NOVIA
UNIVERSITY OF APPLIED SCIENCES

Exoskeleton: Prototype design

Conceptual design review

Oscar Teruel Guisado

Degree Thesis for Bachelor of Engineering

Degree Program in Energy and Environmental Engineering

Vaasa (Finland), April 2016

BACHELOR'S THESIS

Author: Oscar Teruel Guisado

Degree Program: Energy and Environmental Engineering

Supervisor: Lars Enström

Title: Exoskeleton: Prototype Design – Conceptual Design Review

---

Date 22/04/2016 Number of pages 55 Appendices 3

Abstract

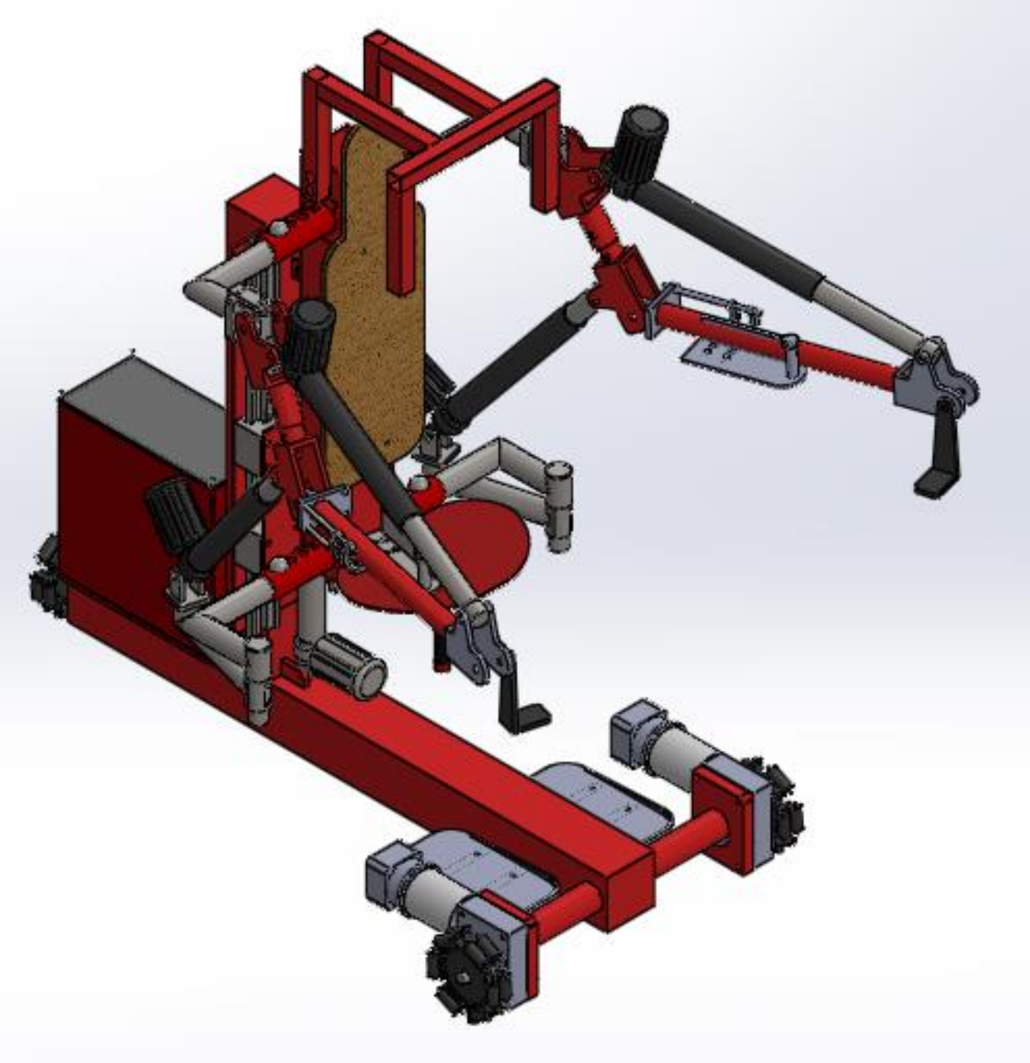
The design projected in this document has features specifications of an exoskeleton structure with loads operation finality. The entire structure is divided into three major parts: the lower body, the chest, and the arms. Each part was considered separately, and all of the parts can be assembled together to create the main structure.

In this document are collected all the corresponding designs of each element that will compound the final prototype. The lower body represents the base of the structure and supports, the weight of the other two parts and the advance, allowing them to move backwards as well as allowing rotational movement. The chest serves the purpose of a user cabin, where the operator will be placed to operate the exoskeleton. The purpose of the arms is to raise and carry loads.

Although some parts of the study could not be completed due to time constraints, the exoskeleton has been designed for a real use. A user is needed to drive the structure and for this reason an anthropometrical study was completed in order to adapt the design to a real situation.

The electrical design and the control system needed for the prototype functionality are not considered in this project. These sections could be studied at a later time by another person or team as a future complementary study for this project.

As it is a prototype design, this project does not consider any law or design legislation. Additionally, no health and security study was done.



Language: English Key words: Exoskeleton, mechanical, design.

Table of contents

Appendix Table of Contents

1 Introduction

The objective of this study is to create a Conceptual Design Review (CDR) of an exoskeleton. The study includes an anthropometrical study and the design and mechanical functionality of the structure. It is an open project aimed to be improved and finished later.

These following points will not be considered:

- Electrical and electronic installation needed for operation.
- Control and automation system that would allow for correct operation.

As this is a conceptual design, security and health risks are not taken into account.

As a mechanical engineering student, one of my wishes is to be able to create a machine from only one concept, and if it is possible, to make it capable of improving society, The reason for completing this project, is to address a current problem in society: Musculoskeletal disorder (MSD).

According to the European Agency for Safety and Health at Work:

- Musculoskeletal disorder is most common professional disease in the EU-27, 25% of European workers complain about back pain and 24% affirm to have muscular pain.
- 63% of EU-27 workers are exposed during one quarter part or more of their time to repetitive movements of the hands and arms, 47% are exposed to painful or extenuating postures and 33% are required to transport or move heavy loads.
- Agriculture and construction are the sectors with the most workers exposed to physical risk and affected by MSD. However, all sectors are affected by it to some extent.
- MSD is an expensive affliction due to direct costs (insurance, compensation, medical and administrative cost) and indirect costs due to loss in productivity.

The lifting of medium and heavy weight loads is a problem for a lot of workers in different works and companies. Hundreds of kilograms of loads are transported by pallet lifters or electric lift trucks, but some loads are too small to be carried by machines but also too heavy to be loaded by people.

This exoskeleton has potential for use with this rank of loads, being a machine able to carry loads of zero to fifty kilograms. These are the loads that are commonly carried by people and can contribute to development of MSD.

Some examples of situations in which the exoskeleton could be useful include:

- Product unloading and transport in agriculture and cattle-raising sectors.
- Baggage transport between an airport's conveyor belts and aircraft loading.
- Transportation and loading of packages in a post office.

Necessary software

The following software will be used for the calculations and design of the prototype:

- Microsoft Office Excel
- SolidWorks

Microsoft Office Excel is a spreadsheet software that will be used for the analytic calculations of the needed parameters to check the validity of the design. These parameters will be represented in tables. This allows the data to be displayed in a visual and intuitive way that facilitates comprehension.

SolidWorks is three-dimensional design software that includes tools for creating, simulating, publishing and administrating data in a simple and functional interface.

2 Definitions

Exoskeleton

In biology the term “exoskeleton” is used to describe the outer rigid structure of an insect or crustacean. In the robotic field, exoskeletons are the external rigid structures that give support to the people motor functions. Exoskeletons include a motor power system that gives part of the energy to the limb movement, and helps the user to move and realize activities, such as carrying weight.

An exoskeleton can be defined therefore as an external structural mechanism whose segments and joints correspond to the human body. It allows direct transmission of the mechanical power and information signals. Therefore, it must be adjustable or adaptable to different human body joints, with the objective of aligning the rotational centers.

Special aspects as security, robustness and the robotic mechanism ability should be considered.

Mechanical structure

An exorobot or exoskeleton is formed by a series of linked elements joined by articulations that allow relative movement. There are three different kinds of joints: translational, rotational and mixed.

Each of the independent movement that an articulation can make with respect to the above is called a degree of freedom. The sum of the robot’s articulation degrees of freedom is the total number of degrees of freedom of the entire robot.

Actuators

Actuators are responsible for generating movement of the elements that forms the exoskeleton. In robotics, an actuator’s classification is based on its power source:

pneumatic, electrical or hydraulic. Table 1 displays a summary of differences in the basic characteristics of actuator types:

Table 1: Different actuator characteristics.

Actuator type	**Advantages**	**Disadvantages**
Pneumatic	Low cost Fast Simple Robustness	It requires a special installation Noisy
Hydraulic	Fast High load capacity Stability against static charges	It requires a special installation Difficult maintenance Expensive
Electrical	Precise and trustable Noiseless Easy control Easy installation	Restricted power

The selection of the actuator will depend upon the following factors: cost, velocity, control, power, precision, weight, volume, maintenance and security.

Biomechanics

Biomechanics is the scientific discipline that studies existing mechanical structures, fundamentally from the human body.

The study of biomechanical is present in different spheres, but three of them are currently the most important.

- Medical biomechanics
- Sport biomechanics
- Occupational biomechanics

3 Design requirements

The following section details the design requirements that the exoskeleton must fulfill.

3.1 Anthropometric study

3.1.1 Introduction

After specifying the exoskeleton's general aspects and its various parts, the necessary measurements of the arm elements will be determined.

First, it must be considered that the machine designed will be used by a person. It is essential to have anthropometric studies where the dimensions of the elements are clearly defined, and movement limitations are imposed. The exoskeleton must fit the human body in order to guarantee commodity and security to the user.

3.1.2 Data used

The exoskeleton should be able to be used for different physical and height size. In the pre-design stage different anthropometric data were used to delimitate the movement range and the dimensions of its elements.

The digital magazine *"Elfdeportes"* has collected a total of 29 anthropometric variables into a table (figure 1). These variables are defined through statistical techniques. The table shows, for each variable, a range of values that were taken into account when the dimensions of the machine were delimited.

FAAC / UNESP / BAURU		Homens			Mulheres		
Dimensões dos Segmentos Corpóreos Humanos		% 05	% 50	% 95	% 05	% 50	% 95
01	Estatura	159	171	182	149	160	170
02	Altura Piso - Ombros	132	142	152	123	133	143
03	Altura Piso – Olhos	151	161	172	141	151	161
04	Altura Assento – Cabeça	82	88	93	76	83	89
05	Altura Assento – Ombro	54	58	63	46	54	59
06	Profundidade do Tórax	23	26	29	21	25	32
07	Profundidade do Abdome	19	22	26	17	21	26
08	Largura do Tórax	26	29	34	-	-	-
09	Largura do Bideltoide (ombros)	39	43	47	34	38	42
10	Distância alcance frontal máximo	69	76	83	62	71	79
11	Comprimento do Braço	33	36	40	-	-	-
12	Comprimento intercular Ombro – Cotovelo	24	29	32	-	-	-
13	Comprimento intercular Cotovelo – Punho	23	25	28	-	-	-
14	Comprimento Cotovelo - Ponta do dedo médio	45	49	55	36	43	50
15	Comprimento intercular Joelho – Maleolo	35	40	44	-	-	-
16	Altura Assento – Coxa	12	14	17	11	14	17
17	Altura Piso – Poplitea	34	44	55	36	40	44
18	Altura Piso – Joelho	50	54	58	49	54	59
19	Distância Nádega – Poplitea	43	48	53	42	47	52
20	Distância Nádega – Joelho	55	60	65	52	58	63
21	Largura do Quadril	30	34	38	31	36	41
22	Altura entre pernas	76	80	87	66	73	80
23	Altura da Cabeça a partir do queixo	21	23	24	19	22	24
24	Largura da Cabeça	17	18	19	14	15	16
25	Profundidade da Cabeça	18	19	20	16	18	19
26	Comprimento do Pé	24	26	28	22	24	26
27	Largura do Pé	9	10	11	9	10	11
28	Largura do Calcâneo	6	7	8	6	6	7
29	Comprimento das mãos	18	19	20	16	17	19

Figure 1: Anthropometrical characteristics table (measurements in cm) / Source: "Elfdeportes"

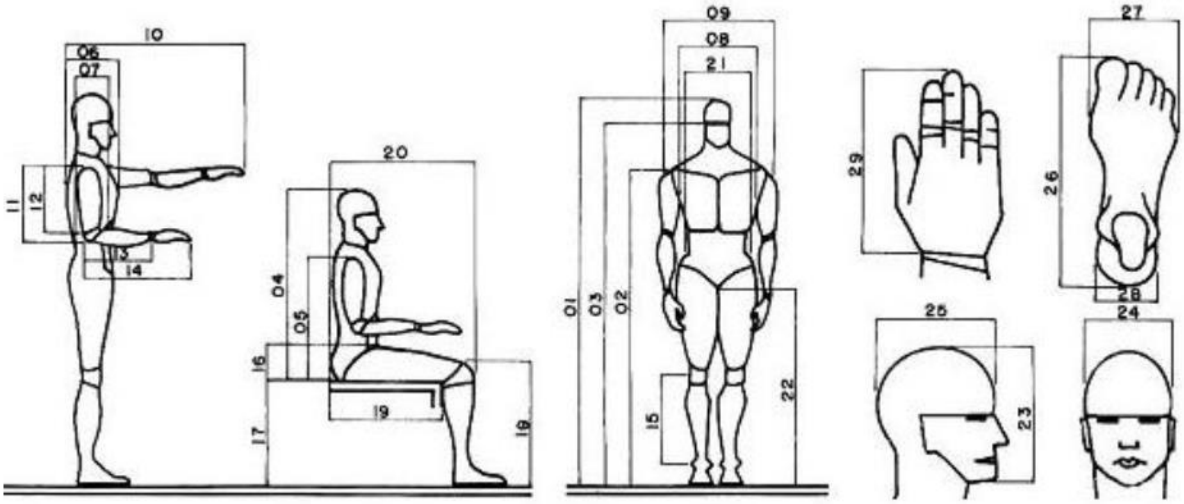


Figure 2: Bidimensional representation for measurements identification / Source: "Elfdeportes"

According to the previous table, the total and partial dimensions of each element were estimated. In an analog way, they were taken into account to define some movement ranges, such as the Top and Bottom Death Centers (TDC and BDC) in the bending actions.

3.2 Interface definition

The exoskeleton is divided in three subassemblies: arms, chest and lower body. These subassemblies were studied individually because each part has a dynamic movement with respect to the others. The joining elements that allow the dynamic movement are called interfaces.

Two different interfaces could be found in the final structure:

- Exoskeleton: **Chest-arms**
- Exoskeleton: **Chest-Lower body**

3.3 General dimensions

3.3.1 Preliminary arm dimensioning

The initial values for the arm design were established in accordance with *“Manual de Antropometria Normal Patológica”.*

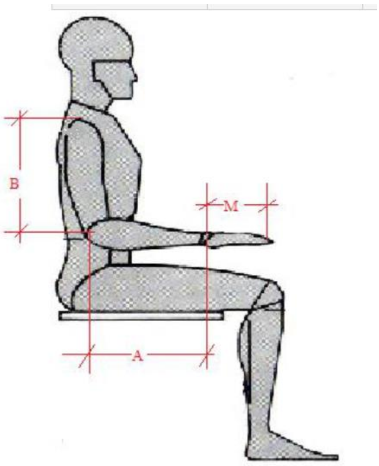


Figure 3: Dimensions used in the arm design / Source: Manual de Antropometria Normal Patológica.

Arm length (distance shoulder-elbow)

It was designed to be used by the majority of the population. Thus, the design considered the extremes to be negligible, with the 5th percentile for women as the minimum and the 95th percentile for man as the maximum (Figure 1).

The following table presents the values mentioned:

Table 2: Anthropometrical arm length measurements

B, Arm length						
Age	**Woman**			**Man**		
16 years	5%	50%	95%	5%	50%	95%
	27,9 cm	30,4 cm	33,4 cm	29,5 cm	32,9 cm	36,1 cm

Finally, the dimensional range will be between 27,9 cm and 36,1 cm.

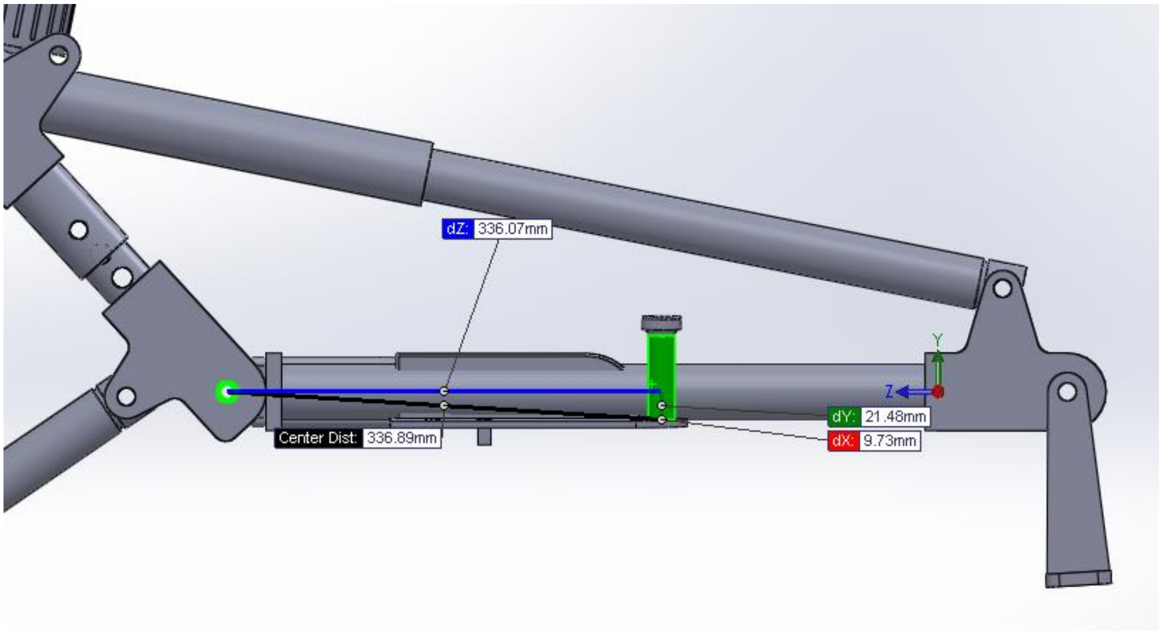


Figure 4: Adjustable arm length

Forearm length

Similarly, the extremes were not considered in the design of the forearm length, with the 5th percentile for woman as minimum and the 95th percentile for man as the maximum.

Table 3: Anthropometrical forearm length measurements.

