“Poster”

Abstract

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X. Introduction

In today's industrial landscape, welding plays a vital role in building and maintaining our world's infrastructure. However, welding is also a hazardous job, and requires significant physical efforts from the worker. Hazards such as toxic fumes, fire or shock risks, and loud noises are paired with musculoskeletal risks in lower or upper back, neck, upper arm, and wrist area. These problems in turn create market opportunities which can be stimulated or subdued by government policies and their advisory organizations, depending on the overall benefit of the provided solution weighted against the cost.

This design project is the collaboration between Translas, a prominent welding company based in the Netherlands, and Skelex, a scale-up company designing exoskeletons. Translas developed an exciting technology in the 8XE fume extractor that extracts the toxic fumes at the source, reducing health risks. However, a common complaint of the new torch is that it's more cumbersome to use, which decreases usability and might also pose an ergonomic risk.
To address this problem, Skelex and Translas are collaborating to create an exoskeleton-like solution that will support and assist workers in handling the new Translas torch.

This project explores various concepts and assesses their feasibility and viability, based on requirements coming from Translas' and Skelex' business case and the context of welding. This is then developed towards a Minimum Viable Product.

X. Primary stakeholders

Translas - A prominent welding technology company that specializes in developing and manufacturing high-quality welding equipment. In addition to their MIG and TIG welding torches they also offer a wide array of welding accessories, such as gloves, helmets, or protective clothing.
Their goal is to improve the acceptance of their Extractor series welding torches by increasing its usability

Skelex - An innovative and technology driven scale-up specializing in passive exoskeletons. With the growing succes of the Skelex-360, a passive exoskeleton supporting overhead work whilst allowing for full freedom of movement, they are looking for new opportunities for products. Having identified the welding industry as a promising market due to the prevalence of physical and repetitive work, Skelex is looking to break into this market.

Welders: Ultimately the most important stakeholder. Welders are skilled tradespeople who use heat to join metal parts together. They work in a variety of industries, including construction, manufacturing, and repair, and they are responsible for creating everything from bridges and buildings to cars and airplanes. In the scope of this project the focus is on MIG welders in industry, who form a major part of the customer base of Translas.

Policy makers - Skelex and Translas both focus on technologies improving the health of various workers by reducing ergonomic and respiratory complaints respectively. As these technologies often have cost and usability complications they are reliant on policy makers like governments, and advisory organs like TNO or Volandis. They can force employers to uphold safety standard, so they are more likely to invest in fume extraction, or raise confidence in emerging solutions like exoskeletons to persuade health insurers to invest in these preventive measures.

X. Welding - Scope and hazards

Welding is defined as the process of joining two materials using high temperatures or pressure (Lasinstituut 2021). Since the second world war there has been a rapid development in arc welding, which uses an electric arc to create heat. There are various types, such as metal inert gas (MIG), Tungsten inert gas (TIG), Flux core, and stick welding, but they all have in common that they use a power source which creates an electric arc between electrode and workpiece. Variations in welding types occur in differences between electrode (consumable or non-consumable), whether material is added and in which way, and how the weld zone is protected against atmospheric contamination.
This project limits itself to metal inert gas (MIG) welding. Here a spool continuously feeds added material to the workpiece through the welding torch. It's connected to a powersource, generally DC, and when the material nearly touches the workpiece an electric arc will create vast amounts of heat and melt both the added material and workpiece. At the same time, an inert gas, conventionally argon, is extruded on the workpiece to protect it against atmospheric contamination - it prevents instantaneous rusting. The workpiece is connected to the negative of the circuit, creating a full loop (Gales et al., 2008).
Figure X shows a simplified schematic of the process.

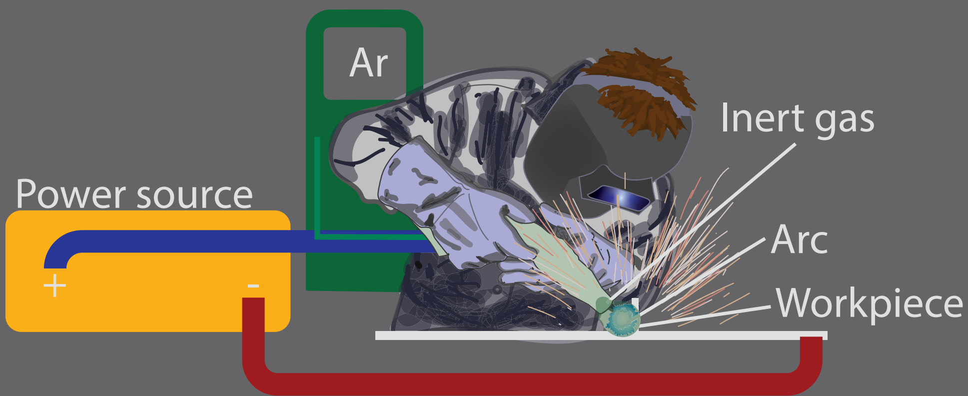
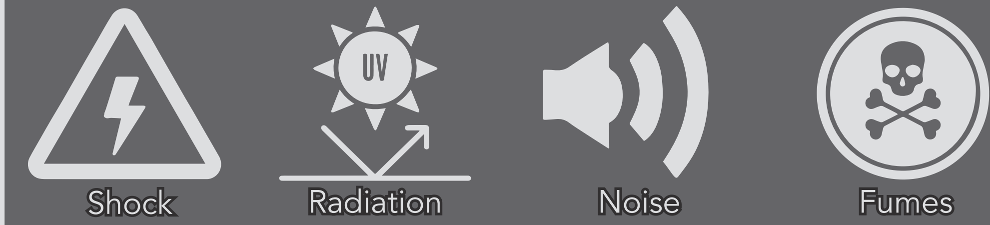


Figure X: Schematic of MIG welding.

