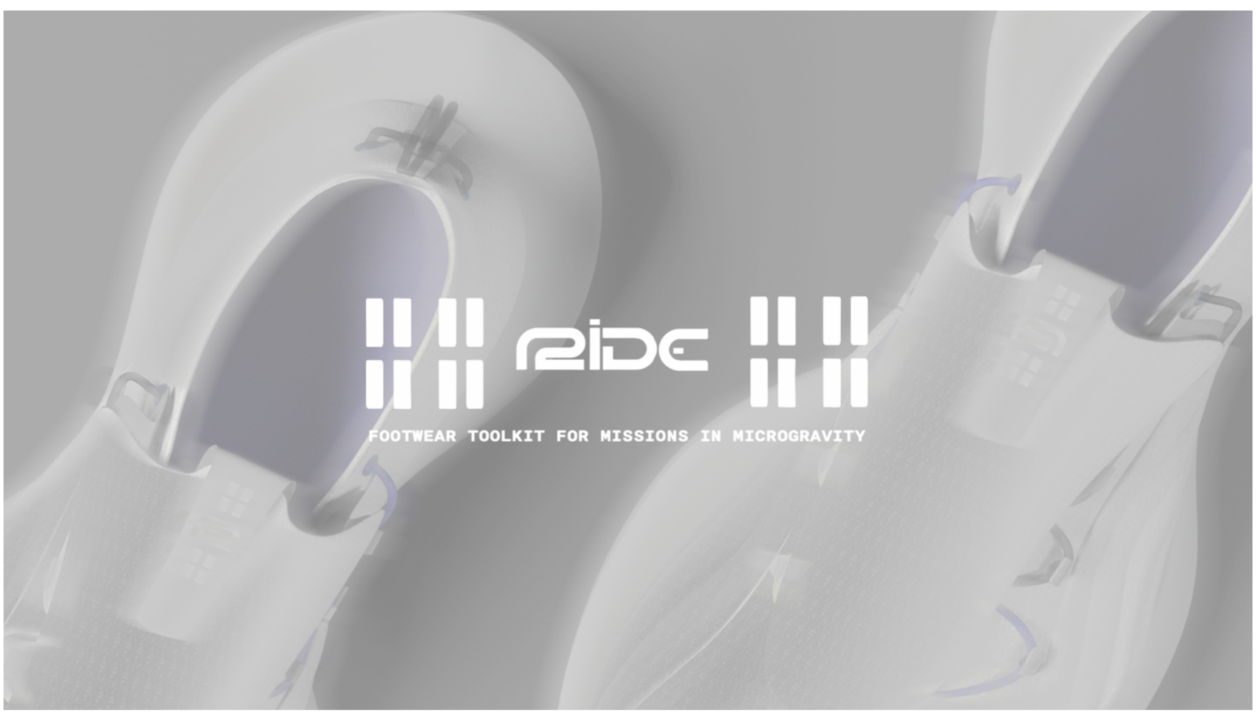
These characteristics will be beneficial to shaping this project because they all sit in the strategic thinking or the relationship-building categories, both of which are very important to the design process. My top strength, being futuristic, allows me to dream about distant possibilities and ask, "What if?" I have always been drawn to new technologies and innovations that are able to push boundaries and disrupt the norms. This project explores the future possibilities of midsole cushions and challenges the current status quo of aesthetics, manufacturing, and performance technology. My ideation and strategic strengths will help me to think big picture, explore all possible ideas, find alternative solutions to problems, and execute deliverables in a purposeful way. In addition, my empathy and adaptability skills will allow me to connect with my target users and better understand their wants and needs.

My design career, goals, and dreams are largely influenced by the contrast of my two top skills: futuristic and adaptability. On the one hand, my work is inspired by the distant future – cutting-edge technologies and disruptive innovations. On the other hand, I am grounded in the "now" and tend to go with the flow. The juxtaposition of these two thought patterns will allow me to execute realistic footwear innovation projects by reaching for the stars but then being able to bring them down to earth in a pragmatic fashion.

Golden Circle

Products should only be created if they bring something new to the table; otherwise, the market is diluted and wasteful. I believe that variation is the foundation of evolution and that a better future can only begin when we dare to think differently. To achieve this goal, my designs will push the boundaries of performance innovation and aesthetic differentiation through thoughtful research and user empathy. The result will be footwear products that will stand the test of time and challenge the status quo.