A, Forearm length						
Age	**Woman**			**Man**		
16 years	5%	50%	95%	5%	50%	95%
	20,8 cm	23,3 cm	25,8 cm	22,7 cm	25,5 cm	28,1 cm

The dimensional range is between 20,8 cm as minimum and 28,1 cm as maximum.

In spite of having an arm length defined in concordance with the previous tables, the different constructive aspects that restrict the design must be considered.

In the case of the arm, the minimum measurement has been changed to 30 cm to account actuator installation conditions. Meanwhile, the maximum measurement of the forearm has been changed to 25 cm.

It must be taken into account that the real mechanical forearm is much longer than the user human forearm, because it needs more longitude to pick the load. Therefore it is enough to set this length to 25 cm. The next table adds the anthropometrical design values.

Table 4: Anthropometrical design measurements for the arm and the forearm

Anthropometrical design values		
	Minimum dimension	**Maximum dimension**
Shoulder-elbow length, B	30 cm	35 cm
Elbow-wrist length, A	20 cm	25 cm

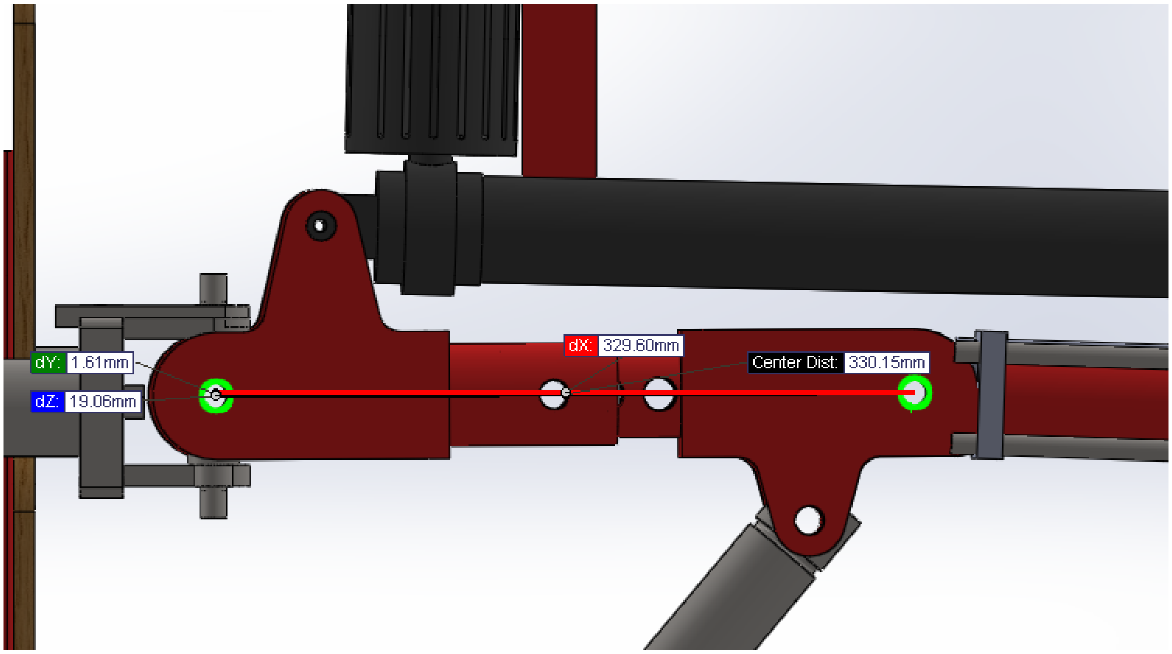


Figure 5: Adjustable forearm length

Consequently, the majority of the population is represented by this specified set of values. The different parts of the mechanical arm will be dimensioned in such a way that the length of the elements can be regulated between these dimensions to adapt to the user.

In accordance with the aforementioned, the mechanical forearm must be bigger than the user's in order to reach the loads. The following table collects the final arm dimensions of the exoskeleton.

Table 5: Dimensional range of the entire arm

Measurement type	Minimum value	Maximum value
Arm length (from shoulder axis to the "shovel" fixation point)	95 cm	100 cm

In conclusion, the different arm positions are:

Table 6: Different lengths for the different arm positions.

Position number	Biacromial width
Position 1	95 cm
Position 2	97,5 cm
Position 3	100 cm

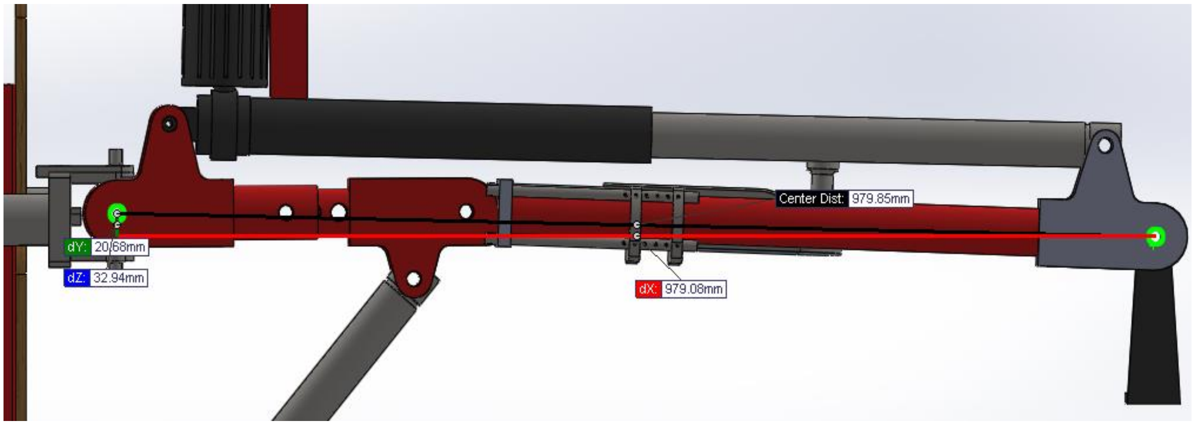


Figure 6: Total adjustable arm length

3.3.2 Preliminary dimensioning of the shoulder-back set.

The measurements that were useful to determine the general dimensions are as follows..

Biacromial distance (between deltoids)

The chest width dimensions were defined using the anthropometrical measurements for the population found in the book *"Manual de Antropometria Normal Patológica"*.

The attached table shows the biacromial back width values for men and women of 19 years old in different percentiles.

Table 7: Biacromial distance for both sexes

Biacromial distance						
Age	**Women**			**Men**		
19 years	3%	50%	97%	3%	50%	97%
	34,1 cm	37,2 cm	40,4 cm	36,3 cm	40 cm	43,5 cm

The minimum biacromial distance is 34,1 cm while the maximum one is 43,5 cm.

These measurements do not include the deltoids distance, because it was impossible to find information regarding this, a distance was assumed. The minimum and maximum assumed distances are displayed in the following table.

Table 8: Biacromial distance of the machine

Measurement type	Minimum value	Maximum value
Final shoulder distance	60 cm	77 cm

The biacromial distance must be adjustable. In detail, it was decided that the back width will vary by 6 cm. The following table shows the final shoulder distances for each position.

Table 9: Adjustable position with biacromial distance.

Position numbers	Shoulder width
Position 1	60 cm
Position 2	66 cm
Position 3	72 cm
Position 4	78 cm

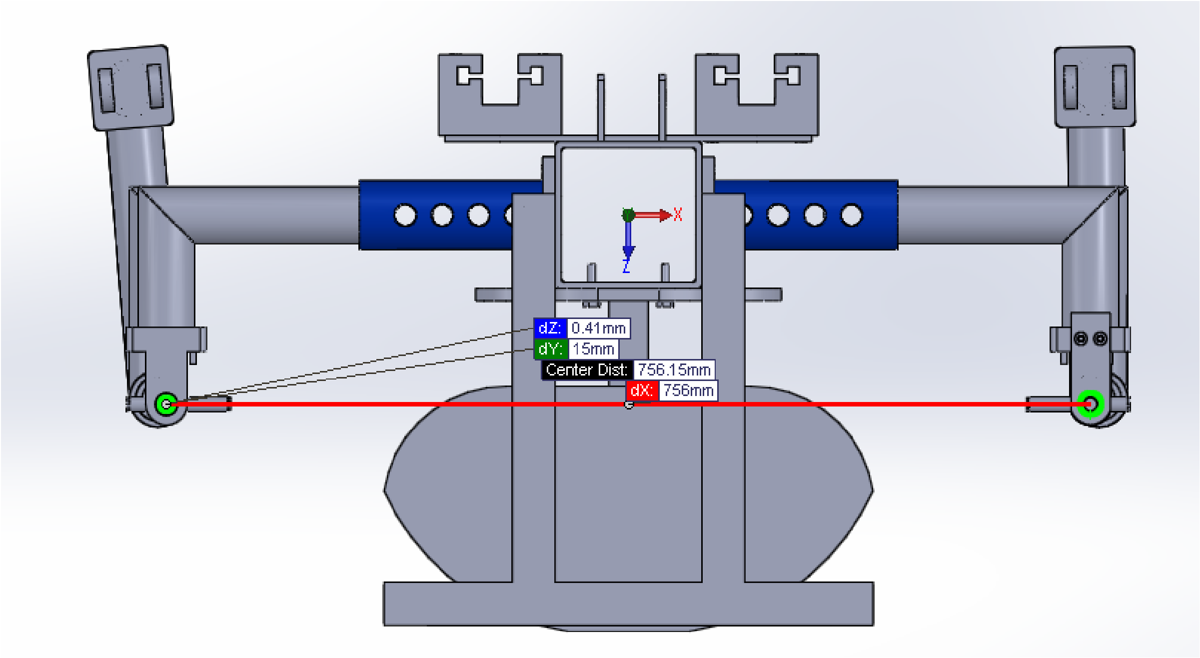
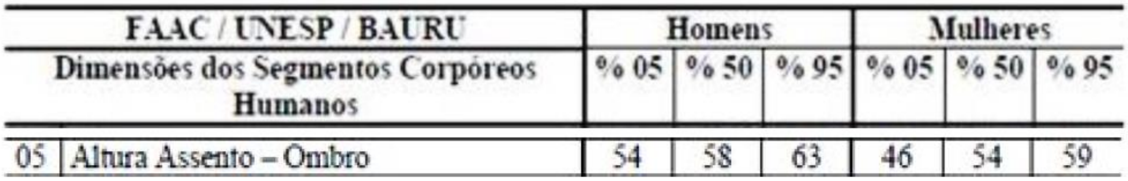


Figure 7: Adjustable shoulder length

Back height (seat-shoulders)

In this case, the digital magazine "*Elfdeportes*" was used again to obtain the ranges and to establish the minimum and maximum values.

As in the previous section, the minimum value corresponds to the 5th percentile for women and the maximum corresponds to the 95th percentile for men.
The following table shows the back height values taken for men and women in different percentiles.



FAAC / UNESP / BAURU		Homens			Mulheres		
Dimensões dos Segmentos Corpóreos Humanos		% 05	% 50	% 95	% 05	% 50	% 95
05	Altura Assento – Ombro	54	58	63	46	54	59

Figure 8: Maximum and minimum distance between seat and shoulders / Source: Elfdeportes

Having these values as a reference and bearing in mind the physical limitation for the exoskeleton design (interferences with other pieces) the final dimension for the back are as follows:

Table 10: Dimensional range for the back height

Measurements type	Minimum value	Maximum value
Back height	45 cm	65 cm

These values are the nominal measurements from the metallic seat base to the middle reference shoulder point. Around 2-5 cm corresponding to the padded final part width of the seat have to be added to these measurements. This is not an exact measurement, because it depends on the chosen material for this function.

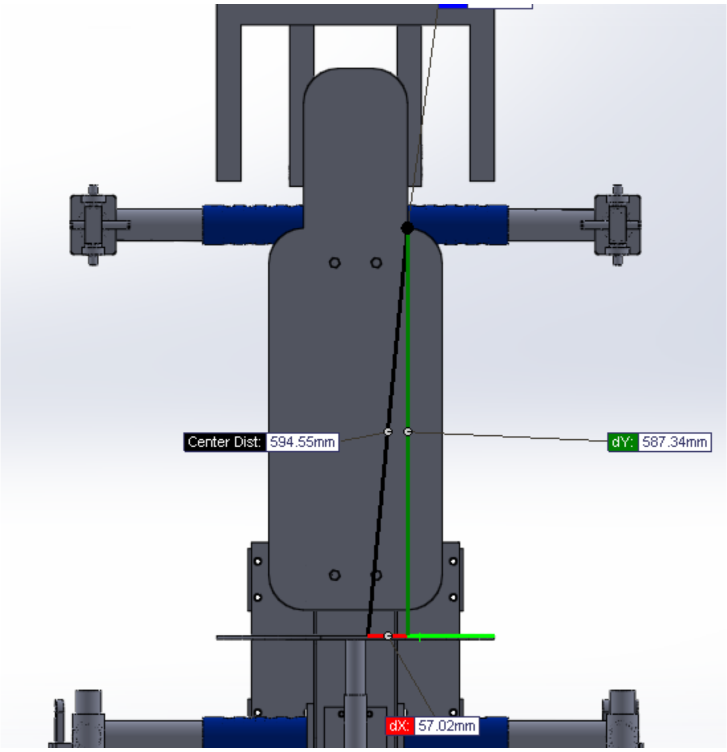


Figure 9: Adjustable back height

Seat dimensioning

The aim of the seat is to provide commodity and the ergonomics for the user in the work place. The anthropometric measurements taken as reference are presented in the following table.

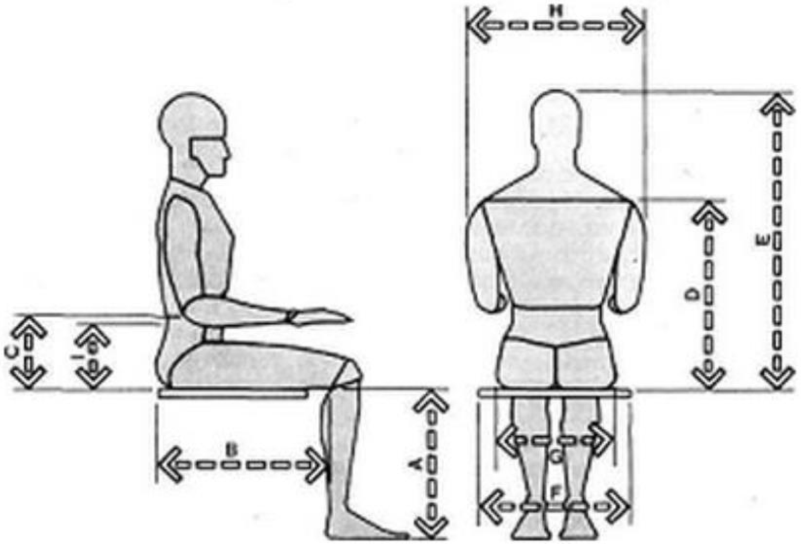
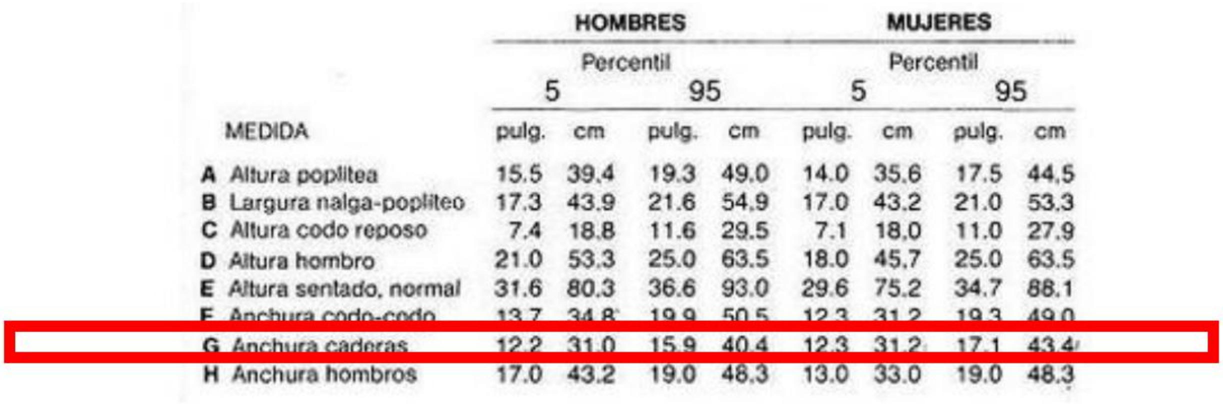


Figure 10: Main distances for a sitting position person./Source: "Mueblesdomoticos" website



	HOMBRES				MUJERES			
	Percentil				Percentil			
	5		95		5		95	
MEDIDA	pulg.	cm	pulg.	cm	pulg.	cm	pulg.	cm
A Altura poplitea	15.5	39.4	19.3	49.0	14.0	35.6	17.5	44.5
B Largura nalga-popliteo	17.3	43.9	21.6	54.9	17.0	43.2	21.0	53.3
C Altura codo reposo	7.4	18.8	11.6	29.5	7.1	18.0	11.0	27.9
D Altura hombro	21.0	53.3	25.0	63.5	18.0	45.7	25.0	63.5
E Altura sentado, normal	31.6	80.3	36.6	93.0	29.6	75.2	34.7	88.1
F Anchura codo-codo	13.7	34.8	19.9	50.5	12.3	31.2	19.3	49.0
G Anchura caderas	12.2	31.0	15.9	40.4	12.3	31.2	17.1	43.4
H Anchura hombros	17.0	43.2	19.0	48.3	13.0	33.0	19.0	48.3

Figure 11: Anthropometrical dimension of a sitting person / Source: "Mueblesdomoticos" website

Such as the seat height has to be adaptable to the user, the most important measurement is the hip width dimension (G parameter in figure 10): 43,4 cm for the 95th women percentile that represents the most unfavorable situation. For the design, the hip width will be set at 41 cm. Such as the seat is designed for human dimensions, these little variations are not representatives.

The chosen depth is 25 cm. This dimension allows a relative commodity for the backside support point when the exoskeleton is in the maximum position from the floor.