Translas' primary product is MIG and TIG welding equipment. In addition they also are involved in robotics, as well as safety equipment such as gloves, respiratory systems, and welding masks (Translas, 2023). This safety equipment is much needed, as welding is a hazardous job, and welders face numerous health risks - both short and long term (Gales et al., 2008).



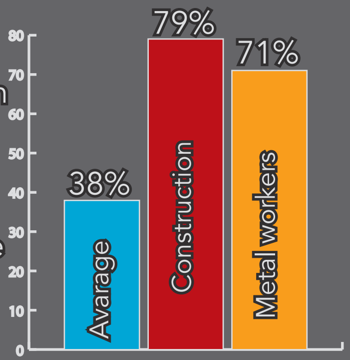
Especially for this last hazard Translas has developed their Fume extractor torch. It features an extractor close to the cup of the torch, through which toxic fumes are suctioned off. It necessiates an additional cable over the regular welding cables, adding weight and stiffness.
Torches are available in a wide array of different amperages. Higher amperages are used in heavy-duty welding applications, such as construction, or shipbuilding - markets where Translas is active.

This project focuses on the welding torches of high amperages (500A), both watercooled, as these are the heaviest products of Translas. The usability complaints are most prominent in this sector, and it's feasible that solving the complains for these products, will solve it for every torch

Figure X: regular and extractor welding torch

X. Welding - Musculoskeletal Disorders

Welding is a physically demanding task compared to other professions. In The Netherlands the experienced physical strain of workers in construction or metalworkers, often welders, is significantly higher than the national avarage (NEA, 2019). It is one of 20 occupations where more than half the population (54%) reported being 'worn out after work' (Kadefors, 2005)



Various studies have investigated the prevalence of musculoskeletal complaints. The results of an Iranian, a Portuguese, and a Indonesian study are shown in Table X. Studies are generally aligned in magnitude and order of prevalence, although the Indonesian study revealed significantly higher wrists/hands and shoulder complaints, and significantly lower elbow and lower back complaints.

Table X: Prevalence MD's according to different studies

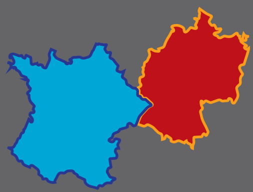
Source	(Ebrahimi et al., 2011) (n=75)	(Susihono et al., 2020) (n=33)*	(Lourenço & Luís, 2021) (n=40)
Region	Welders [%]	Welders [%]	Welders [%]
Neck	82.0	88%	65%
Elbows	72.2	26%	-
Lower back	72.2	44%	50%
Knees	59.0	70%	-
Shoulders	41.0	82%	-
Thighs	36.4	36%	-
Wrists / hands	27.3	52%	23%
Upper back	27.3	24%	35%
Legs / feet	22.7	24%	-

*This study distinguished the right side body parts from the left side. The higher number was chosen for every category to ease comparing

The studies are all based on questionnaires and are based on self assessed complaints instead of diagnosed disorders. To what degree these numbers are representative of musculoskeletal disorders in general is unclear.
The numbers illustrate the magnitude of the overall problem, and show specific design directions for Skelex and Translas.

Suffering from an musculoskeletal disorder lowers quality of life, not only directly through bodily pain (Lourenço & Luís, 2021)
To translate these individual damages to quantifiable metrics useful to organisations and companies one can look at estimated costs of damages.

MD's are responsible for a loss of 0.5-2% of the GNP in The Netherlands and Nordic countries (Swift et al., 2001)



Germany and France, major markets for both Skelex and Translas, can as such be estimated to lose 30-130 billion dollar yearly due to MD's (WPR, 2023).

In more intuitive language 51% of welders attributed at least one period of sickness to MD's, which accounts for 44% of all work days lost (Burdorf et al., 1998). These numbers show that there is a market demand for MD solutions.

Still, the current price of exoskeletons is quoted to be one reason for slow adoption (TNO, 2020). As such, exoskeletons are dependant on companies and insurers to invest. Companies, like Skelex, should not risk making products that form a 'ergonomic risk'

Figur X: Movements in welding require all parts of the arm to work

X. Exoskeletons - criteria

A successful exoskeleton is both accepted by policy makers and by the target demographic. These stakeholders rate the exoskeleton on more than efficacy.

At its core, passive exoskeletons are tools to reduce physical strain on the body by transfering forces in critical points to other parts of the body. In various review studies (Toxiri et al, 2019), (McFarland et al, 2019), (De Vries et al, 2019) efficiency of an exoskeleton is rated on direct (physical strain), short term (fatigue & discomfort), and long term effects (health). These effects and their measurable parameters are summarised in Table X.