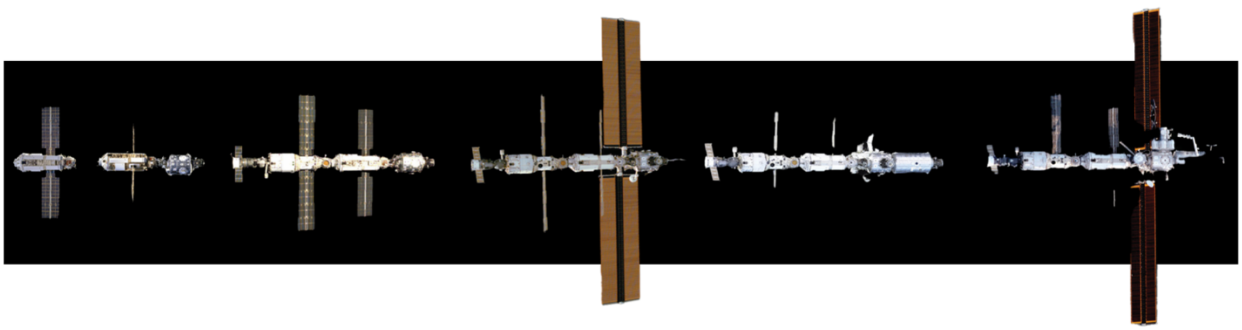
Appendix

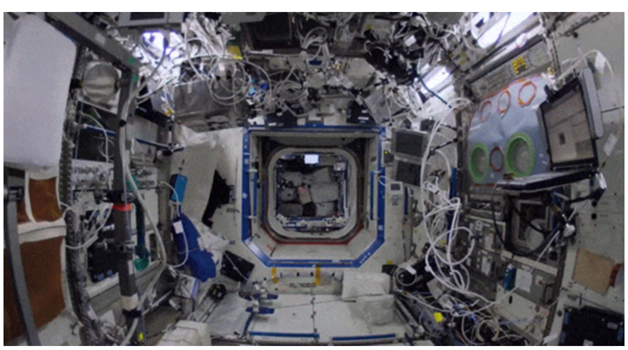


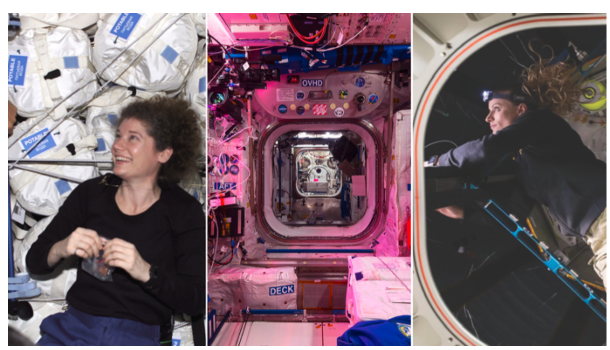
INTERNATIONAL SPACE STATION

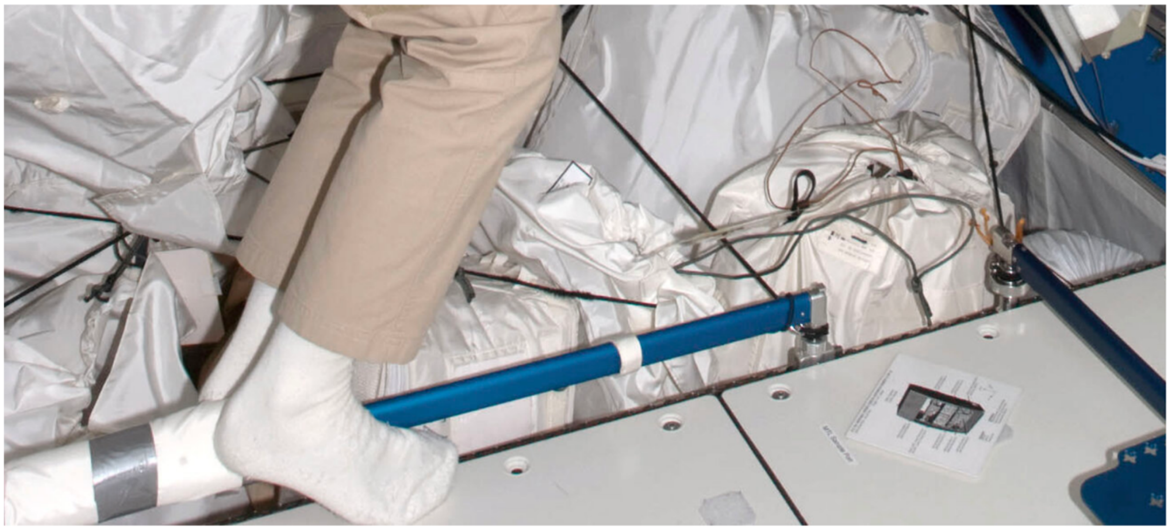
MISSION:

Enable long-term exploration of space & to provide scientific research to people on Earth.