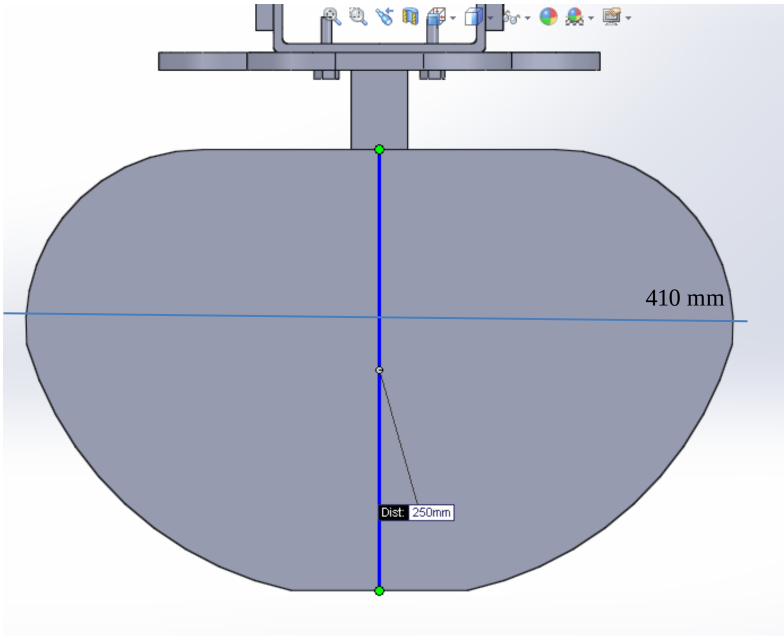


Figure 12: Final seat dimension

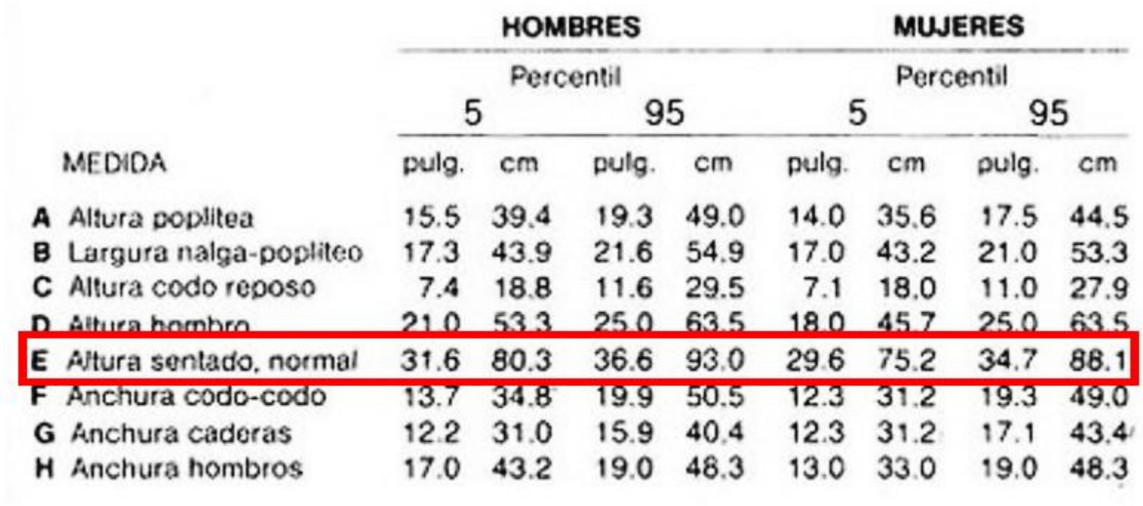
Back support dimensions

The back support in any common seat has to support the lumbar region such as essential function. The configuration of this has the objective of adapting the spinal profile but it will avoid the complete coupling that does not allow changing the position of the body.

Considering the previously imposed conditions and the absence of concrete data about the referent pattern values to follow, the measurements were determined through an anthropometric study of some known people. These values are shown in the following figure.

The shown measurements in mm allow a sufficient support for the user, giving enough comfort and stability sensation. Head support and back support compose a unique piece.

To determine the maximum height from the seat to the head support, the measurements were taken from "normal sitting height" (parameter E, Figure 13).



	HOMBRES				MUJERES			
	Percentil				Percentil			
	5		95		5		95	
MEDIDA	pulg.	cm	pulg.	cm	pulg.	cm	pulg.	cm
A Altura poplitea	15.5	39.4	19.3	49.0	14.0	35.6	17.5	44.5
B Largura nalga-popliteo	17.3	43.9	21.6	54.9	17.0	43.2	21.0	53.3
C Altura codo reposo	7.4	18.8	11.6	29.5	7.1	18.0	11.0	27.9
D Altura hombro	21.0	53.3	25.0	63.5	18.0	45.7	25.0	63.5
E Altura sentado, normal	31.6	80.3	36.6	93.0	29.6	75.2	34.7	88.1
F Anchura codo-codo	13.7	34.8	19.9	50.5	12.3	31.2	19.3	49.0
G Anchura caderas	12.2	31.0	15.9	40.4	12.3	31.2	17.1	43.4
H Anchura hombros	17.0	43.2	19.0	48.3	13.0	33.0	19.0	48.3

Figure 13: Sitting individual anthropometrical dimensions.

Considering the 95th men percentile such as the most unfavorable height situation with 92,5 cm, and taking such as head support a point of 3,5 cm under the maximum height of it, it was determined a maximum permissible exoskeleton height of 89 cm, taking the minimum seat height such as reference. The measurement is shown in the following figure.

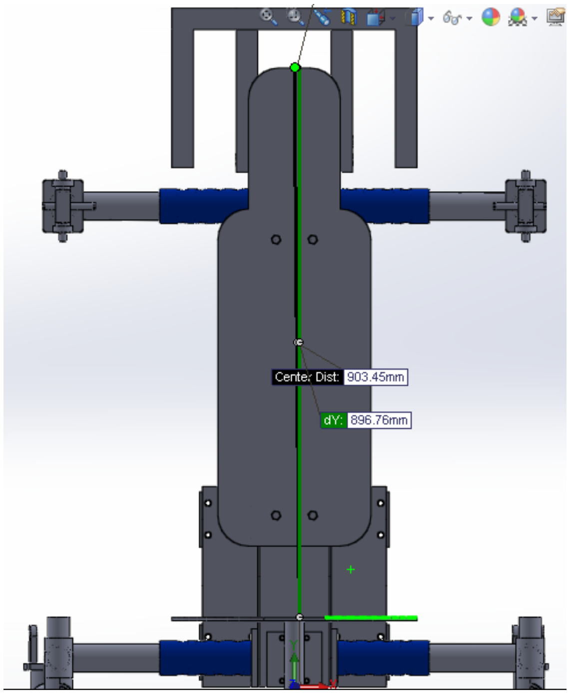


Figure 14: Back support height

Head security structure dimensioning.

Using the book *"Felisberto e Pascuoarelli (2001)"* the head security structure dimensions were established.

Table 11: Human head anthropometrical dimensions.

Seat to head height (04)					
Women			**Men**		
3%	50%	97%	3%	50%	97%
81,5 cm	87,5 cm	92,5 cm	75,5 cm	82,5 cm	88,5 cm
Head height from chin (23)					
Women			**Men**		
3%	50%	97%	3%	50%	97%
20,5 cm	22,5 cm	23,5 cm	18,5 cm	21,5 cm	23,5 cm
Head height (24)					
Women			**Men**		
3%	50%	97%	3%	50%	97%
16,5 cm	17,5 cm	18,5 cm	13,5 cm	14,5 cm	15,5 cm
Head depth (25)					
Women			**Men**		
3%	50%	97%	3%	50%	97%
17,5 cm	18,5 cm	9,5 cm	15,5 cm	17,5 cm	18,5 cm

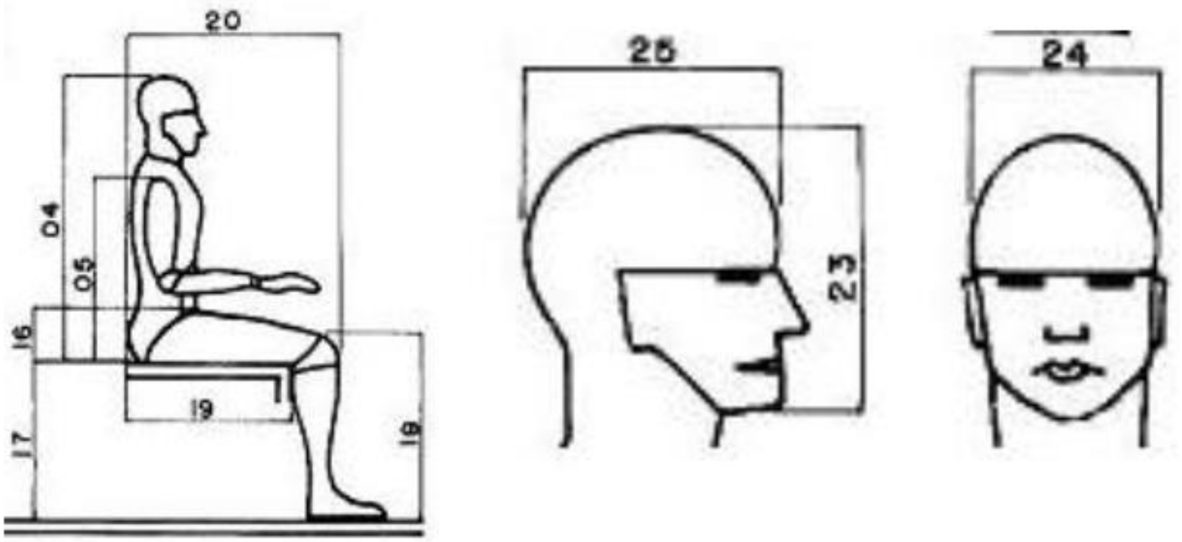


Figure 15: General head dimensions/Source: Elfdeportes

The measurements used in this section were the head width, height and depth, as well as the height from it to the seat. Such as this element does not need to be adjustable, the measurements taken were the most unfavorable; the 95th men percentile measurements were the chosen ones.

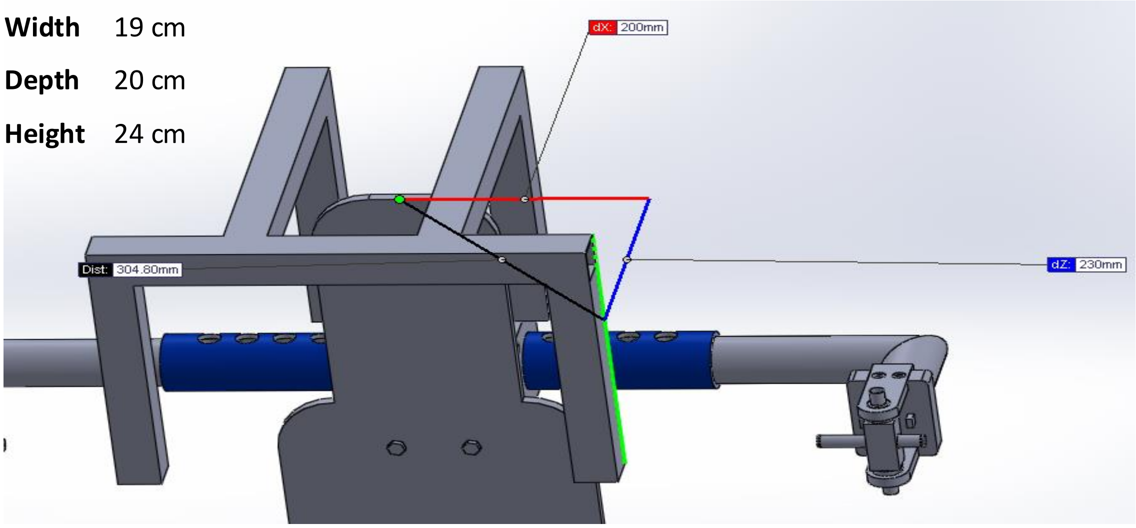


Figure 16: Security structure dimensions

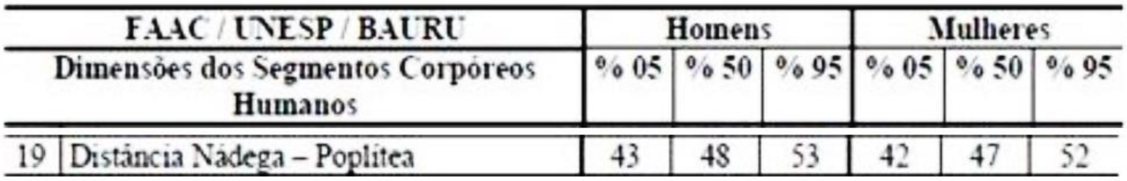
The head is localized at 93 cm from the seat base, taking into account the most unfavorable user height (04 measurements from table 11).

3.3.3 Lower body preliminary dimensions

In this case all the data were found in the book "*Felisberto e Pascuoarelli (2001)*".

Buttock-knees distance

The distance between the back part of the seat to the footrest must be between 42 cm and 53 cm approximately as is shown in the following table.



FAAC / UNESP / BAURU		Homens			Mulheres		
Dimensões dos Segmentos Corpóreos Humanos		% 05	% 50	% 95	% 05	% 50	% 95
19	Distância Nádega – Poplítea	43	48	53	42	47	52

Figure 17: Buttock-knees distance / Source: Elfdeportes

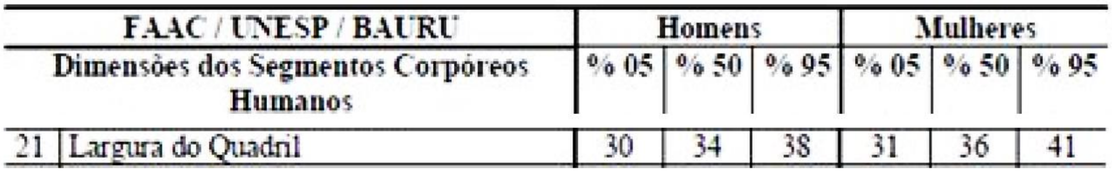
Table 12: Buttock-knee dimensional range

Measurement type	Minimum value	Maximum value
Buttock-knee distance	43 cm	52 cm

Hip width

Bearing in mind the user comfort, ergonomics and functionality, the distance between feet was also considered. The exoskeleton user will spend almost all the working day with feet in the same position, so this should be such as comfortable and natural as possible.

For these reasons, it was decided that the ankle, knee and hip will be in the same vertical plane. For this design the hip width from the book "*Felisberto e Pascuoarelli (2001)*" was used.



FAAC / UNESP / BAURU		Homens			Mulheres		
Dimensões dos Segmentos Corpóreos Humanos		% 05	% 50	% 95	% 05	% 50	% 95
21	Largura do Quadril	30	34	38	31	36	41

Figure 18: Hip width dimension for both sexes / Sources: Elfdeportes.

As 30 cm is the 5th women percentile and 41 cm is the 95th women percentile, the measurements range is:

Table 13: Hip width dimensional range

Measurement type	Minimum value	Maximum value
Hip distance	30 cm	41 cm

To ensure that the entire dimensional specter was completed, it was decided that between 14 cm and 48 cm from the vertical body are the footrest measurements.

The aim is to change the position of the feet during the usage of the machine.

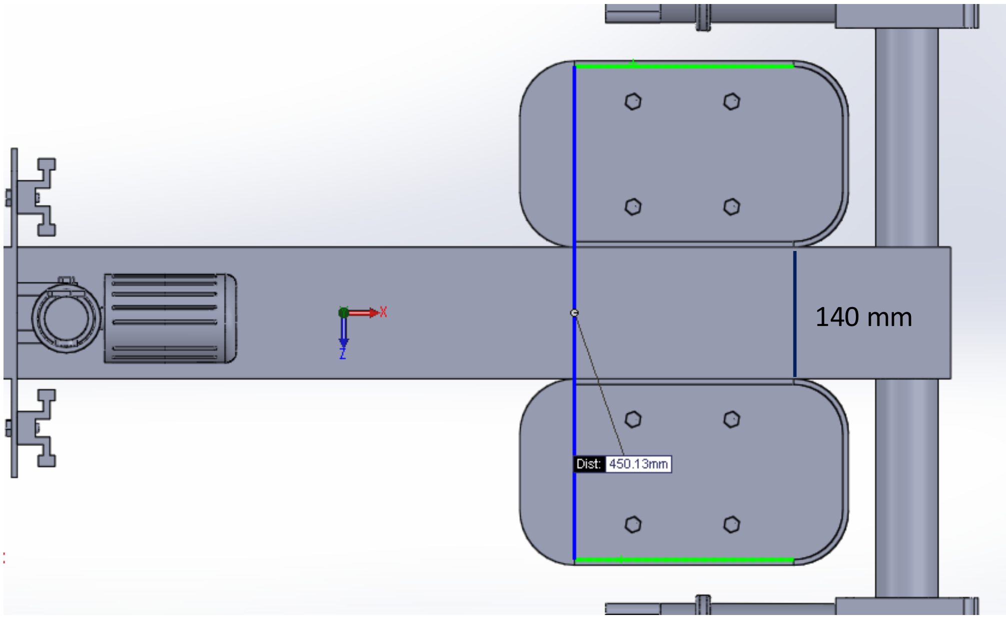


Figure 19: Maximum footrest dimension

3.4 Movement range

Once the interfaces are defined, the movement range of the adjustable elements was delimited. The delimited elements are: shoulder rotation in the horizontal plane, shoulder rotation in the vertical plane and the rise and decline movement in the squat action.

3.4.1 Shoulder movement

Movement in the horizontal plane

The design is based on the idea that the user should be capable of holding different loads with different shapes and dimensions. It was defined that the horizontal movement range would be between -10º to 20º, it is supposed that the 0º is the position where the arm is perpendicular to the back support.

This angle is conditioned by the ensemble stability and utilization, as the facility to pick up and discharge any kind of allowed load inside the exoskeleton use limitations.

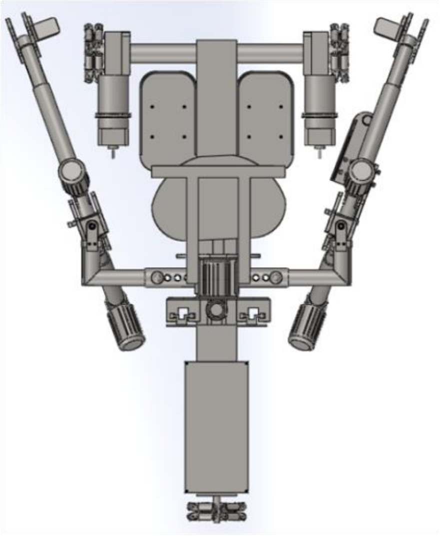


Figure 20: Maximum opening angle (+20º)

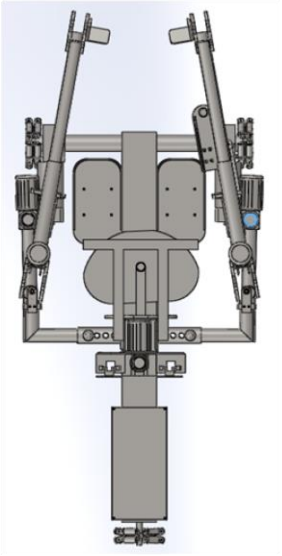


Figure 21: Minimum opening angle (-10º)

Movement in the vertical plane.