Table X: Parameters for exoskeletons

Physical strain	Fatigue & discomfort	Health
• Experienced strain • Muscle activity (EMG) • Heart frequency • Oxygen uptake • Joint moments • Internal forces	• Locally experi-enced discomfort (LEC) • Endurance time work task • Changes in mus-cle activity (EMG)	• Prevalence and incidence of health com-plaints

According to De Vries (2019) it has been shown for upper extremities passive exoskeletons (like the skelex-360) to reduce physical strain, and fatigue or discomfort, which in turn might reduce long term injury.

Still, advisory organisations like TNO are hesitant in recommending the use and development of exoskeletons due to long term risks summarised in table X (TNO et al, 2020). These risks were stressed in an interview with a ergonomy expert (Casper, 2023). Any proposed design for an exoskeleton should be mindful of these risks, as it could influence the long term acceptance of exoskeletons.

Table X: Long term risks of using exoskeletons (TNO et al, 2020)

1	Exoskeletons might influence the natural movement of the body, and interfer with a complex system.
2	Exoskeletons might influence the natural movements of the body: some muscles work less, some work more.
3	Getting used to the exoskeleton might negatively influence worker behaviour.
4	Exoskeletons use straps and other features causing local stresses. There might be longterm effect not yet understood.
5	Undesired side-effect : weakening of the muscles.

The acceptation of exoskeletons depends on the experience of the users. They generally prioritise immediate and short term effects, and generally weigh the reduction of required effort against a wide array of usability complaints. Acceptance is also dependant on imago. See table X.

Table X: Factors determining the acceptance or 'intention to use' of exoskeletons

Positive	Negative
• Reduced effort • Less discomfort • Less fatigue (Bosch et al, 2016), (Spada et al, 2018), (de Vries et al, 2020a)	• Restraining freedom of movement • Difficulty donning / doffing • Damage to work due to protruding parts • Pressure • Heat (de Vries et al, 2020b), (Spada et al, 2018), (Hensel and Keil, 2019)
• Image: responsible (TNO et al, 2020)	• Image: weak (TNO et al, 2020)

X. Money talks

The Skelex-360 is an exoskeleton supporting the upper extremeties by applying an external force on the upper arms. Currently, buying one Skelex-360 will cost upwards of around $3000,- (SOURCEINMAIL, 2023). Skelex faces broad competition, such as EksoBionics, Hilti, or SuitX to name a few. Where in 2018 a SuitX u exoskeleton would cost $4000,- (Shankland, 2018), and an EksoBionics exoskeleton $6000,- (Crowe, 2018), currently an Ottobock (Who now own SuitX) exoskeleton costs around $2000,- (Ottobock, 2023), and the Hilti-01 exoskeleton retails at around $1750,- (Hilti, 2023). The visible trend is that passive exoskeletons will continue to decrease in price, making it an easier investment for companies, even with the reserved recommendations due to the inability of proving long term health effects (TNO, 2020).

As it stands, for Translas this solution is too expensive. Their regular 8XM torch retails around $210,- , and their 8XE Extractor torch at $715,- . A viable solution for Translas should be priced in the same order of magnitude (counted in hundreds instead of thousands), but strongly relates to the amount it supports and the piece of welding equipment it is integrated in. It can be summarised by saying the price:

1.

This means that products integrated in a welding belt ($200,-) that has a good effectivity/usability balance can cost around $300,- , whilst a glove ($20,-) can cost around $30,- .
Whilst for Translas a cheap solution that improves sales of the 8XE extractor might be economically viable, for Skelex this would not necessarily result in a economically viable situation.

But also cost of welding torches
and extractor torches

Conclusion: extractor torch is a lot more expensive but a commercial succes nonetheless.

Then: Welding equipment: belt, mask, gloves (anecdote multiple pairs each shift maybe?)

Market research pending

X. Problem analysis - usability

Welding is a task that requires dexterity. Depending on the specific task a welder might be required to make turns or rotations whilst moving at a constant pace, occasionaly with small rotation, to maintain a proper weld pool. This requires the shoulder, elbow, and wrist to make considerable effort.

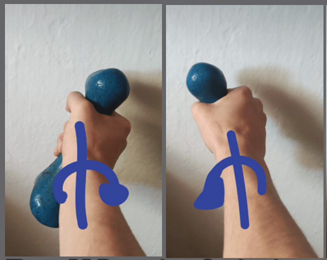


Figure X: Pronation, Supination

Figure X: Flexion, Extension

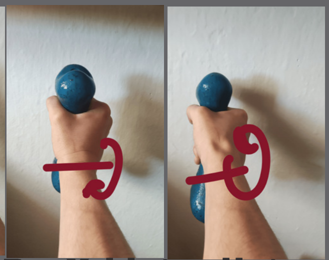


Figure X: abduction, adduction

The ease at which this can be done depends primarily on three factors: the weight of the cable and torch, the flexibility of the cable, and the mobility of the connection joint. The weight of the regular torch and extractor torch do not differ much, and is around 1.6kg 1m from the ground, see Appendix X. The added weight of the extractor torch is unlikely to influence the usability

The joint between torch and cable can rotate 360 degrees to move with the flexion and extension of the wrist. A ball-and-socket joint allows for an abduction/adduction of 30 degrees, and supination/pronation of 30 degrees. Any further rotation will force the cable to bend instead.