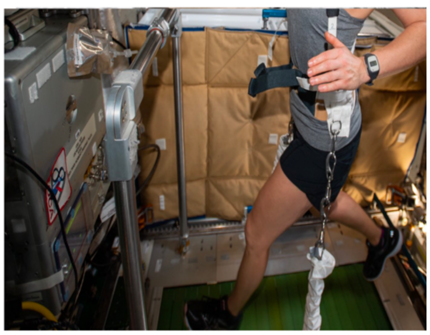




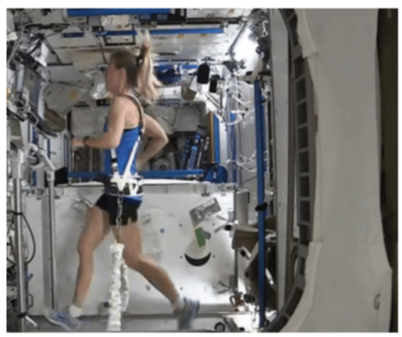




FOOTRAILS
Help astronauts navigate in microgravity and anchor themselves in place



DAILY EXERCISE
A customized 2.5 hour workout is scheduled for each individual astronaut every day



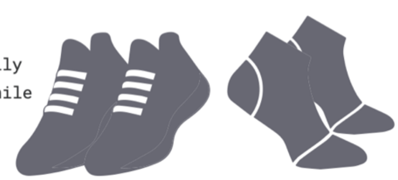
T2 TREADMILL
User is strapped to treadmill to simulate the force of gravity while running

ARED MACHINE
Multi-purpose weight machine to target muscles around the entire body

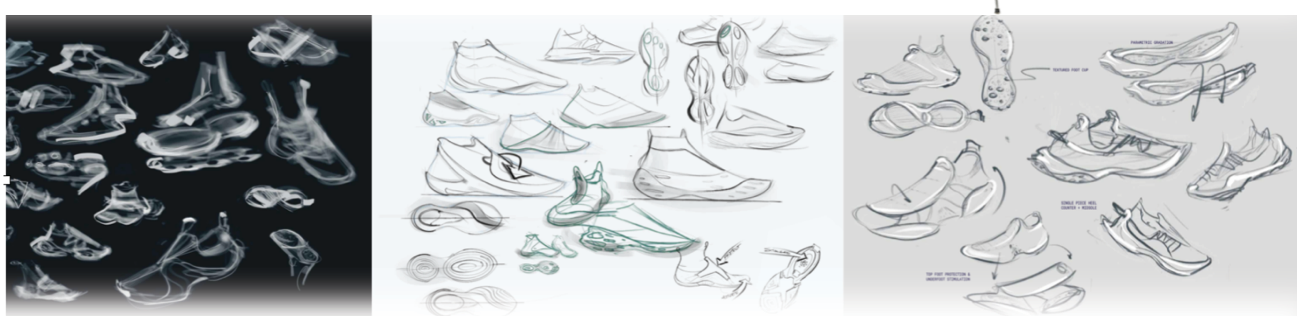
MUSCLE ATROPHY
Astronauts face a long road of rehab when they return to space, with difficulty walking and picking themselves up off the ground due to weakened back and leg muscles