In order to not put in danger the security of the user, it was decided to restrict the elevation angle from -70º to 40º from the horizontal plane. In this way, the load cannot be in any moment over the user head, avoiding losing the stability and the danger for the operator of the exoskeleton.

The raising arm angle is limited for the maximum actuator force in the maximum rod extension. On the other hand, the going down angle is limited for the actuator dimensions.

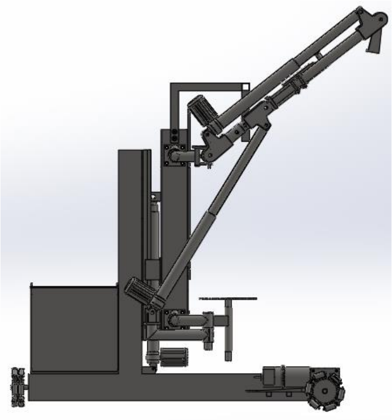


Figure 22: Maximum raising angle (+40º)

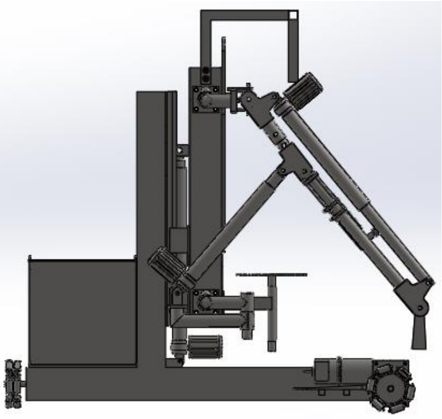


Figure 23: Minimum raising angle (-60º)

3.4.2 Elbow movement

Arm flexion angle

The minimum axial angle between the arm and the forearm is limited for the maximum extension of a human arm and it corresponds to the axial axis alignment. On the other hand, the maximum angle is restricted by the minimum extension possibility of the actuator.

Table 14: Arm movements' limitations

Movement limitations	
	Angle (º)
Arm over the horizontal plane	40
Arm under the horizontal plane	-60
Minimum angle (arm 1 – forearm 1)	0
Maximum angle (arm 1 – forearm 1)	90
Maximum opening from vertical plane (arm 1- arm 2)	20
Maximum closing from vertical plane (arm 1- arm 2)	-10

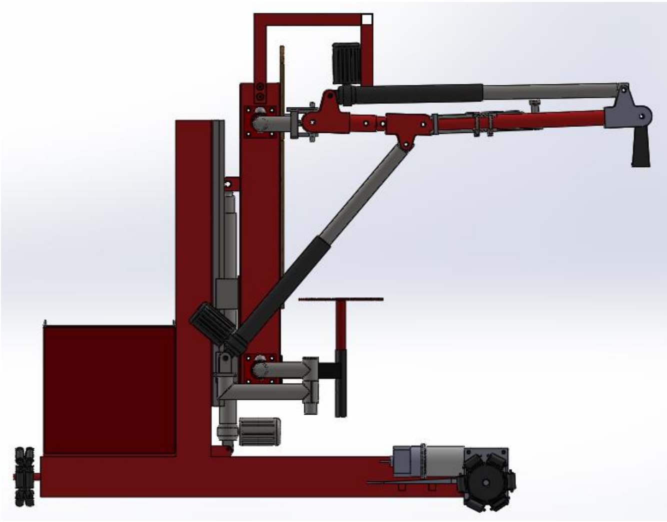


Figure 24: Minimum elbow angle

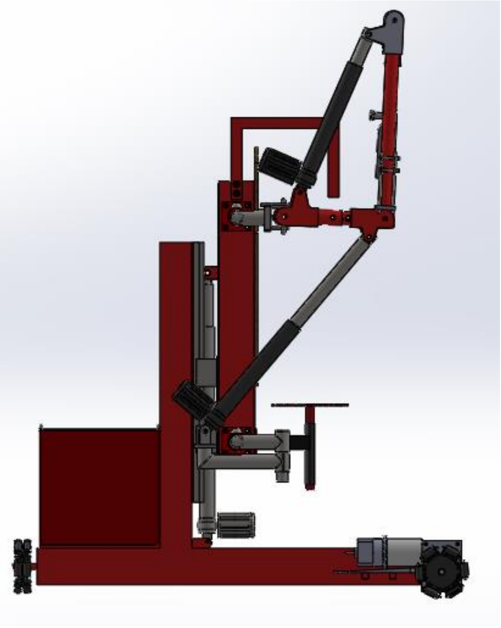


Figure 25: Maximum elbow angle

3.4.3 Hip movement

Movement limit: squat and stand up.

The action was studied in an empirical way in an average person. In this way, a set of parameters were obtained for, in an ergonomic and comfort point of view, the user could realize this action in a functional and satisfactory manner.

The most adequately feet-seat distance was obtained; this is between 42 cm and 53 cm. Then, it was defined a bottom dead center (BDC), it is the distance between the exoskeleton base to the seat in its lowest position, 30 cm. The distance from the exoskeleton base to the footrest is 6 cm, being at the end a total of 37 cm.

On the other hand, it was assumed the distance from the exoskeleton base to the highest position of the seat, 80 cm, as the top dead center (TDC). Thus these values were considered enough to realize the movement in a functional way, avoiding the risk that could create the total extension or articulation of the knee, as it is done in the real life.

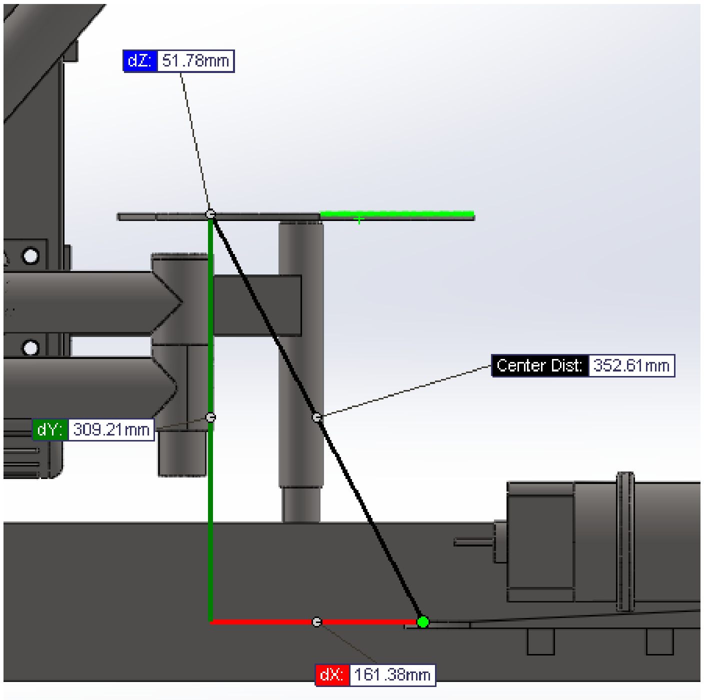


Figure 26: Minimum seat height

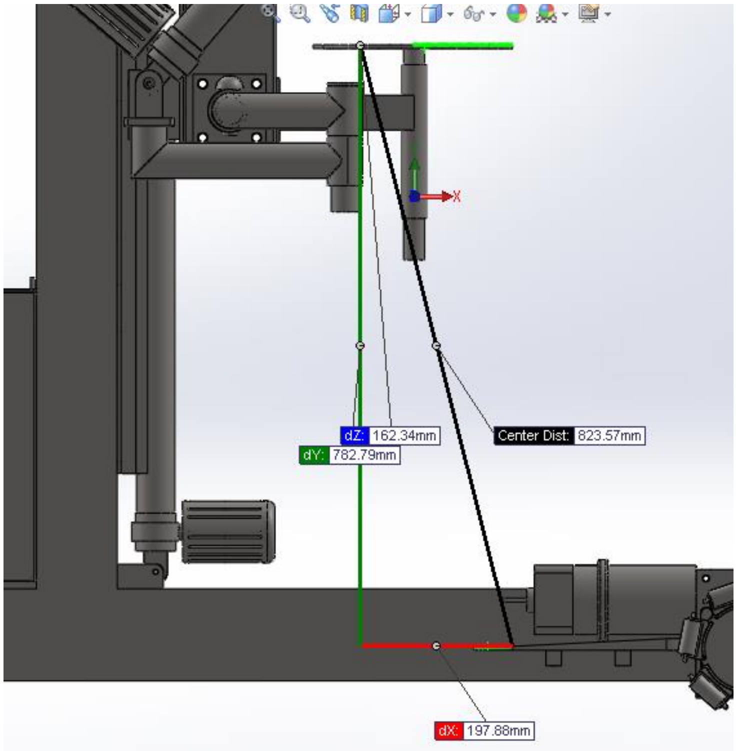


Figure 27: Maximum seat height

3.5 Global dimensioning

Next, it is explained and shown the general exoskeleton dimensioning.

The less compact configuration is when the arms are completely stretched at 40º over the horizontal plane, the shoulder in its larger position and the seat in its highest configuration and the highest position is when the arms are completely shrunk, the shoulders in its lowest position and the seat in its lowest configuration.

Table 15: Extreme exoskeleton dimensions

Case	Height	Length
Less compact	2151 mm	1591 mm
Most compact	1450mm	990mm

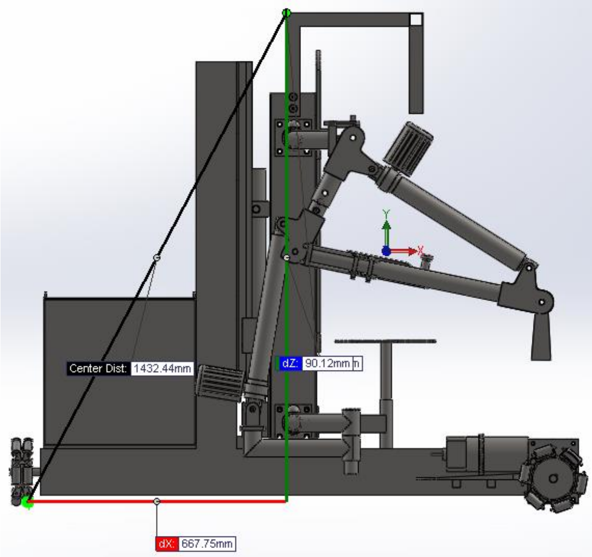


Figure 28: Most compressed position

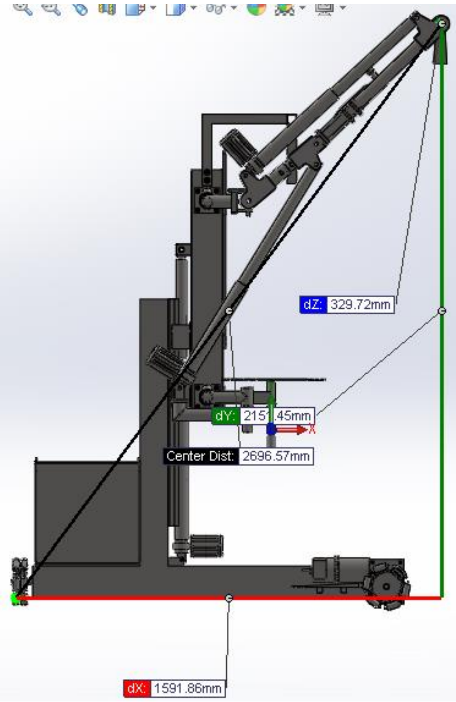


Figure 29: Most extended position

3.6 Components unification

With the goal of reducing costs and unify the assembly processes, it was tried that the similar functional elements had the same design, it is called “Design intention” in the 3D parametric design world. With that, the maintenance work is easier and the spare stock is reduced with all the advantages that it involves, like a smaller requirement in warehouse space.

The following elements were dimensioned with design intention:

- Footrest
- Tubular profiles
- Retractile shoulder structure
- Rotating cylinder
- Demountable ear
- Retractile support structure
- Tubular profile and support hairpin

4 Design evolution

4.1 Common elements in the design

4.1.1 Wheels

One of the most important decisions was the wheel election, it should be capable to realize the progress and reverse movement, as the rotation in both directions.

After comparing different kind of wheels, it was decided that the one that was more useful for this project is the *"omni wheel"*.

The main omni wheel advantage in front of the common wheels is the disappearance of the dragging component. Consequently, the exoskeleton could rotate and advance in any direction without any restriction. In addition, the machine storage would be better with this kind of wheels.

It is needed to know how much weight each wheel must bear, all the calculations are shown in "Annex 1: Analytical calculations", and the method to choose the wheel in the section "Final design".

4.1.2 Actuator

It was needed to decide which kind of device would be chosen to elevate the load and the weight of the operator.

The first idea was that the seat was rooted in the platform; in this situation the actuator shouldn't raise the weight of the user. But, as the objective is that the exoskeleton has to be able to be driven for different heights people, it means that the seat should be adaptable, because the user must fit in the exoskeleton to have the shoulders in the correct height to concordance with the exoskeleton shoulders.

The easiest way to solve that problem is that the shoulders and seat were joined and floating regarding the platform. With this solution, the user only has to sit and adjust the seat to have the shoulders in the correct position. Then the actuator would move the entire floating load like a set until the user was in the most comfortable position with their feet in the footrest.

Hydraulic actuator

It is capable of carrying big load with precision, but in this prototype there is no need to carry excessive loads, then the disadvantages are bigger than the advantages it offers.

Mainly the needed space for the oil deposit, the actuator dimension and the expensive maintenance are the reasons why this kind of actuator was not chosen.

Pneumatic actuator

The pneumatic actuator is capable to raise lower loads than the hydraulic actuators, but it works faster. In this prototype, this high speed is not needed, and it also was not chosen for the needed installation space that requires this kind of actuator, as the compressor and the air deposit.

Electrical actuator

The lineal electrical actuator is shown as the best choice for this prototype. It is able to raise big loads and the energy can be storage in batteries that feed as the wheels engines as the actuators engines.

Another important fact is the energy cost of each actuator, being the electrical one the most profitable.

Finally studying all the previous kind of actuators, the chosen one is the electrical actuator because is the one that fits better in this prototype.

With the maximum allowed load, maximum user weight and the exoskeleton arms and back weights, it can be done the stress force calculation that each actuator will bear. With this data, it was possible to choose the correct actuator through catalogues. The calculations can be found in the "Annex 1: Analytical calculations, section 2: Actuator election calculations". 3090 N was obtained as the maximum load value, having this force; it was able to choose the actuator ALI4 24-Vdc. that has a capacity of 4100 N.

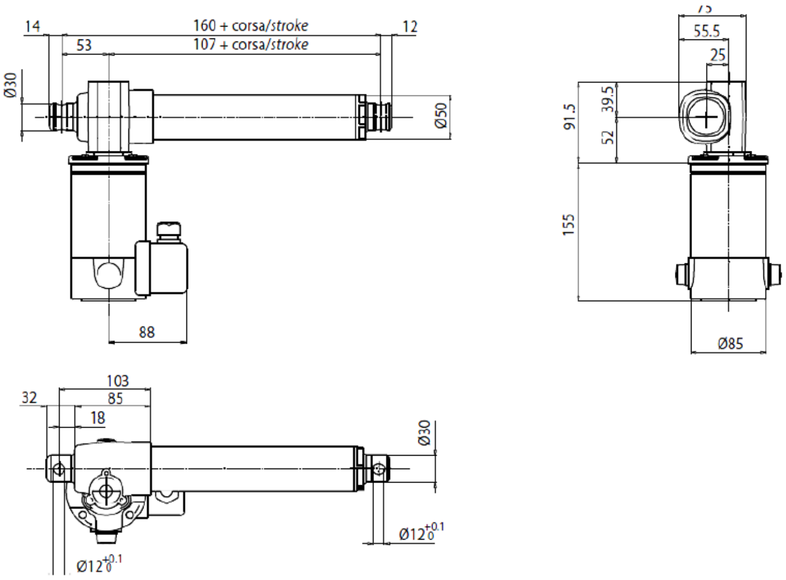


Figure 30: ALI4 24-Vdc. / Source: Actuator catalogue.

After contrasting different technologies to get arm movement, it was decided to also choose a combination of actuators to create the arm movement in the vertical plane. As this previous actuator can raise all the structure weight plus the load, it is also a good option to use the same model in the arm subassembly, because the measurements of it fits inside the design and the actuator in this mechanism do not need to raise as much weight.

Being at the end a total of five actuators in the final assembly; one in the lower body-chest interface and a composition of two of them in each arm to create the "muscle" in the arms articulations.

4.1.3 Vertical profile, lineal guides and subjection plate

The back and lower body union had to be made in a way explained in the previous section, the operator will be suspended regarding the platform and the actuator will move up and down.

But both parts, lower body and the back must be joined, without restricting the up and down movement. This can be solved installing a lineal guide. In the back should be screwed the guides, and in the lower body would be placed the corresponding rails. To insert the rails, it was decided to weld a vertical square profile on the lower body, being this profile parallel to the back.

Two kinds of guides were in mind: lineal guides with trapezoidal slide and lineal guides with straight slide.

Lineal guides with trapezoidal slides

This kind of guides present a high assembly complexity due to its geometry, they also are more expensive than the straight lineal guides.

On other hand, due to the need to place the actuator centered between both guides, the only feasible solution was adding a U profile. To this profile would be welded the trapezoidal slides, and the guides would be screwed to the base vertical profile.

Lineal guides with straight slides

However, analyzing the configuration of the lineal guides with straight slides, I can be seen that the simplicity in its geometry is the biggest advantage, as in the economical field as in the maintenance and assembly.

In this case, to add this element in the design there is any need to add any profile, because it can be screwed in the back or in the vertical base profile.

Due to these advantages, finally the lineal guides with straight slides were the chosen ones for the prototype.

Next will be explained which configuration was chosen to add the actuator and why finally was decide to add two lineal guides instead of one.

Two guides election

At first, it was considered to use a unique guide-slides set (from now on advance it will be called "lineal table"). Finally, the design was changed because the situation of this lineal table was not fitting with the electrical lineal actuator, also the stability of the chest-arms set was not enough, thus finally, it was decided to use two lineal tables to guarantee the correct operation.

Support plate

As the final design has in consideration using two linear tables, it is needed to add a support plate; the central column has not enough space to screw both of them. The dimension of it must to be fit into the design, guarantying the no interference with the other elements.

- Height: The height of the plate has the same longitude than the lineal tables, all the plate-guides set is installed in the same direction than the back electrical actuator direction (490 mm). It is decided to add a little dimensional marge (in this case is 55 mm each side) to avoid impacts on the top and bottom dead point (TDP-BTP). The final height of the support plate is 600 mm.

- Width: This value has to be enough to accommodate to lineal guides and allows the alternative vertical actuator movement. On the same way, a security marge is added (30 mm in total). The final width is 260 mm. Enough to satisfy the previous necessities.

- Thickness: The value was procured to fit in the preliminary design. However, it should be enough to withstand all the service tension and resist the stress caused for the screwed unions used in the guides. Bearing in mind this requests, the final thickness value is 10 mm.