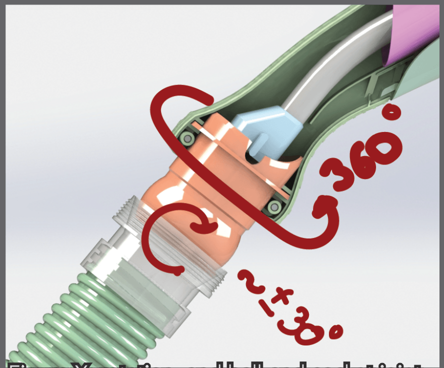
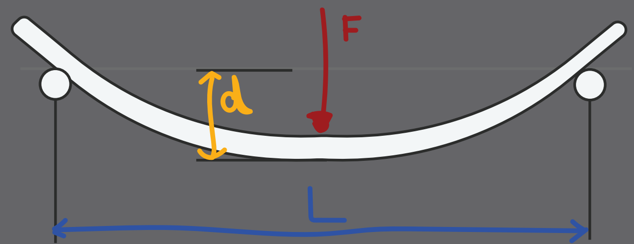


Figure X: rotation, and ball-and-socket joint

As such, a direct improvement to usability can be found in designing a more mobile ball-and-socket joint, although this is hard in combination with remaining airtight

To understand the magnitude of the increased stiffness of the cable a first degree bending test was done on the regular and the extractor torch (Tarnowski, 2015).



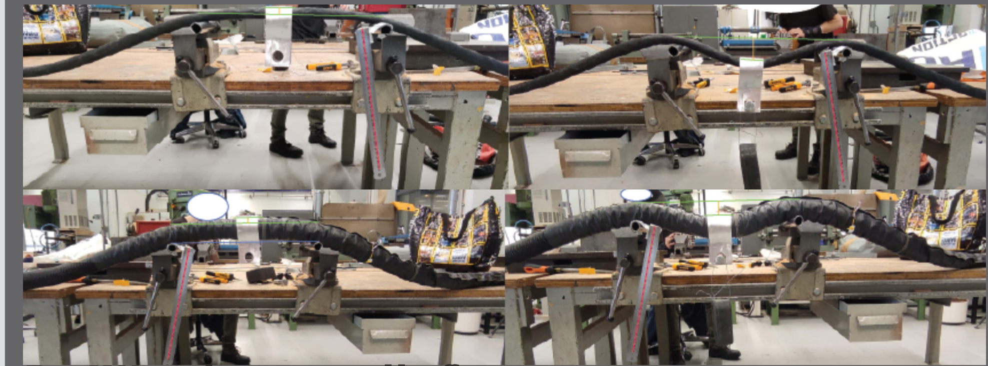


Figure X: Magnitude measurement cable stiffness

It was found that the extractor cable is 30% stiffer, although due to limitation of the setup the precision of the results might be low. Translas is able to standardise a stiffness test, to get insights into the material properties of their product. In the scope of this project it suffices to say that the added stiffness of the cable plays a bigger part into the decreased usability than the added weight. See appendix X.

Other usability complaints not related to ergonomy included the larger cup to facilitate extraction, the bigger cable, and the general size of the torch.

X. Problem statement

As stated in chapter X, this project has two primary stakeholders. It is important that both their goals are met. Their goals were combined in the following design goal:

"Design an exoskeleton-like product that eases welding with the extractor torch, without inconveniencing the welder"

This design goal exhibits two flaws.

1. Any solution that eases welding with the extractor torch, could ease welding with a regular torch. As such it does not directly change the opinion of welders who simple compare the usability of the two torches.
2. Any product, no matter how well designed, will to some degree inconvenience the user. It has to be donned, or fastened, or make contact with the body and potentially apply a force. As such, it is improbable to improve the usability of the extractor torch compared to the regular torch by adding another product to the user experience.
3. The goal is very specific to Translas' product. Targeting welding in general has a significantly higher potential to result in an economically viable product.

The only way to improve the user experience of the extractor torch compared to the regular torch is by improving the design of the extractor torch. As such, appendix X will explore redesign options for the next edition of the XE extractor torch series.

This project's design goal is therefor defined as:

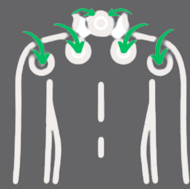
"Design an exoskeleton-like product that eases welding with the heavier welding torches, that welders actually want to use, and requires no added effort to obtain"

X. Drivers

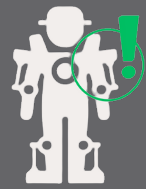
Chapter X defined exoskeleton criteria. These will function as design drivers for a succesful exoskeleton-like product.

Complete Freedom of movement

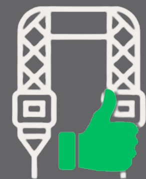
Simplicity



Minimal contact points



Minimal Protruding parts



Easy donning / Doffing

Next to these general drivers the following three requirements are defined. These determine the succes of the designed solution.

Seamless equipment integration

Eases welding experience

Ergonomic responsibility

Next to these general drivers the following three requirements are defined. These define the succes of the designed solution.