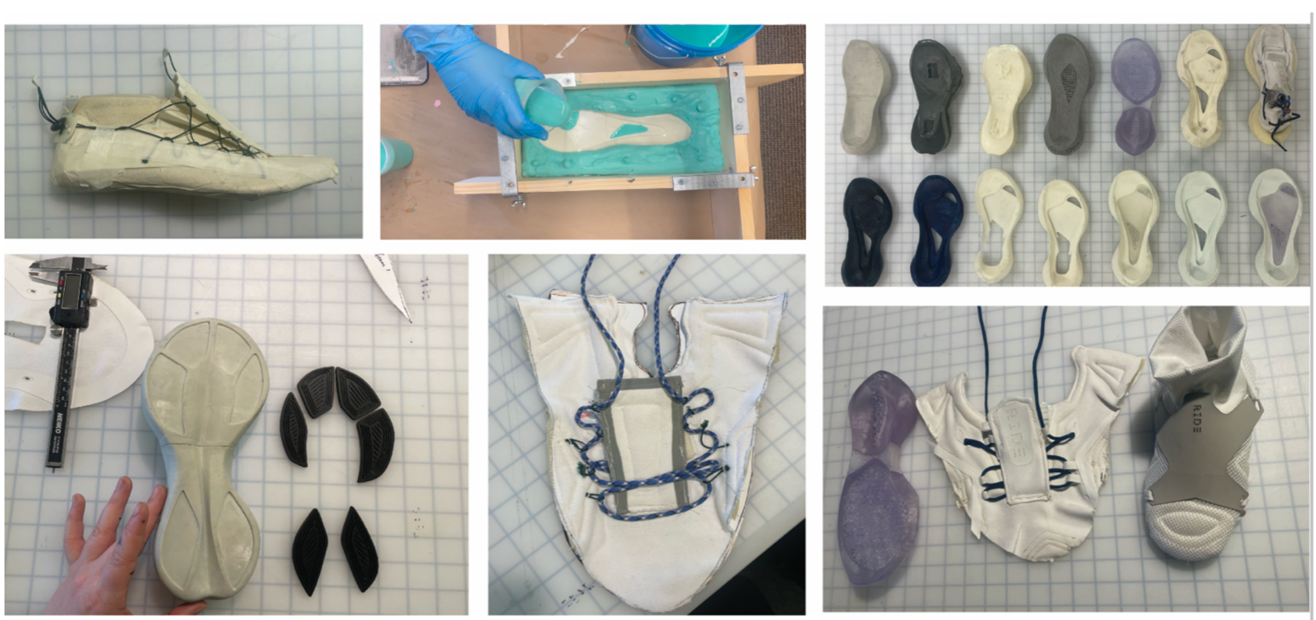
NERVE HYPERSENSITIVITY
After not being stimulated for months, nerves become hypersensitive which can cause months of pain.

EXERCISE SHOES
For wearing during the 2.5 hours of daily excersize, running on a treadmill & while using the weight machine.

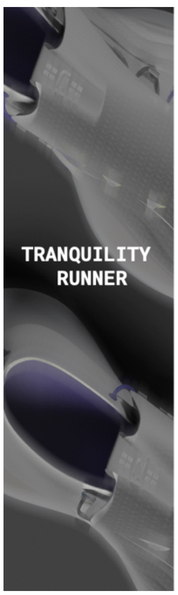


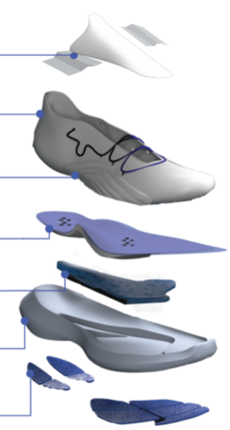
BOOTIES
For wearing throughout the space station during daily tasks to provide foot comofort and protection.






RIDE
FOOTWEAR TOOLKIT FOR MISSIONS IN MICROGRAVITY


TRANQUILITY RUNNER


GUSSETED TONGUE
Makes donning & doffing shoes in a microgravity environment easier
STRATEGIC LACE PLACEMENT
Locks down the foot while avoiding high-pain areas
PLUSH UPPER MATERIAL
Supportive and comfortable against hypersensitive feet
PERFORATED INSOLE
Brings airflow through the shoe to promote faster drying
RESIN LATTICE POD
Dampens ground reaction force without restricting mid-foot torsion
NEGATIVE TOE-HEEL DROP
Promotes a mid-foot strike and lower-leg muscle activation
HEX-FLEX TREADS
Provides traction without restricting flex


HARMONY BOOTIE


TEXTURIZED SOCKLINER
Underfoot stimulation to activate nervous system
VAMP GUARD
Top of foot protection against microgravity navigational foot-rails
ELASTIC "LOCK-UP" SYSTEM
Pulls texture upwards to press into foot in microgravity
PLUSH PADDING
Protective and comfortable against hypersensitive feet


RIDE
FOOTWEAR TOOLKIT FOR MISSIONS IN MICROGRAVITY

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