The first material thought to be used to construct the support plate was aluminum, but as the central column would be made of steel, some considerations must to be done when two different material have to be welded.

Two materials with different fusion points and different dilatation coefficients could generate internal tensions that would raise the service weld bead fragility and the corrosion risk. To weld steel and aluminum, some chemical compounds are generated, these compounds are brittle and for avoiding then, it is need to use special welding technics.

Finally, to reduce cost and facilitate the assembly, the material chosen for the support plate is AISI1020 steel, the same used in the structure.

Table 16: Support plate measurements.

Magnitude	**Measurement (mm)**	**Marge (mm)**	**Total measurement (mm)**
Width	200	30·2 =60	260
Height	490	55·2 =110	600
Thickness	10	0	10

Two slides per guide

If only one slide per guide is put in the design, this will support the entire torque of all the structure, because the gravity center is between them. However, if two slides are put in each guide, the distance from each slide to the gravity center rise, decreasing the stress supported per each one.

In this way it is observed that for a same torque, the stress supported per each slide is lower when the distance between the slides and the gravity center rises.

In *Annex 1: Analytical calculations, section 3: Calculation referred to the lineal guide election*, are some suppositions for the arm and load positions. From this analysis is obtained that the worse position is where one arm is at 0º while the other is at 20º outward and supporting the totality of the load.

After this analysis, all the following studies will be done in the same position, because is the worst one. If the design is favorable in this position, it means that it is favorable for all the others positions.

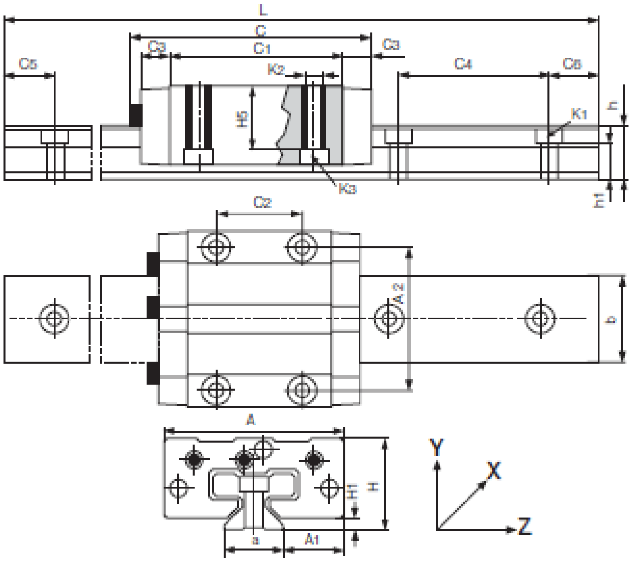


Figure 31: Lineal table DryLin TK01 / Source: Lineal guide catalogue

4.1.4 Engine and engine bearing/Battery

This element will be related with the chosen wheel and the final weight of the structure. These two elements will be defined when the final design will be over.

Depending on the engine and actuator consumption, it will be chosen a battery with different capacities, this element also will be defined when the final design will be over.

4.2 Subassemblies

The following pictures show the different subassemblies that compounds the final structure.

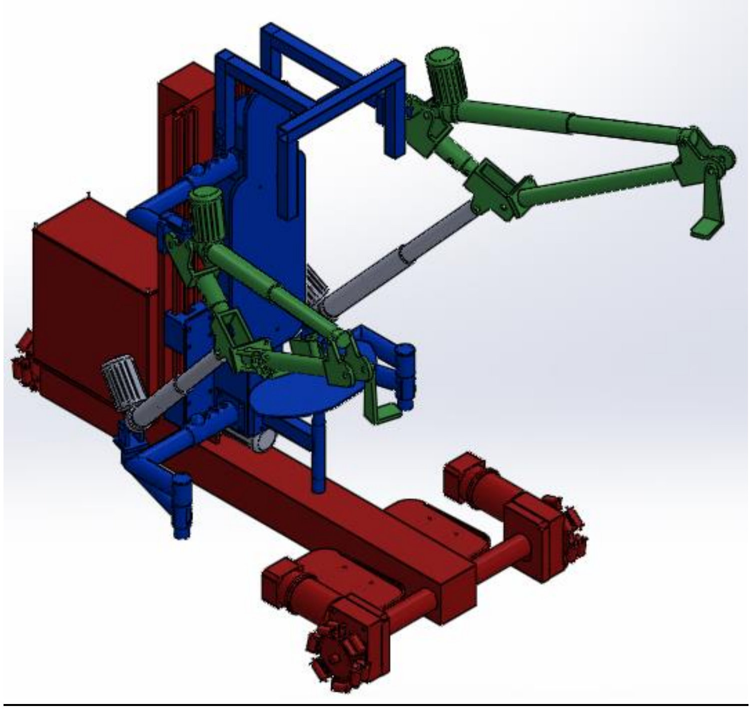


Figure 32: Isometric view. Chest, arms and lower body subassemblies.

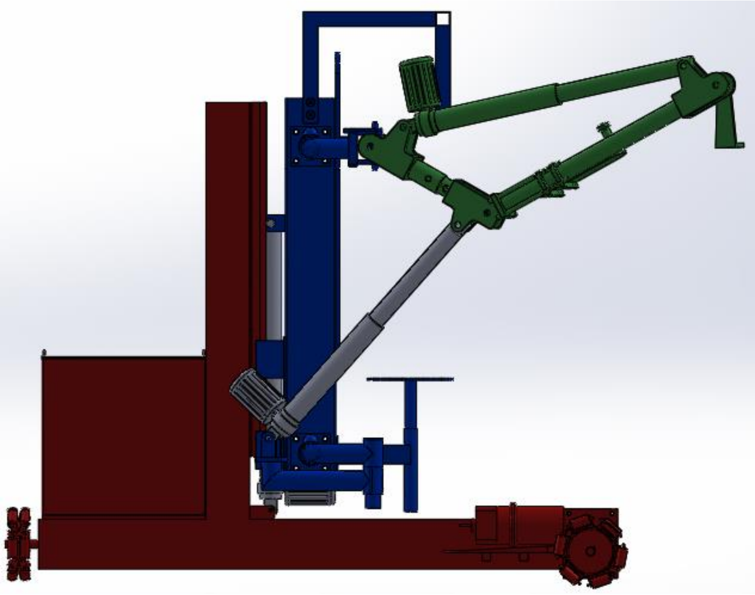


Figure 33: Lower body, Chest and Arms subassemblies

4.2.1 Lower body

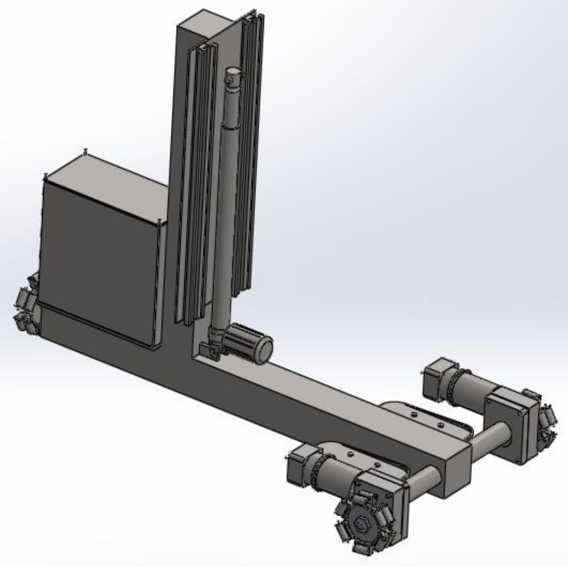


Figure 34: Lower body subassembly

Main components:

- 1 x Crew profile
- 3 x Omni wheels
- 3 x Engines
- 3 x Engine fixing piece
- 2 x Footrest
- 2 x Lineal guide
- 1 x Lineal guide support plate
- 1 x Actuator
- 1 x Box battery
- 1 x Battery tape

Analyzing this design, it can be observed that the exoskeleton could realize the needed movements without an engine in the back wheel; it means a weight reduction and energy savings for the needed battery storage.

The lateral movement is erased to convert it into two actions, rotation and advance (two wheels rotating into opposite directions).

The principal structure changed a total of 3 times, first it was a composition of two square pieces, one was the base and the other was the lower body interface, it was designed to be able to mount and dismount both pieces; this design was changed for some inconveniences:

- A square base do not give enough stability to the entire structure, the gravity center was displaced too much.
- The joint between both parts was a useless idea, this exoskeleton is not designed to be dismounted and the join is one of the weakest points in the structure, a big torque is generated in this place.

The second design consisted in only one piece in crew shape, the joint disappeared and the stability improved, but it still was changed for the following disadvantages:

- High weight
- Big dimensions
- Low maneuverability

The final design reduced the dimensions of the piece, doing it thinner and adding two wheel supports that allow maintaining the distance between the wheels and therefore the stability of the structure.

Wheels, engine and engine bearing.

First, the omni wheel is chosen by catalogue, it must bear the third part of the weight. The calculations are shown in *Annex 1: Analytical calculations, section 5.1 Minimum power needed to move the wheel*. The chosen wheel is HANGFA QLM-20 that can bear a maximum load of 160kg.

With the chosen wheel specifications and determining a minimum advance velocity, it is possible to calculate the engine power needed. These calculations are shown in *Annex 1: Analytical calculations: Engine election.*

In accordance with the results, the chosen engine is PM63-50BG9, its catalogue is shown in *Annex 3: Catalogues*.

Concluding, knowing the engine dimensions and its geometry, it was needed to think the way to link it with the design.

The solution was to design a piece with the same shape and length and width dimensions with four concentric holes, the engine and this piece would be linked with four bolts.

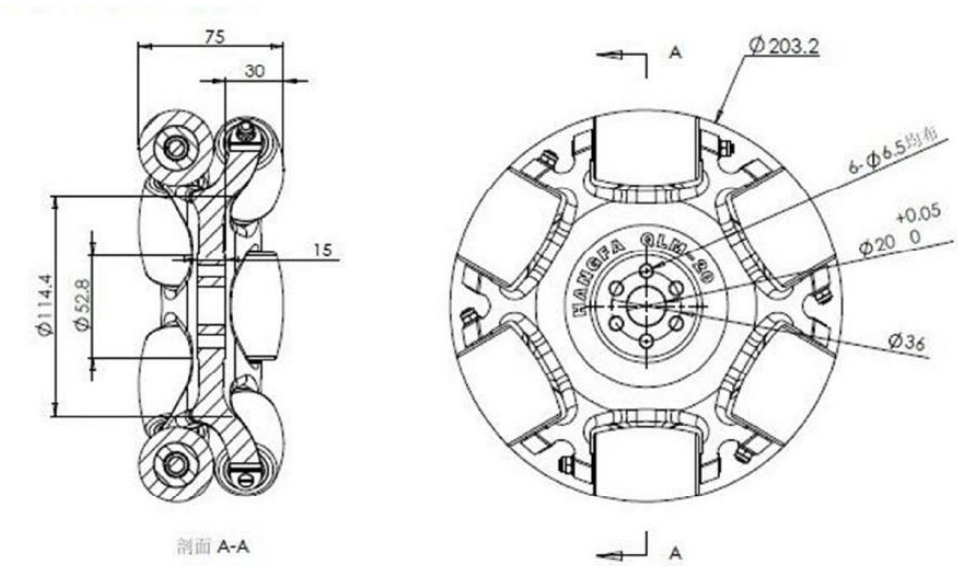


Figure 35: Omni wheel HAMFA QLM-20

Battery

The final design contains three wheels, two engines and 5 actuators (2 in the arms, 2 in the shoulders and one in the lower body). It is possible to calculate the consumed power and then choose the battery needed.

Calculations are in *Annex 1: Analytical calculations, section 7 Battery calculations.*

Finally, the chosen battery is TROJAN J185H-AC.

4.3 Chest

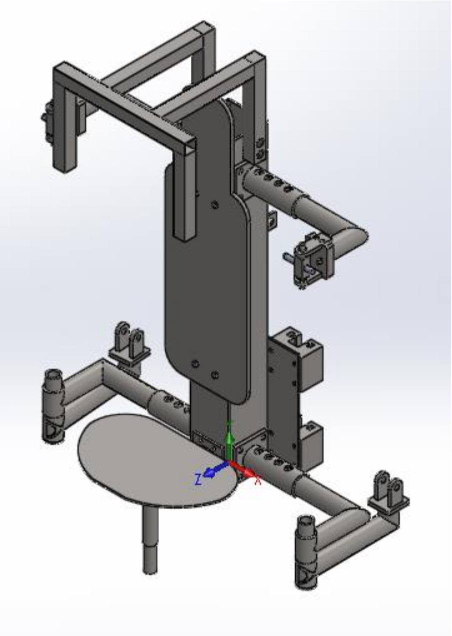


Figure 36: Chest subassembly

Main components:

- 1 x Security structure
- 4 x Tubular profile
- 2 x Retractile shoulder structure
- 2 x Rotating cylinder
- 2 x Shoulder pin
- 2 x Demountable ear
- 2 x Cooper hub
- 1 x Column
- 1 x Back support
- 1 x Seat support
- 1 x Seat
- 2 x Retractile support structure
- 2 x Tubular profile and support hairpin
- 1 x Cooper hub and tape
- 4 x Lineal slides

The main problem in this subassembly design was how to reach the user dimension range and how to give horizontal and vertical mobility to the arms subassemblies.

The design changed three times, the first design was created only to have a preview of how the shape should be and to visualize the dimensions of it. It was know that this design would not have any real finality. After having this preview, the next problems were found:

- It has not any extensible element, it was not reaching one of the main goals (it should be able to be used by different stature users).
- The chest-arm interface was created with a rectangular profile element, this shape is not the best election in this situation and it has to bear big torques.
- The vertical and horizontal arm movement is not contemplated.

In the second design some problems were solved, the rectangular profile elements were changed for cylindrical ones, this change improved the torque resistance, and also some new elements were created (Retractile support structure and retractile shoulder structure) to add some different joint positions that give a variable dimensioning to the final composition, reaching in this case the retractile goal. Finally, the most important change is the addition of a spherical element that allows the arm movement.

Even with these changes, some little problems were found:

- The dimensions of the column were too big and therefore the weight was creating an unnecessary big torque.
- The spherical element was working fine, but as the goal of the project is to raise loads of 50 kg, it was supposed that the element would break in a near future.

In the final design, these problems were solved, the dimension of the column was reduced and to add the lineal slides, a thin plate was welded in the new column. The spherical element was changed for a hub with a bolt crossing it, the hug gives the horizontal movement, while the bolt allows the vertical one.

4.3.1 Arms

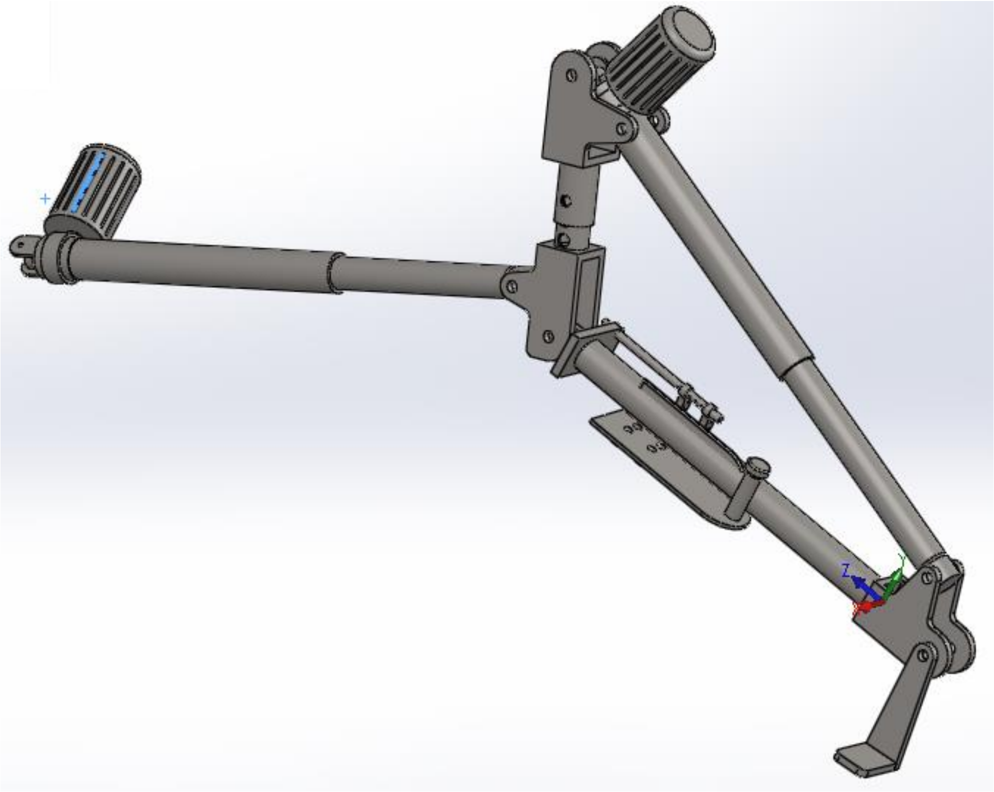


Figure 37: Arm subassembly

Main components:

The final arm subassembly is composed for two symmetric subassemblies; it was intentioned to create as much equal element that could be used in both arms, to maintain the design intention.

- 2 x Kneecap elbow arm
- 2 x kneecap shoulder arm
- 2 x Shovels
- 4 x Extensible tubular joint
- 4 x Arm support joint
- 1 x Left forearm
- 1 x right forearm
- 1 x Left arm support
- 1 x Right support

The arm design was not changing a lot after the first idea, it was based in the chest design to create the retractile possibility and it was also created with cylindrical profiles. The unique addition IS the arm support element; it allows the user to rest the arm and to create a joint between the user and the structure to transmit the mechanical energy, it is an essential element that should be combined with different sensors and electronic devices to make possible the objective of the exoskeleton (carry big weight without using a big force), the user's arms and the exoskeleton's arms should work synchronized, but it is a complementary work for this main project.

Shovels

To dimension the box handle is needed to know the minimum measurements of the shovel that will be used to hold the load.