X. Program of Requirements

The following is the complete list of requirements at the time of the midterm report. These will be revised at the beginning of the second phase of this design project. Appendix X shows a short list of additional wishes.

Table X: table of requirements

Category	Requirement	Motivation	How to measure/measurable unit
Viability	The welder must experience that the welding activity is significantly easier.	Design goal	Experienced strain Muscle activity (EMG) Heart frequency Oxygen uptake Joint moments Internal forces Locally experienced discomfort (LEC) Endurance time work task Changes in muscle activity (EMG)
	The experienced torque on the wrist in rotating the torch upward / downward (Ulnar flexion / Ulnar deviation) should be within EU health and safety regulations.	The product should improve the health of the welder.	1.10Nm during 30% intensive welding?
	The product must support the welder in atleast one of the common welding positions. (above shoulder, below shoulder, crouched etcetc.	Industrial welding is a varied job and exoskeletons need to become more flexible to ease adoption.	1.10Nm during 30% intensive welding?
	The product must not limit the degrees of freedom of the welder.	Restriction of movement inhibits acceptance of the welder	DoF, welder's opinion
	The product must have adequate level of comfort.	Comfortability influences the acceptance of the welder	Welder's opinion after using is for 2 hours.
Feasibility	should not exceed $500,- (hard limit) Is related to the product's effectivity Is related to the product's usability Is related to the base equipment price	Very affordable add-on compared to the price of the extractor torch	500eu
	Product cant be easily integrated into existing welding equipment.	Getting welders who are already hesitant about the 8XE to buy additional equipment is not feasible.	
Safety	Product should not be flammable, or provide other flamability risks	Welding --> sparks --> fire is dangerous	
	Product should not be conductive, or provide other shock risks	Welding --> current --> getting shocked is dangerous	
	Product should not **significantly** aggravate musculoskeletal risks to the other areas (neck, dorsal, lumbar)	Welding is a high risk activity - the product should solve the problem, not redirect it.	
	If directly connected to the skin, it should be easily thrown off, and not prevent the glove from being thrown off.	In handling hot metals, the welding glove and potentially the product might get hot and pose a burn risk to the welder - the welder must be able to easily throw it off.	1 action, less than a second.
Durability	Product should be UV resistant		
	Product should be heat resistant		
	Product should function for ___ years.	Depends on how often welders are willing to replace equipment, how long welders expect products to last.	cycles: cycles/weldingsession *260*years env
	Product should not be structurally damaged after a 2m drop on metal.	Welders wouldn't want to be especially careful with their tools.	No permanent deformation, no cracking, breaking, loosening etcetc.

Flex Guard

FlexGuard

Initial ideation focused on reducing the strain on the wrist, as this was found to be too high (Skelex, 2020).

A wrist brace was suggested by A. A. Nobaveh et al (2020) that can carry the weight of the hand (eases flexion), to support people with musculoskeletal weakness. See figure X. The torque normally on the wrist joint would be supplied by a compliant mechanism, and transferred to a couple on the underarm.

Figure X: Prototype wrist support by A.A. Nobaveh et al (2020).

This idea was adapted to aid welding by carrying the weight of the torch (eases abduction), and by fitting inside a welding glove. A concept poster can be seen in appendix X.

This prototype shows a simple brace that was to be fitted inside a glove, so that it can be donned as easily as a regular welding glove. Upon wearing the glove a spring is deformed providing an upward moment. The spring can rotate around a simple pin, as to not hinder flexion/extension.

Figure X: Prototype: Weld support

In using the brace some support could be experienced, although it was found difficult to firmly attach the brace to the underarm without the use of straps. When the brace was used in combination with the glove, donning (and thus doffing in one movement) was becoming increasingly difficult. Another problem was the 'sliding' of the spring over the underside of the hand (ulnar border).

An initial solution to these two problems was found in a redesign of the brace. See figure X. The spiral curves inside the glove, making it possible to don and dof in one movement. The spiral deflects inwards, so the 'ulnar border' does not have to slide over the spring during abduction/adduction.

Figure X: Helix brace: Can deflect inwards

Some experimentation was done with a brace firmle strapped to the hand, to minimise product latency. This was done to more closely explore the required spring constant to feel supported.

Figure X: Wrist support - firmly strapped

Some experimentation was done with a brace firmle strapped to the hand, to minimise product latency. This was done to more closely explore the required spring constant to feel supported. It was found that the required spring constant to noticeably ease adduction is high, due to the short length of the spring.

Positives:

- Donning/doffing in one movement
- Supports adduction, resists abduction, whilst allowing flexion/extension and supination/pronation.

Negatives:

- Requires (uncomfortably) stiff spring
- Product latency seems inseperable from glove integration


Weld
Wing

WeldWing

Passive upper extremeties exoskeletons generally transfer forces and strain from a weaker part of the body to a stronger part. This concept explores the most straight forward way to transfer a weight carried by the arms to the stronger hips and legs.

A crude hook an a simple frame was welded together for the first prototype. The cable can slide through to hook to make sure the right length of the cable can be given for any welding position. There was also experimented with a simple lock mechanism so the cable could be 'locked' in a certain position, to aid overhead welding. See figure X.