Height	10 mm
Length	50 mm
Width	70 mm

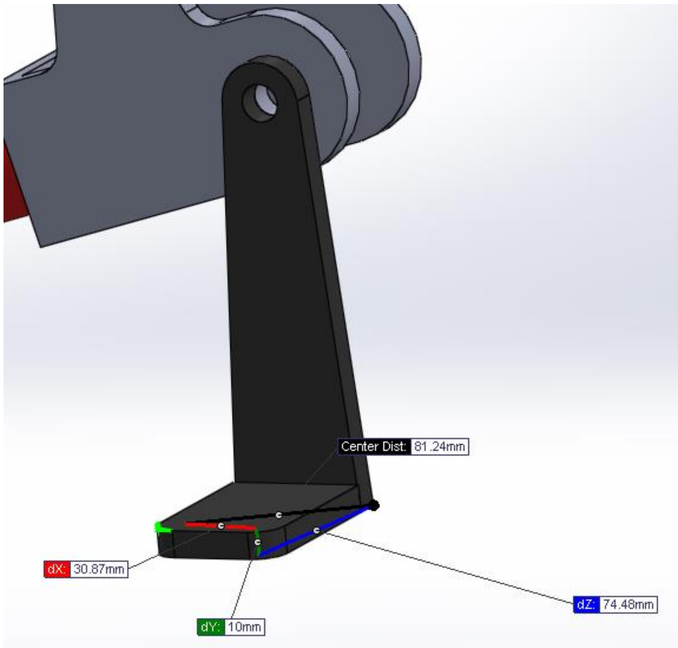


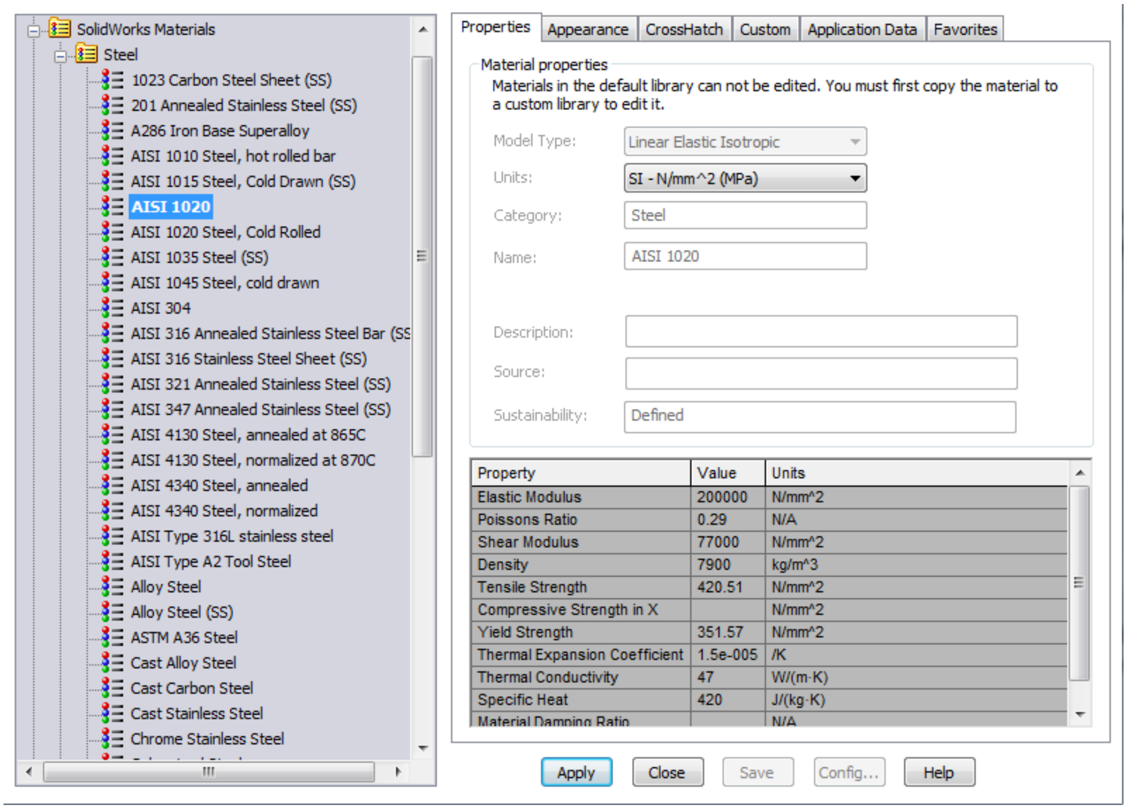
Figure 38: Shovel illustration

The shovels will never be in distance lesser than 360 mm; all these measurements will be used to calculate the box handle dimensions in a following section.

4.3.2 Material

This section is important to know the final weight of the entire structure, but as this project will not be absolutely finished, it is possible that the final design version could suffer some changes in the chosen material, when the axis studies would be realized, it should be decided if the material has the correct specifications to reach our requirements or it should be changed to another one with better characteristics for our necessities.

The material chosen for the structural elements is AISI1020 steel, in the following picture (taken from the software SolidWorks) is possible to see the material specifications:



Material properties

Materials in the default library can not be edited. You must first copy the material to a custom library to edit it.

Model Type: Linear Elastic Isotropic
Units: SI - N/mm^2 (MPa)
Category: Steel
Name: AISI 1020
Description:
Source:
Sustainability: Defined

Property	Value	Units
Elastic Modulus	200000	N/mm^2
Poissons Ratio	0.29	N/A
Shear Modulus	77000	N/mm^2
Density	7900	kg/m^3
Tensile Strength	420.51	N/mm^2
Compressive Strength in X		N/mm^2
Yield Strength	351.57	N/mm^2
Thermal Expansion Coefficient	1.5e-005	/K
Thermal Conductivity	47	W/(m·K)
Specific Heat	420	J/(kg·K)
Material Damping Ratio		N/A

Figure 39: AISI 1020 steel SolidWorks specifications /Source: SolidWorks oftware

This kind of steel is chosen as first option for its good fatigue resistance and the easy mechanization.

The total weight of the steel structure has a final weight of approximately 540 kg. It was calculated with the measurement tool from SolidWorks.

4.3.3 Box

Limit dimension of the box to carry.

First, it must be calculated the limit dimensions of the box that is needed to be elevated.

The worst situation is when it is needed to raise the load from the floor. Then, the limit dimensions of the box is when the exoskeleton is situated in the bottom dead center (BDC), the arms in this positions are in the closest distance from the floor.

In addition, in this position can be found interferences between the shovels and base structure when the arms are closed to its maximum angle (-10º), then some specifications have to be done before doing this study.

After testing the structure with SolidWorks, the position that makes possible to carry the load from the floor is this:

- Both arms completely extended and closed at -10º
- Both arms at -40º from the horizontal plane.
- Chest subassembly situated in its IDC.

Studying this position is possible to get the minimum volume that the box should have.

Width	360 mm
Length	309 mm
Height	360 mm

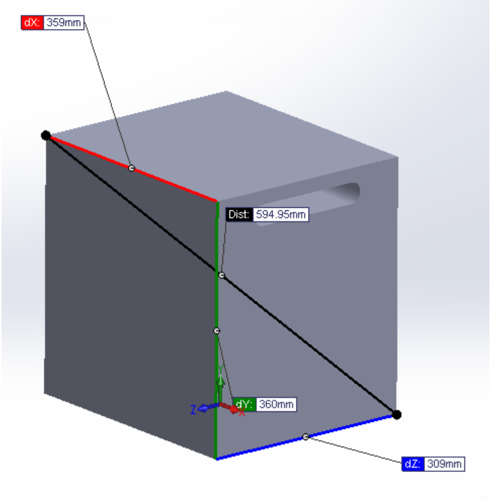


Figure 40: Example box dimensions

After having all this measurements, it is possible to define the minimum dimensions of the handle, it has to be positioned at 310 mm from the floor and it has to maintain the symmetry with the box to improve the stability.

Width	180 mm
Length	360 mm
Height	30 mm

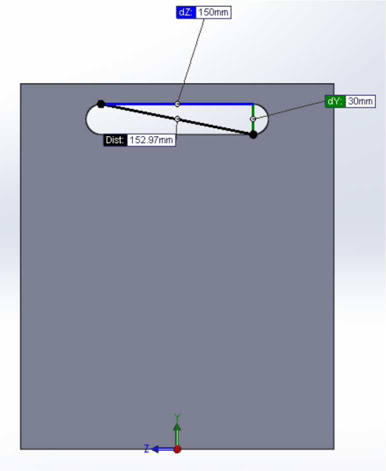


Figure 41: Example box handle

Next is showed a representation of how the exoskeleton would carry and raise a minimum size load.

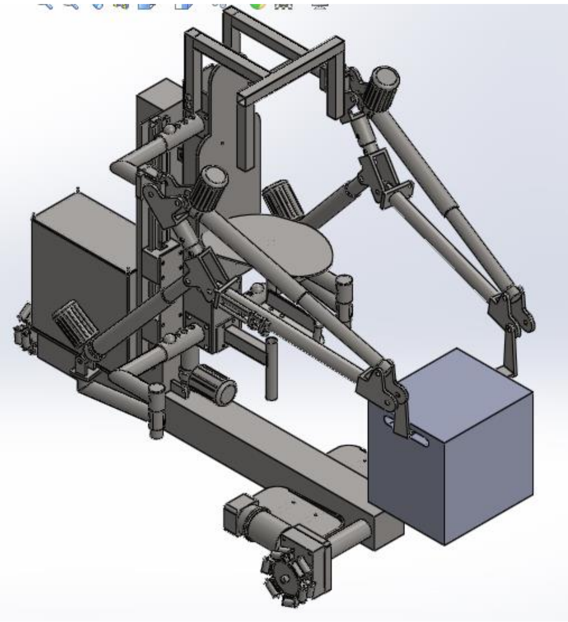


Figure 42: Exoskeleton carrying a load

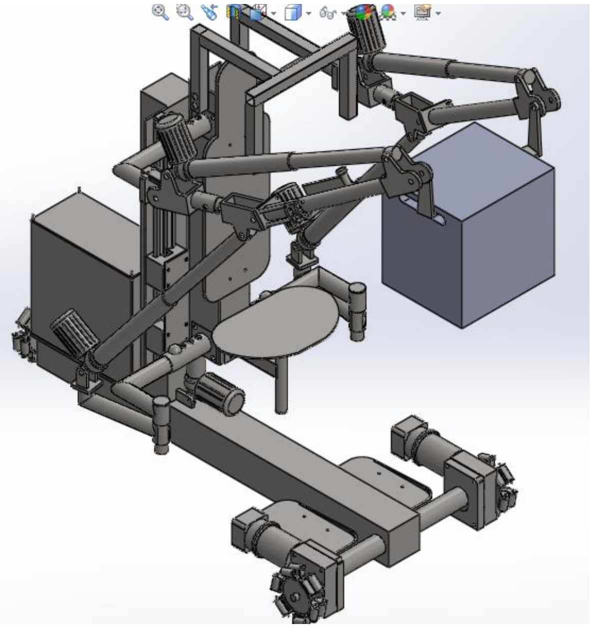


Figure 43: Exoskeleton raising a load

4.3.4 Maximum height that the load could be raised

To determine this parameter, it is needed to move the exoskeleton until his maximum height position. This position is determined as:

- Arms completely extended
- Arm turned 40º over the horizontal plane
- Structure in the top dead center (TDP)

After positioning the exoskeleton in this position it was possible to measurement the total height that is possible to elevate the load.

Maximum stacking height	2084 mm

It is a good result, this measurement simulates the height that a normal human could raise a normal height, but in this case, it would be possible to do the same action but with a load two or three time heavier than a normal person could carry.

4.3.5 Ideal transporting position

The ideal position to transport the load is where the gravity center is lower, but as one of the goals of this project is to be care about the user comfort, the transport cannot be realized in the bottom dead center (BDC), where the user should be all time completely flexed. It I estimated that an average normal height is 500 mm, in this way the user is not in any of the extremes positions.

The ideal transporting position is got with:

- Arm-forearm angle at 100º
- Seat at 500 mm from the footrest
- Elbow actuator completely closed

After analyzing this position, a big problem was found; the visibility of the user can be reduced when the load is in front of him. It is a big problem that should be studied and tried to be solved in the next prototype design.

4.3.6 Manoeuvrability

In this section will be detailed which will be the needed workplace to use this exoskeleton prototype carrying the maximum load of 50 kg.

First, the width and height corridor measurements will be defined to have enough space for the exoskeleton realizing its goal.

These dimensions are established assuming that the user is working in the ideal position and having a marge of 10 cm between the exoskeleton and the walls.

The minimum wall height should be 1680 mm if we assume the last assumptions; it is not a problem because any industrial workplace has a minimum height of 3 or 4 meters.

To talk about the needed width, two different situations must be studied. It is considered the following carrying position:

- Arms completely extended
- Arms opened at their maximum angle from the vertical (20º)

Situations:

1- The exoskeleton does not need to rotate, only carry the weight in straight direction.

In this situation the dimensions between both arms is 1480, and bearing in mind the marge with the walls, the minimum corridor width must be 1580 mm

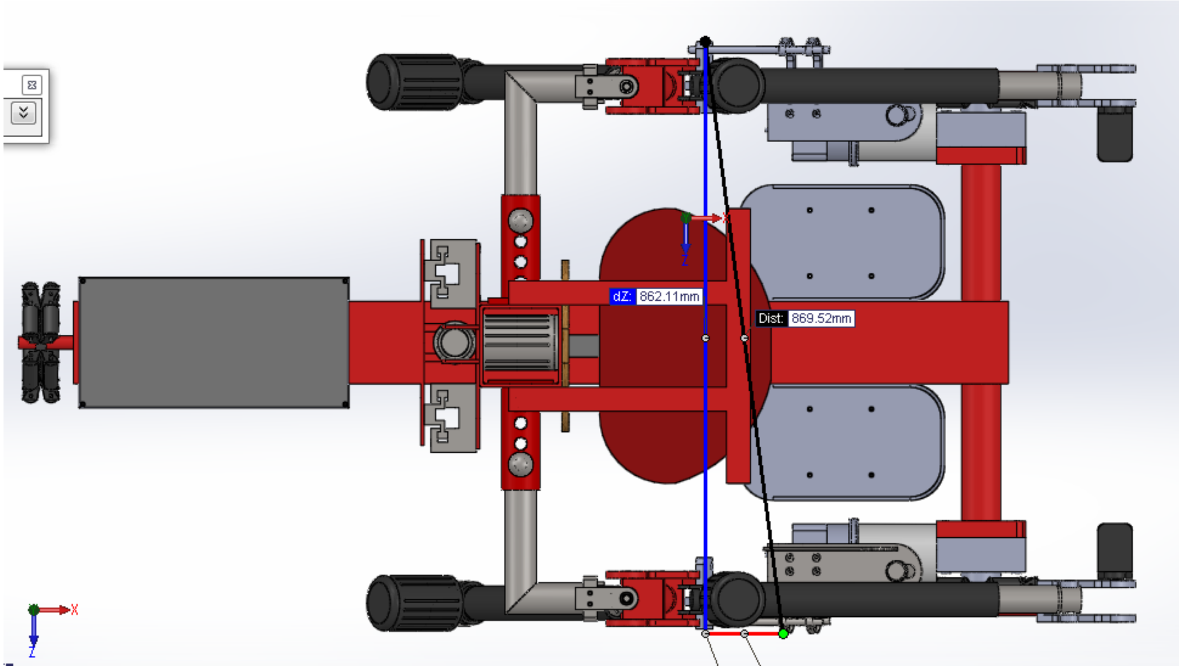


Figure 44: Absolute width dimension

2- The exoskeleton needs to rotate.

When the exoskeleton needs to rotate, it creates an imaginary pivoting axis in the middle point between the wheel, the length between this point and the back wheel represents a radius of an imaginary circumference. This radius has a length of 1400 mm.

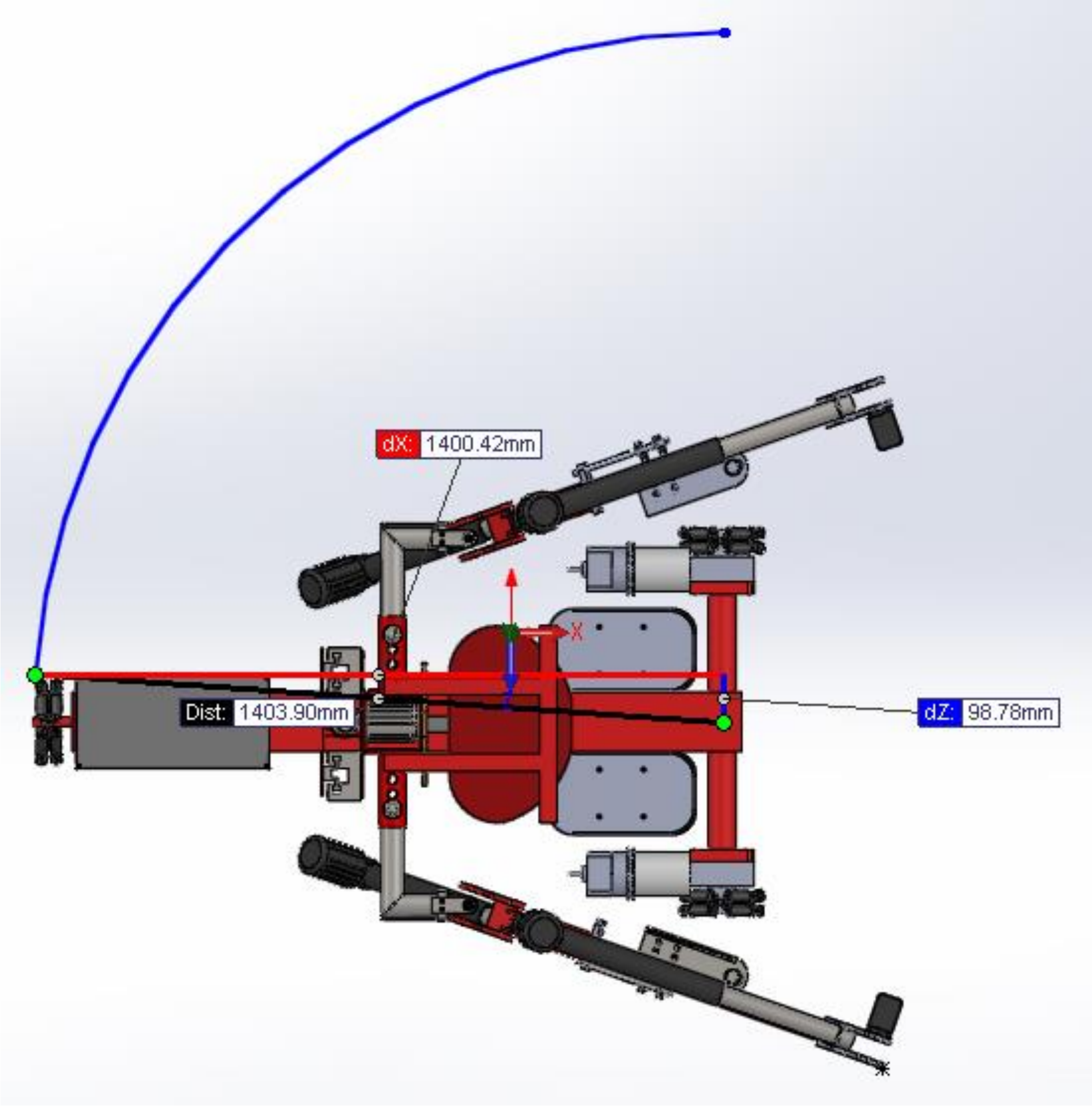


Figure 45: Pivoting radius

But as the arms in the most extended position, the distance from the pivoting axis to the farthest arm point must be added to the total measurement, also the marge with the walls have to be counted, finally being the minimum corridor width in this position, 2305 mm.