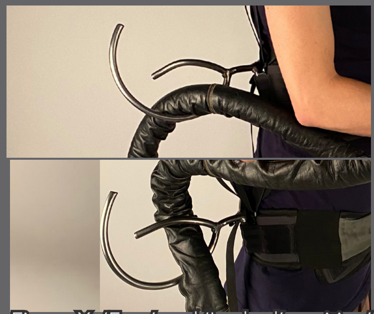


Figure X: 'Free' and 'Locked' position

Using the WeldWing there was a reduction in weight carried by the arm, as a most of the weight of the cable was now carried by the hip. However, this concept required a smartly engineered reel system that can automatically set the needed lenght.

Suspending the cable on the hip has two major flaws: shortening the effective length of the cable, and increasing the needed cable deflections.

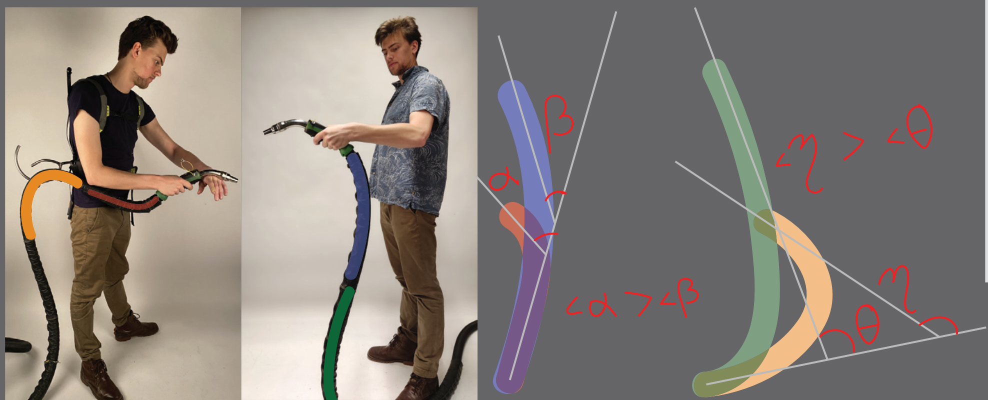


Figure X: Different cable lengths and deformations of a suspended vs free falling welding cable

This results in increased tension in the cable a defined by:

$$M = \frac{\phi EI}{L}$$

Where M [Nm] is the moment experienced by the wrist, ϕ [°] is the deflection of the cable, EI [Nm^2] the bending stiffness of the cable, and L [m] is the effective length of the cable. Shortening the cable, and increasing deflections both increase torque on the wrist.

Previously three concepts were proposed by Skelex (2020) to suspend the cable from the lower arm. These face the same issues: Although the weight of the cable and torch is reduced, movement of the wrist is made harder.

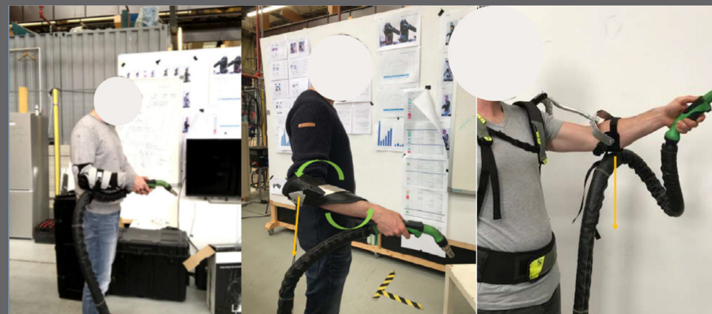


Figure X: Skelex concepts

These issues are not unsolveable; if the length of the connection cable can be easily or automatically changed such that the welding cable can hang free the weight can still be transferred to a stronger part of the body. This concept is explored in a parallel project by R. Conjaerts (2023).

Positives:

- Less weight on the wrist
- Integration with welding belt (or welding sleeve)

Negatives:

- Additional inflection points increasing cable stiffness
- Complexity ; several systems required to solve problems


Exo
Force
Pulley system
Constant force spring
upwards force
Exo
Force
2.0?

ExoForce

The Skelex-360 is a succesful product but it cannot provide a solution to Translas' problem due to two problems:

1. Expensive; the solution is disproportionately expensive to the 8XE fume extractor.
2. Operational range; welding also requires an operational range in neutral position and below the waist.

The ExoForce aims to circumvent these two problems by using a simpler mechanism to carry the weight of the welding cable and torch, and transfer it to the back and hips.

The first prototype consisted of a carbon fibre rod attached to a steel frame. The dimensions were such that the torch would be weightlessly suspended in front of the welder. To allow for a greater operational range the rod can rotate in the frame, so the torch can freely move in a 180 degrees angle in front of the welder.


Figure X: carbon fibre rod suspending torch.

Moving it higher would reduce tension in the rod, reducing the upwards force. Moving the torch lower increases the upwards force (requires effort). Moving the torch towards and away from the welder likewise requires force. See figure X.