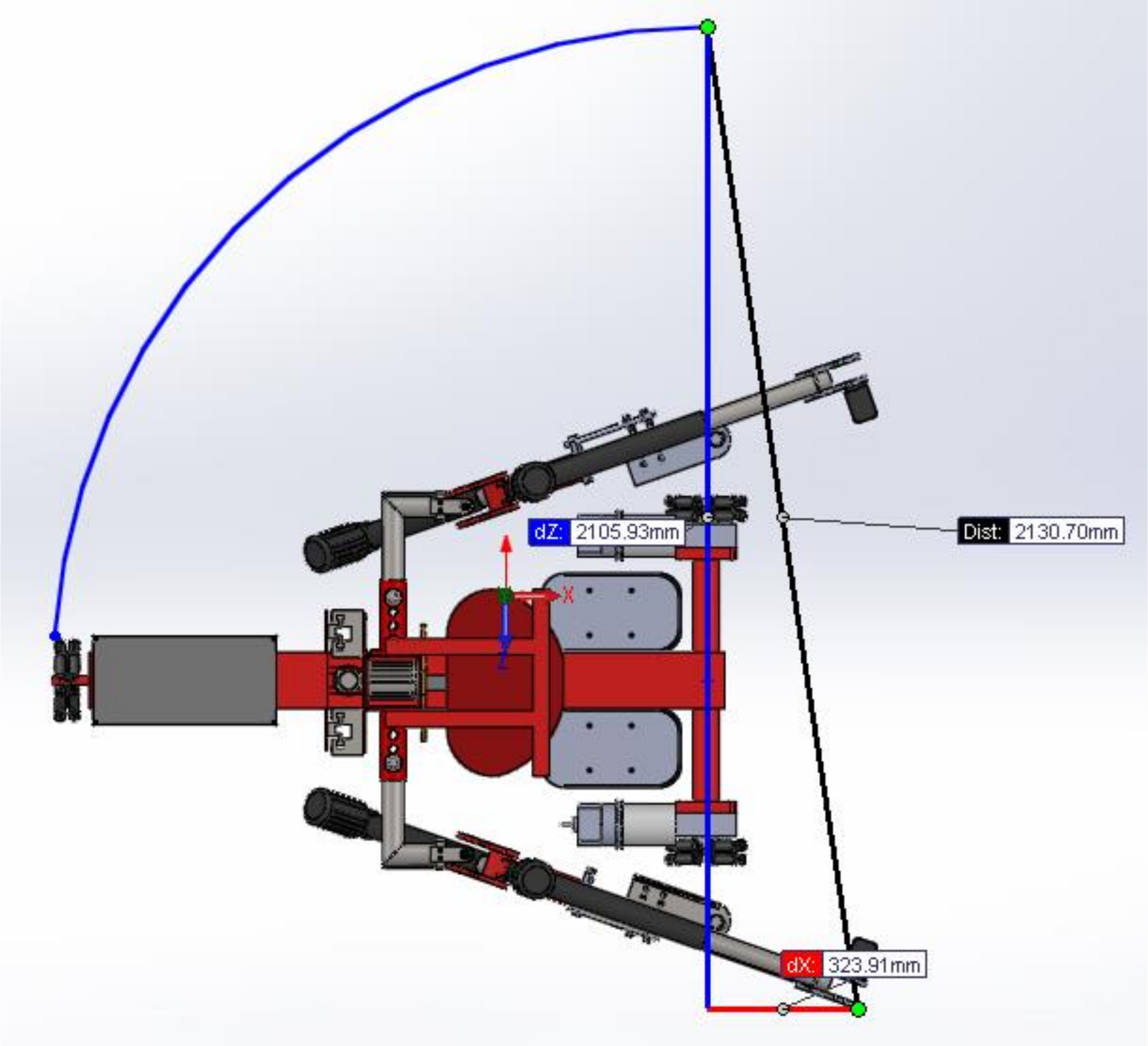


Figure 46: Absolute pivoting dimension.

4.3.7 Exoskeleton storage

As last, an important aspect in the industrial field is the machinery storage.

The most compressed position is the one that is used as storage position. This position was studied in section *3.5 Global dimensioning*, but the measurements are shown in the following table.

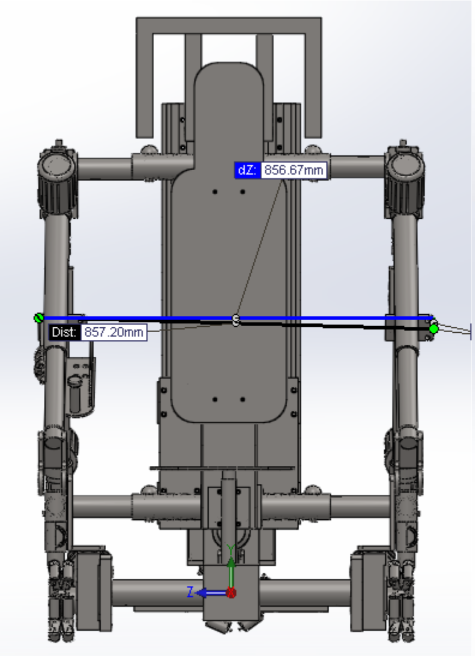


Figure 47: Storage width

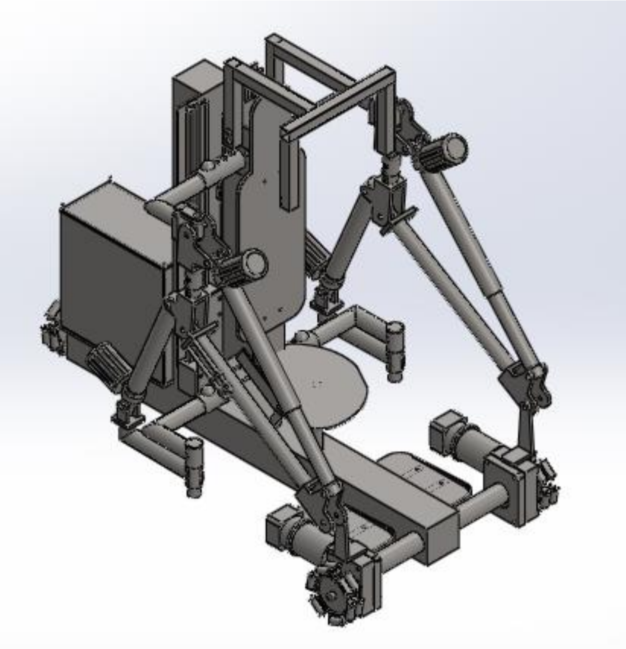


Figure 48: Storage position

Table 17: Exoskeleton storage dimensions.

	SolidWorks rounded measurement	**Final dimension (with 100 mm to the wall)**
Width (mm)	860 mm	1060 mm
Length (mm)	1500 mm	1700 mm
Height (mm)	1450 mm	1550 mm

4.4 Final design

After the previous study and after drawing some different structures, it was chosen the one that can allow all the elements without interferences and at the same time can realize all the movement needed and described.

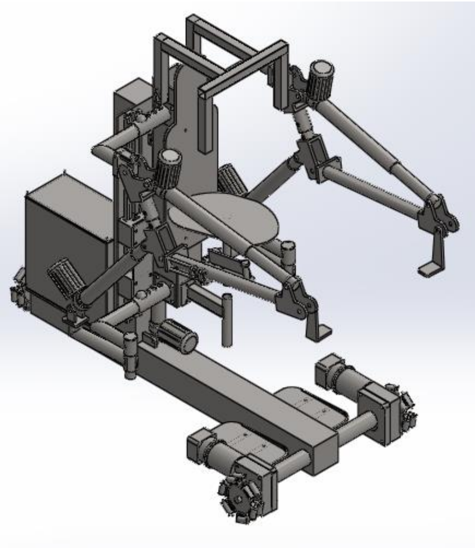


Figure 49: Final assembly (Front isometric view)

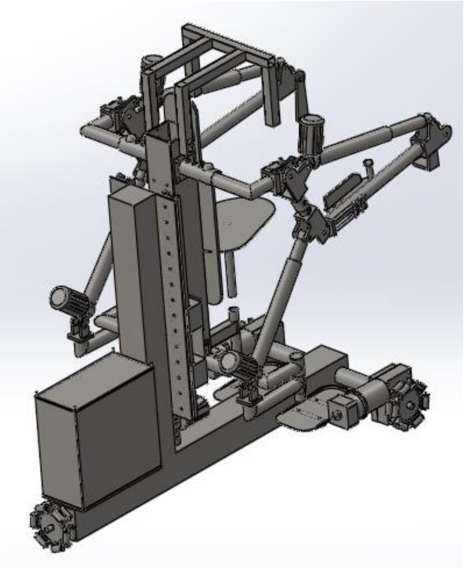


Figure 50: Final assembly (Back isometric view)

Finally, confirming the final design based in simplicity, profitability and easy assembly, it is possible to define the final components.

5 Budget

This section was created to have a cost estimation to compare it with machinery those are currently functional. It has to be emphasized that it is not a final version and the electronics part is not studied in this project, therefore this little economical comparison is show the situation where this study is right now.

To realize this budget, different table were created with an Excel worksheet.

Each subassembly was studied individually.

Lower body

Manufacturer bought elements		1200	€
Square and circular tubes (AISI1020)		30	€
Solid steel rod (AISI1020)		1	€
Steel plates (AISI1020)		25	€
Screws		25	€
Mechanized	Cutting	175	€
	Drilling	210	€
	Milling	100	€
	Lathing	100	€
Welding		280	€
Assembly		75	€
Total		2221	€

Chest

Shoulder subassembly	900	€
Support subassembly	750	€
Column subassembly	740	€
Seat subassembly	230	€
Electrical actuation system	1500	€
Assembly	250	€
Total	4370	€

Arms

Final pieces cost	470	€
Welding	90	€
Screws and hubs	140	€
Electrical actuation system	1500	€
Total	2200	€

Final assembly

Total	**17582**	**€**

After doing this estimation, it was searched another machinery that could realize the same work as the exoskeleton.

Searching on internet, some devices were found, it was chosen the one that could realize the same objective in the most similar way.

The chosen device is a forklift, in specific the model WP 3000 from the company CROWN, its catalogue is added in Annex 2: Catalogues.

The main points that were studied are the general dimensions and the capacity to realize the work. The forklift dimensions show the range that compounds all the models.

Table 18: Machine comparison

	Exoskeleton	**Forklift**	
Height	1450	780-1197	mm
Width	860	712	mm
Length	1500	1799-1899	mm
Elevation height*	2048	750	mm
Rotation radius	1408	1534-1634	mm
Maximum raising weight	50	800	kg
Device weight (without battery)	540	490-535	kg
Price	17582 + Elect. Dev.	3000	€

*Maximum load raising height

The comparison gave promising results. The dimensions of the exoskeleton are little enough to be competitive in the market while in other aspects are even better; the elevation height is more than twice, allowing this better stack options, but on the other hand, the estimated price of the exoskeleton is extremely high to be an available option.

There are still some options to improve the exoskeleton and reduce the cost, it would be possible to change the material, even the design could be changed to give more stability reducing the dimensions or even increasing the load weight that could be carried.

6 Conclusion

The realization of this project was done following the engineering design processes, it was done a necessity recognition, followed by a problem definition, the synthesis of the design, the essential analysis and optimization was done until the third design, as it is a thesis report and the global goal of it is showing my engineering knowledge, the design process stopped in this point and it continued to the evaluation step to finally finished in the presentation.

In the final design, after realizing all needed modifications, I obtained a design that met all the requirements initially aimed, the anthropometrical dimension for the dimensioning are reflected in the design and the interfaces were successfully defined, allowing the desired movement without interferences. As a result, the final prototype studied is considered to be the simplest and the cheapest option.

Even the exoskeleton specifications are good enough to realize its goal; it still has to be improved in many ways. As the intention is to design an exoskeleton, the next versions should be evolved to a humanoid shape, the most important factor would be the movement system, the design should allow the user working in many different workspaces, not only in flat floors, the biggest restraint of this project.

Also, during the study it was possible to check that using the right element and materials, the lifting capacity of this dispositive could be highly improved, combining this fact with a good base stability, it would be possible to get a real exoskeleton that allows the user lifting huge loads in many different spaces. These improvements could hide the high manufacture cost and convert this project in a real market option.

7 Literature references

/1/ Elfdeportes. Digital magazine. *Antropometria: necessidade de constantes investigações para a efetiva contribuição na área da Ergonomia*
http://www.efdeportes.com/efd149/antropometria-contribuicao-na-area-da-ergonomia.htm
Retrieved: 25.03/2016

/2/ European Agency for Safety and Health at Work. *Transtornos musculoesqueléticos*.
https://osha.europa.eu/es/themes/musculoskeletal-disorders
Retrieved: 25.04.2016

/3/ Felisberto, L. C.. Pascuoarelli, L. C. 2001. *Dimensionamento preliminar de postos de trabalho e produtos – modelos antropométricos em escala. In: ENCONTRO NACIONAL DE ENGENHARIA DE PRODUÇÃO.Anais... VII International Conference on Industrial Engineering e Operations Management, Salvador. Proceedings, 1 CD ROM.*
Retrieved: 23.03.2016

/4/ Lapunzina, P. *Aielo H. 2002. Manual de antropometria normal y patologica: fetal, neonatal, niños y adultos. Elsevier España, p.503.*
https://books.google.fi/books?id=6dqdadnpvckC&printsec=frontcover&hl=es#v=onepage&q&f=false
Retrieved: 30.03.2016

/5/ MUEBLESDOMOTICOS. *Medidas para diseñar sillas o asientos.*
http://mueblesdomoticos.blogspot.fi/2010/12/medidas-para-disenar-sillas-o-asientos.html
Retrieved: 05.04.2016

/6/ NATIONAL AERONAUTICS AND SPACE ADMINISTRATION. *Man-Systems Integration Standards. Revision B, July 1995. Volume I, Section 3 ANTHROPOMETRY AND BIOMECHANICS.*
http://msis.jsc.nasa.gov/sections/section03.htm#_3.2_GENERAL_ANTHROPOMETRICS
Retrieved: 07.04.2016

Catalogues

/7/ EMD. *Gearbox BC-9*
http://www.parvalux.com/downloads
Retrieved: 13.04.2016

/8/ HANGFA *Omni wheel QML-20*
http://www.hangfa.com/EN/omniwheel/QLM20.html
Retrieved: 10.04.2016

/9/ IGUS. *DryLin TK-01 Lineal slide.*
http://www.igus.com/wpck/3576/DryLin_T_Einstellbares_Spiel
Retrieved: 03.04.2016

/10/ MECVEL. *Lineal Actuators ALI4 24-Vdc.*
http://www.mecvel.com/linear-actuator-ali4-ac/
Retrieved: 03.04.2016

/11/ TROJAN. *Battery. J185H-AC*
http://www.trojanbattery.com/product/j185h-ac/
Retrieved: 07.04.2016

Table of contents: Figures

Table of contents: Tables

NOVIA UNIVERSITY OF APPLIED SCIENCES

Mechanical-Environmental Engineering

Bachelor's thesis:

Exoskeleton: Prototype design

Annex 1: Analytical calculations

Oscar Teruel Guisado

The degree program of Environmental Engineering
Vaasa/Novia April 2016

Table of contents: Annex 1

1. Abbreviation and definitions

	Symbol	Variable	SI Unit
Forces	F_{max}	Maximum force that the actuator has to bear	N
	F_x	Force in "x" axis	N
	N	Normal force	N
	F_{max}	All the weight over each wheel	N
	F_{own_wheel}	Weight of the own wheel	N
	F_{min}	Minimum force to move the wheel	N
Torques	T_{load}	Torque generated by the load	Nm
	T_{arm}	Torque generated by the arms	Nm
	$T_{actuator}$	Torque generated by the actuator	Nm
	T_{chest}	Torque generated by the chest	Nm
	T_{seat}	Torque generated by the seat	Nm
	T_{total}	Torque generated by the total sum of the load, arms, chest, seat and actuator	Nm
	$T_{position\_1}$	Final torque module in position 1	Nm
	$T_{position\_2}$	Final torque module in position 2	Nm
	$T_{position\_3}$	Final torque module in position 3	Nm
	T_{fx}	Torque generated in the lineal guides on axis "x" in position 1	Nm
	T_{fz}	Torque generated in the lineal guides on axis "z" in position 2	Nm

	$T_{resistant}$	Maximum torque generated by the wheel	Nm
	$T_{starter}$	Torque needed to start the movement	Nm
	T_{res}	Maximum torque generated by all the structure	Nm
Power	P_{wheel}	Power needed to move the wheel	W
	P_{total}	Power needed to supply all the devices	W
Velocities	v	Structure maximum velocity	m/s
	w	Wheel angular velocity	rad/s
Others	d	Variable to represent the perpendicular distance in torque calculations	mm
	m_t	Total structure mass	kg
	m_{wheel}	Maximum mass that each wheel can carry	kg
	R	Radius of the wheel	mm
	μ_r	Eccentricity	mm
	a_{sim}	Simultaneity factor	

2. Calculation referred to the actuator election

To realize the calculation for the actuator that is situated in the base platform, is needed to know the approximate weight that it will bear. It is known that for this configuration, the actuator have to support the arm and back weight, and the user weight. These weights were obtained with the measurement tool from SolidWorks software with AISI1020 as chosen material.

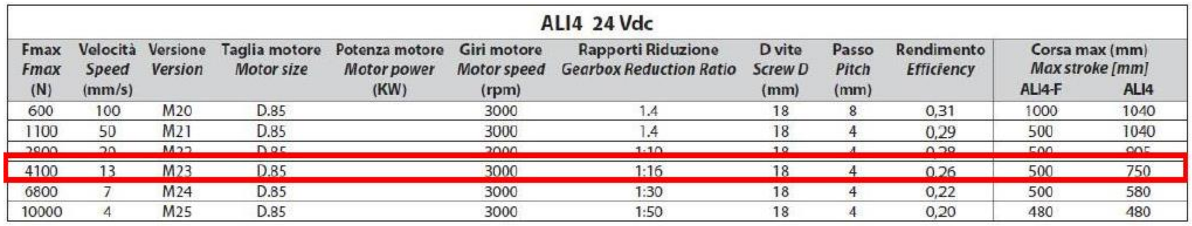
In the following table are shown the different weights:

Table 19: Sum of the weights that the actuator should bear.