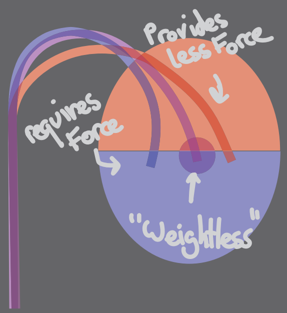


Figure X: Operational range

The bending stiffness of the rod depends on its stiffness. A rod with a great operational range should have a low stifness. If the rod has a low stifness, it needs to be relatively long as a result in order to carry the considerable weight of the torch. As such, there will always be a trade-off between minimising protruding parts and maximising freedom of movement and effectivity.

An alternative, more compact and arguably inherently safer, concept is using a spring loaded spool to suspend the cable. It was also found that it's probable that the optimale connection point on the welding cable is not its centre of mass (CoM), but before the front of the cable, just before the ball-and-socket joint. This effectively increases the flexibility of the connection between cable and torch.

Prototype 2.0 and conclusions pending

Positives:
- Significantly less weight on the upper extremeties
- Integration with welding belt
- Alternate uses (other tools) and complementary to skelex-360
- Ergonomic improvement (Casper, 2023)

Negatives:
- High complexity
- Susceptible for common exoskeleton problems

Tether Tech

TetherTech

As discussed in Chapter X. - WeldWing, suspending the cable to the lower arm risks adding inflection points on the cable, effectively increasing the moment on the wrist. There is however one realistic exception to this rule: In suspending the cable at the beginning of the cable* the suspension point can effectively function as part of the connection joint with the welding cable. See appendix X.

When the weight of the torch is suspended on the underarm, the torch can feel as light as a pencil in the hand. This has the direct ergonomic benefit that the torch does not need to be gripped tightly anymore. This potentially decreases musculoskeletal risks in the elbow (Caspers, 2023).

Figure X: Suspended torch

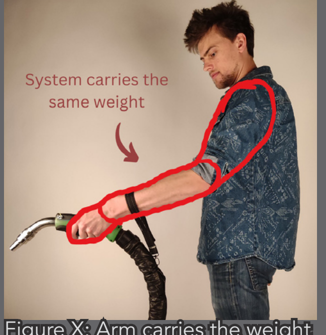


Figure X: Arm carries the weight

The weight on the whole system of the arm is unchanged. Since the cable is not always straight, tension can exert additional forces on the underarm. The welder will also have to carry the weight in different ways his body is accustomed to. These factors risk increasing ergonomic risks on the shoulder, or increase fatigue.

However, initial tests with capable welders showed an initial decrease in experienced strain and effort, and the innovation was met with general positivity. (van Eeden et al., 2023)

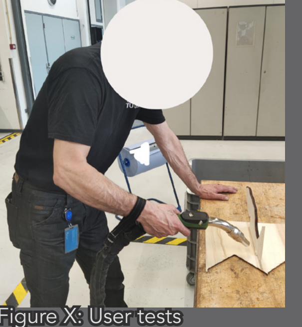


Figure X: User tests

*At Translas they define the beginning of the cable as the torch side, and the end as the housing side.

For TetherTech to work the torch has to be in a vertical position. It has been observed that welder have to rotate their torch. As such, this solution cannot support all welding positions. Likewise, welding above the head requires slight tightening of the connection cable, and welding significantly lower than the neutral position exerts forces on the underarm.

Figure X: TetherTech limitation

Figure X: Prototype: TetherTech

A less obvious downside of this concept is the simplicity - Translas and Skelex deal in cutting edge, high quality, and specialised products. It's difficult for a cheap product to be economically viable.

Positives:

- Reduces strain on the wrist and elbow. (Casper, 2023), (van Eeden et al., 2023)
- Integration with welding gloves possible.
- Simplicity, does not suffer from common exoskeleton complaints.

Negatives:

- Upper extremeties carry the same load in total, and it might increase shoulder complaints in the long term.
- Difficulty in embodying a hi-tech, specialised product.

Harris profile

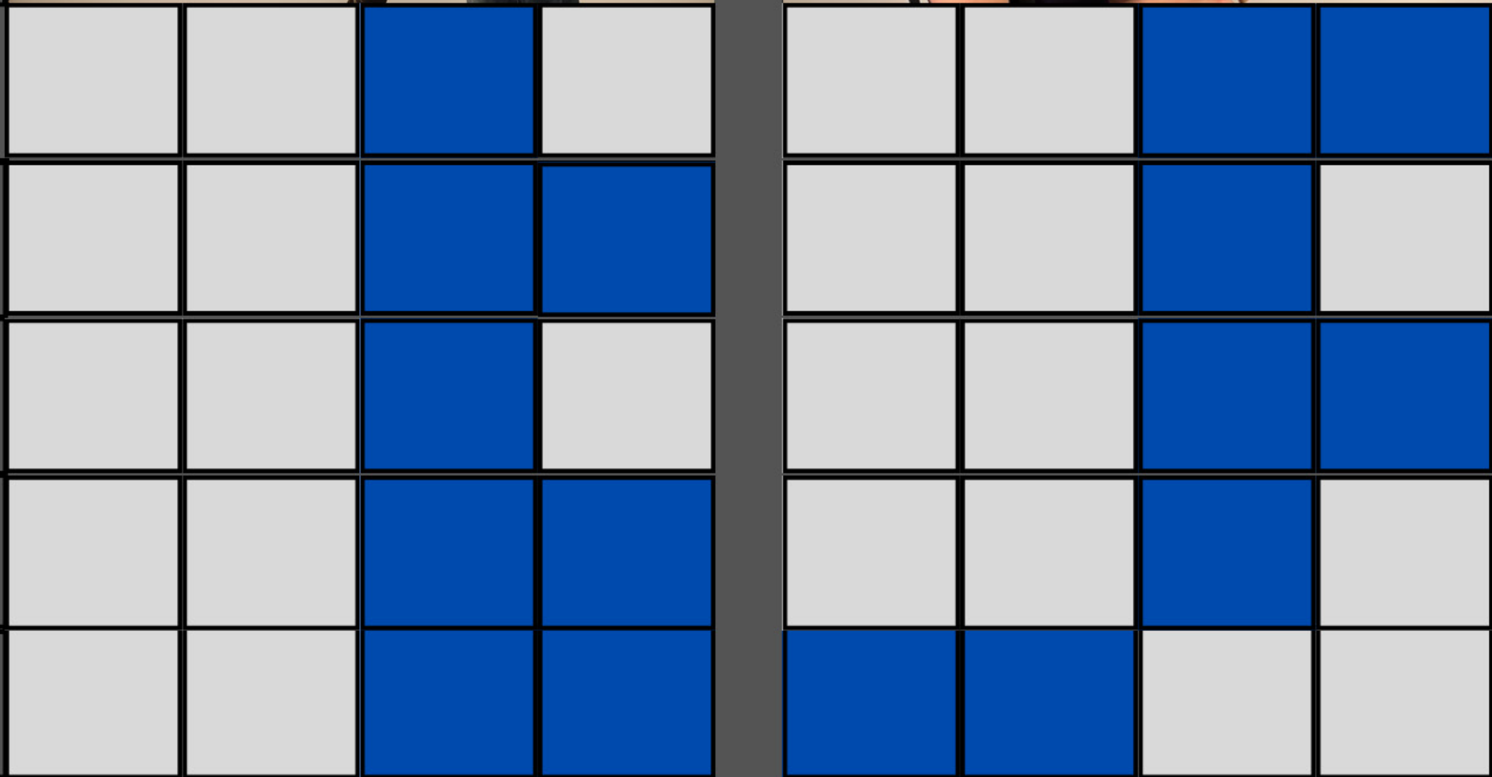
Effectivity

FoM

Ergonomy

Ease of use

Simplicity



Final product

Validation

Process of Creation

Final product

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Appendix X - Stiffness test

The weights of the welding torches are close to equal when manually lifted to a height of 1m with the use of a force meter; Extractor torch: 16.0±0.3N, Regular, 15.8±0.3N. More importantly, when asked to four experienced welders which one was heavier, two answered they were identical, one picked the regular torch, and one picked the extractor torch to be heavier. It's probable that the added weight of the extractor torch is not responsible for the decreased usability.

The welding cable was placed upon two cylinders, with the beginning (welding torch) and end (housing) rested upon the table as to minimally influence the movement over the two cylinders. A weight of 2.5±0.1kg was suspended in the middle of the cable. After lifting the weight to relieve the tension in the cable a picture was taken, and after slowly lowering the weight a second picture was made of the bending cable. In the shot a ruler at the same depth is placed, to make cross referencing in Adobe Illustrator possible. The path length was measured in every picture, and the difference in deflection measured.

The stiffness of a cable depends on the material and geometric properties. Since the welding cable consists of a bundle of cables with different material and geometric properties it is difficult to calculate the value, but the combined stiffness can be described as:

$$EI = \frac{F\,L^3}{48\,d}$$

where EI is the bending stiffness [Nm^2], F [N] is the force on the cable, L [m] is the length between the poles, and d [m] is the deflection.

It was found that the extractor cable is approximately 30% stiffer. The accuracy of the test is relatively low due to the wide contact areas of resting cylinders and weight. The precision might also be relatively low due to the interference of the torch and housing, as well as imprecise depth placement of the ruler, and the differences in friction coefficients between the cable covers, as well as the inability to get rolling cylinders. As such it can be concluded that the extractor cable is significantly stiffer, but to find accurate and precise measurements the test should be done with just the cable bundle and rolling pins.

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Figure X: Length and vector analysis - suspension cable. See appendix X.

To explore this concept several images were taken of the welding cable in different positions. Two points on the underarm and three points on the beginning of the welding cable were defined, and the resulting vectors were analysed. See Appendix X. These resulted in the following design guides:
Choosing a connection point close to the wrist results in a more vertical connection cable - this is beneficial as this carries the weight without introducing additional stresses.

A connection point close to the beginning of the cable has a weaker relation to the position of the torch - this means it can have a greater operational range without added mechanisms. But there's a trade-off here: a connection point further from the beginning of the welding cable is more vertical, which is beneficial.

X. Wishes

The product should not move or slip during use
Welders want to use the product
Product feels innovative & futuristic
Product feels responsible
The product should not be frustrating to use or carry around during the working day
Product should be usable in many environments. As flexible as possible.
Product must be lightweight
Product can be integrated into welding equipment
Product is usable for left handed people and right handed people.
Product should cover as many different sizes as possible.
Should be easy, quick, and intuitive to put the device on.
Design for repairability
Design for sustainability
Design should be easy to store.