	Unit	**Weight (kg)**	**Total (kg)**
Arms	2	20	40
Back	1	75	75
Operator	1	100	100
Load	1	100	100
			315

$$F_{max} = 315\ kg \cdot {}^{9{,}8\ N}/_{1\ kg} \approx 3100\ N$$

Calculation the total reaction that it should bear and using a security marge, finally it was selected the actuator "ALI4 24-Vdc" that could bear a maximum of 4100N. See catalogue in *Annex 2: Catalogues*.



ALI4 24 Vdc

Fmax *Fmax* (N)	Velocità *Speed* (mm/s)	Versione *Version*	Taglia motore *Motor size*	Potenza motore *Motor power* (KW)	Giri motore *Motor speed* (rpm)	Rapporti Riduzione *Gearbox Reduction Ratio*	D vite *Screw D* (mm)	Passo *Pitch* (mm)	Rendimento *Efficiency*	Corsa max (mm) *Max stroke [mm]* ALI4-F	 ALI4
600	100	M20	D.85		3000	1.4	18	8	0,31	1000	1040
1100	50	M21	D.85		3000	1.4	18	4	0,29	500	1040
2800	20	M22	D.85		3000	1:10	18	4	0,28	500	905
4100	13	M23	D.85		3000	1:16	18	4	0,26	500	750
6800	7	M24	D.85		3000	1:30	18	4	0,22	500	580
10000	4	M25	D.85		3000	1:50	18	4	0,20	480	480

Figure 1: Catalogue detail showing the chosen actuator.

3. Calculation referred to the lineal guide election

3.1Calculation of the moment that the lineal guide must bear

To choose a lineal table that allows the alternative vertical movement, movement generated for the squat action, it must be considered the forces that act on the table. For that, the moments generated for the load are calculated in the union point of the lineal guides and the back. The loads that were considered are:

1- Raising load
2- Arm weight (including the flexion movement actuator)
3- The actuator that permits the raising and going down arm movement.
4- Chest weight
5- Maximum operator weight

Three different arm positions are chosen to decide which one is the most unfavorable.

To consider the tree dimensional system, a vector analysis was done and **SI units** system was used.

All following matrix are based in the next vector expression:

$$\bar{T} = \bar{r} \cdot \bar{F}$$

$$\bar{T} = \begin{bmatrix} \bar{\imath} & \bar{\jmath} & \bar{k} \\ \overline{r_{\imath}} & \overline{r_{\jmath}} & \overline{r_k} \\ \overline{F_{\imath}} & \overline{F_{\jmath}} & \overline{F_k} \end{bmatrix}$$

Figure 51: Vectorial directions

The “i” vector direction corresponds to the exoskeleton width, the “j” vector direction to the exoskeleton height and finally the “k” vector direction to the exoskeleton length.

Position 1:

Arms at 0º from the horizontal plane, both loaded with weight.

- Load to raise

It is supposed that in this position the load is raised with both arms with the same force (50kg each arm).

Right arm load (50 kg)		
i	j	k
0.432	0.641	1.287
0	-500	0

Left arm load (50 kg)		
i	j	k
-0.432	0.641	1.287
0	-500	0

- Arm weight (including the flexion actuator)

Left arm load (25 kg)		
i	j	k
0.432	0.641	0.71
0	-250	0

Right arm load (25 kg)		
i	j	k
-0.432	0.641	0.71
0	-250	0

- The actuator that permits the raising and going down arm movement.

Left actuator (5 kg)		
i	j	k
-0.391	0.32	0.323
0	-50	0

Right actuator (5 kg)		
i	j	k
0.391	0.32	0.323
0	-50	0

- Chest weight.

Chest (75 kg)		
i	j	k
0	0.361	0.11
0	-750	0

- User weight

User (100kg)		
i	j	k
0	0.052	0.31
0	-1000	0

The resultant torque that the lineal table should support is:

	i	j	k	Resultant (Nm)
T_{load}	1287	0	0	1287
T_{arm}	355	0	0	355
$T_{actuator}$	32.3	0	0	32.3
T_{chest}	82.5	0	0	82.5
T_{seat}	310	0	0	310
T_{total}	2066.8	0	0	2066.8

It can be observed that in this position the lineal guides only work in flexion around the "x" axis. The resultant moment in position 1 is:

$$\left|\boldsymbol{T_{position\_1}}\right| = \left|\boldsymbol{2067\bar{\imath} + 0\bar{\jmath} + 0\bar{k}}\right| = \boldsymbol{2067\ Nm}$$

Position 2

Arms at 0º from the horizontal plane: Right arm loaded and turned 20º from the vertical plane, left arm without load.

In this situation, it is supposed that the entire load is supported for only one arm. To do this calculation the load is multiplied for a security factor of 2. With this security factor is assumed that the dynamical load, the own weight or any other lateral unplanned impact are counted.

This kind of load is hypothetical and it is not possible in the real life.

Following the same procedure as in the position 1, it is showed the vector analysis that give as result the moment generated for each load:

- Load to raise

In this position, the most unfavorable situation would be that the maximum load (100 kg) was elevated with only one arm.

Right arm load (100 kg)		
i	j	k
0.747	0.641	1.21
0	-1000	0

Left arm load (0 kg)		
i	j	k
-0.431	0.648	1.282
0	0	0

- Arm weight (including the flexion actuator)

Left arm load (25 kg)		
i	j	k
0.554	0.641	0.71
0	-250	0

Right arm load (25 kg)		
i	j	k
-0.344	0.641	0.71
0	-250	0

- The actuator that permits the raising and going down arm movement.

Left actuator (5 kg)		
i	j	k
0.431	0.33	0.31
0	-50	0

Right actuator (5 kg)		
i	j	k
-0.39	0.33	0.31
0	-50	0

- Chest weight.

Chest (75 kg)		
i	j	k
0	0.362	0.11
0	-750	0

- User weight

User (100 kg)		
i	j	k
0	0.055	0.31
0	-1000	0

The resultant moment that the lineal table should support is:

	i	**j**	**k**	**Resultant (Nm)**
T_load	1210	0	-747	1422.01
T_arm	355	0	-52.5	358.86
T_actuator	31	0	-2.05	31.07
T_chest	82.5	0	0	82.50
T_seat	310	0	0	310.00
T_total	**1988.5**	**0**	**-801.55**	**2143.97**

It can be observed that in this position the lineal guides work with frontal flexion around the “x” axis and with lateral flexion around the “z” axis. The resultant moment in the position 2 is:

$$\left|\boldsymbol{T}_{\boldsymbol{position\_2}}\right| = \left|\mathbf{1989}\bar{\imath} + \mathbf{0}\bar{\jmath} - \mathbf{802}\bar{\boldsymbol{k}}\right| = \mathbf{2115}\ \boldsymbol{Nm}$$

Position 3

Arms at 40º from the horizontal plane: right arm with a load turned 20º from the vertical plane, left arm without load.

As in the position 2, a security factor of 2 will be applied.

- Load to raise

In this position, the most unfavorable situation would be that the maximum load (100 kg) was elevated with only one arm.

Right arm load (100 kg)		
i	j	k
0.656	1.331	0.942
0	-1000	0

Left arm load (0 kg)		
i	j	k
-0.431	0.639	1.278
0	0	0

- Arm weight (including the flexion actuator)

Left arm load (25 kg)		
i	j	k
0.51	0.952	0.559
0	-250	0

Right arm load (25 kg)		
i	j	k
-0.367	0.949	0.559
0	-250	0

- The actuator that permits the raising and going down arm movement.

Left actuator (5 kg)		
i	j	k
0.431	0.353	0.255
0	-50	0

Right actuator (5 kg)		
i	j	k
-0.431	0.353	0.255
0	-50	0

- Chest weight.

Chest (75 kg)		
i	j	k
0	0.353	0.11
0	-750	0

- User weight

User (100 kg)		
i	j	k
0	0.055	0.31
0	-1000	0

The resultant moment that the lineal table should support is:

	i	**j**	**k**	**Resultant (Nm)**
T_load	942	0	-650	1144.49
T_arm	279.5	0	-35.75	281.78
T_actuator	25.5	0	0	25.50
T_chest	82.5	0	0	82.50
T_seat	310	0	0	310.00
T_total	**1639.5**	**0**	**-685.75**	**1777.14**

It can be observed that in this position the lineal guides work with frontal flexion around the "x" axis and with lateral flexion around the "z" axis. The resultant moment in the position 3 is:

$$\left|\boldsymbol{T}_{position\_3}\right| = \left|\mathbf{1640}\bar{\imath} + \mathbf{0}\bar{\jmath} - \mathbf{686}\bar{k}\right| = \mathbf{1777}\ \boldsymbol{Nm}$$

After analyzing the results, it is clear that the most unfavorable frontal flexion is produced in the position 1, however, the biggest lateral flexion is in position 2. On the other hand, in any situation exist torsion forces (around "y" axis).

Having the most unfavorable moments that the lineal table must support (slides and guides set), it is searched one that fulfills the requirements and general dimensions of the design.

After searching in the catalogues from different manufacturers, it was checked that the best guide line is DryLinTTW-01-15. It can be seen in *Annex 2: Catalogues*.

To guarantee the correct operation and with the intention of sharing the forces and so making them lower, it is decided to place two slides in each guide.

The distance between guides is the needed to avoid interferences with the actuator and it is assumed that the vertical distance between both slides is the same length that one slide.
The slide and guide dimensions are given for the manufactured in the catalogue.

4. Force calculation on the slides -guide set.

Stress caused by the lateral flexion (Around the “z” axis)

First it is studied the lateral flexion (around the “z” axis). It will be used the biggest moment value calculated in the previous section. This is the moment of the position 2:

$$\left|\boldsymbol{T_{position\_2}}\right| = \left|\mathbf{1989}\bar{\boldsymbol{\imath}} + \mathbf{0}\bar{\boldsymbol{\jmath}} - \mathbf{801}\bar{\boldsymbol{k}}\right| = \mathbf{2115}\ \boldsymbol{Nm}$$

Therefore:

$$T_{fz} = 801\ Nm$$

The moment respect the “z” axis is the force per distance since the application point to the gravity center. To do the force calculation it is assumed that only two slides will support the biggest part of the stress.

$$T_{fz} = 2 \cdot F_z \cdot d$$

Table 20: Lateral flexion stress calculation (F_x)

T_{fz} (lateral shift)		
T_{fz}	801	Nm
d	0.1075	m
F_z	3726	N

4.1 Stress caused by the frontal flexion (around the "x" axis)

Next is analyzed the frontal flexion phenomena (around "x" axis). For that it is taken the biggest moment (Tf_x) calculated in the previous section.

The chosen torque is the calculated in the position 1:

$$\left|\boldsymbol{T_{position\_1}}\right| = \left|\boldsymbol{2067\bar{\imath} + 0\bar{\jmath} + 0\bar{k}}\right| = \boldsymbol{2067\ Nm}$$

Therefore:

$$T_{fx} = 2067\ Nm$$

It is assumed that the 4 slides are supporting the stress, for that:

$$T_{fx} = 4 \cdot F_x \cdot d$$

Table 21: Frontal flexion stress calculation

T_{fx} (frontal shift)		
T_{fx}	2067	Nm
d	0.1075	m
F_x	4807	N

4.2 Supported values verification

Slides-guide catalogues were consulted to check the technical specifications; DryLin TTW0105 was the chosen model. The relation between the maximum admissible stress of the slide-guide set and its service condition is:

Table 22: Comparison between the admissible stress and service stress in both directions

Fz_adm (N)	Fz (N)	Fx_adm (N)	Fx (N)
7500	3726	14500	4807

In any situation, the admissible stress is reached. Therefore, the Dylin lineal table is definitely chosen for the exoskeleton design.

5. Calculations for wheel election

The three wheels that form the final exoskeleton design must bear the total weight of the structure, it contains: the arm and back, the user that is supposed as maximum 100 kg, the maximum load to carry, the base, the 5 actuators and the slides and guides.

Next, it is showed a table with the weights:

Table 23: weight sum that onmi wheel wheels must bear

	Units	Weight (kg)	Total (kg)
Arms	2	25	50
Back	1	65	65
Operator	1	100	100
Load	1	100	100
Base	1	70	70
Actuators	5	0.9	4.5

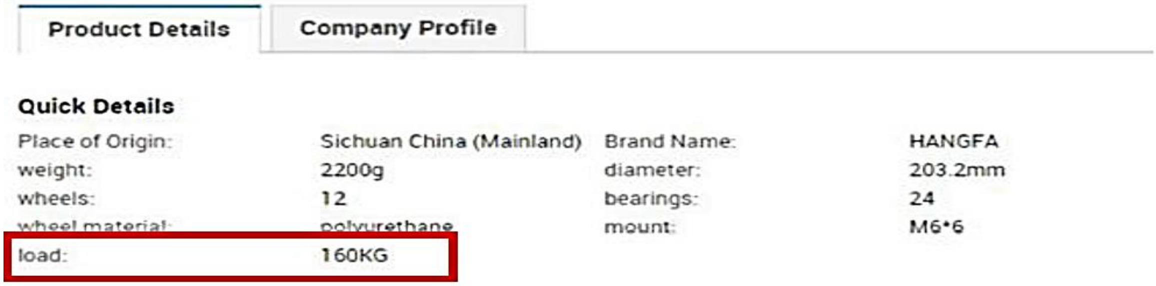
Lineal guide	2	0.7	1.4
Slides	4	0.12	0.48
			392

It must to be considered that the wheels also have to bear the battery and engines weight, these values are still unknown. It is supposed that the three wheels should bear 70 kg for these components.

$$m_t = 392\ kg + 70\ kg = 462\ kg$$

$$m_{wheel} = {}^{462\ kg}/_{3\ wheels} \approx 154\ kg$$

Calculating the total reaction that one of the omni wheels must to bear, it was chosen the QLM-20 Omni wheel that bears 160 kg exactly.



Quick Details

Place of Origin:	Sichuan China (Mainland)	Brand Name:	HANGFA
weight:	2200g	diameter:	203.2mm
wheels:	12	bearings:	24
wheel material:	polyurethane	mount:	M6*6
load:	160KG		

Figure 52: QLM-20 catalogue details.

5.1Minimum power needed to move the wheel.

In real situations, the objects are not ideally rigid, they always have deformations. The contact is not in the generatrix where P and N are placed. It means that the reactions appear on the supports; reactions that create a torque that has to be beaten to start the wheel rotation. It is equivalent to consider that the N normal force is displaced a determined longitude (μ_r), it is the called rolling resistance coefficient.

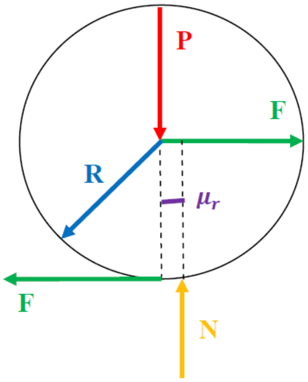


Figure 53: Wheel distribution forces.

$$T_{resistant} = \mu_r \cdot N$$

$$T = \mathrm{F} \cdot \mathrm{R}$$

In critical conditions, to start the rolling, the applied torque, that in this situation is the starter torque, must to be bigger that the resistant torque.

$$T_{starter} > T_{resistant}$$

Being F the force applied on the wheel to move it.

$$F \cdot R > \mu_r \cdot N$$

$$\mathrm{F} > {}^{\mu_r \cdot N}/_{R}$$

For the following values chosen for the wheel:

$$R = 101.1\ mm$$

$$F_{max} = 1519\ N$$

$$F_{own\_wheel} = 20.58\ N$$

$$N = P_{max} + P_{own} = 1519 + 20.58 = 1540\ N$$

And assuming an eccentricity:

$$\mu_r = 5\ mm$$

The minimum force needed to start the wheel movement:

$$F > {\mu_r \cdot N}/_{R}$$

$$F > {5\ mm \cdot 1540\ N}/_{101.1\ mm} = 76.2\ N$$

$$F_{min} = 76.2\ N$$

Finally, to calculate the power it should be assumed the exoskeleton speed (P in this section means power):

$$v = 1\ m/s$$

$$P = F \cdot v$$

$$P_{wheel} = 76.22\ N \cdot \frac{1\ m}{s} = 76.22\ W$$

Applying the security factor:

$$P_{wheel} = P_{wheel} \cdot n_{sec} = 76.22\ W \cdot 2 = 152.44\ W$$

Each wheel needs an engine of 155 W to start the movement.

6. Engine election

To choose an engine to transmit the movement to the wheels it should bear in mind some parameters, as the power, the torque that has to be transmitted and the velocity.

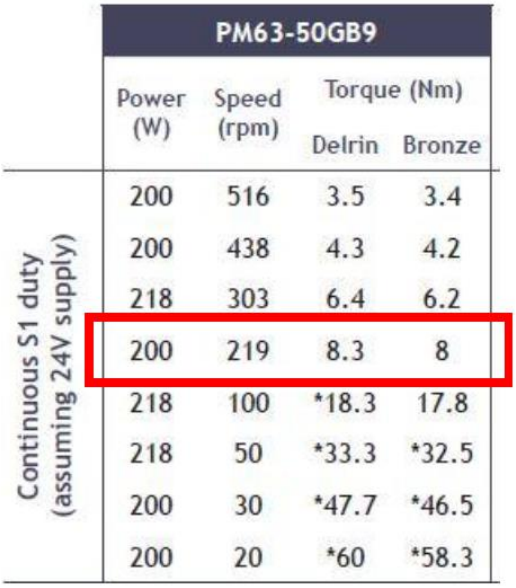
First, the resistance torque is calculated (T_{res}), it is the torque needed to be beaten to start the movement of all the structure. Therefore:

$$T_{res} = \mu_r \cdot N = 7.7\ Nm$$

$$P_{wheel} = T_{res} \cdot w$$

$$w = {}^{P_{twheel}}/_{T_{res}} = {}^{155\ W}/_{7.7\ Nm} = 20.13\ \frac{rad}{s} = 194\ rpm$$

Defined the engine characteristics parameters, it is searched a commercial engine model capable to provide these values. The most appropriate is the MDPM6350GB9.



PM63-50GB9

	Power (W)	Speed (rpm)	Torque (Nm)	
			Delrin	Bronze
Continuous S1 duty (assuming 24V supply)	200	516	3.5	3.4
	200	438	4.3	4.2
	218	303	6.4	6.2
	200	219	8.3	8
	218	100	*18.3	17.8
	218	50	*33.3	*32.5
	200	30	*47.7	*46.5
	200	20	*60	*58.3

Figure 54: Engine catalogue details. Model: MDPM6350GB9

7. Battery calculations

7.1Total power needed for the set calculation

To perform the total power calculation that all the set can consume, with all the elements working at the same time, it has to be counted as the wheel engines as the actuators in the arms, shoulders and platform.

$$P_{wheel} = 155\ W$$

$$P_{actuator} = 550\ W$$

$$P_{total} = 2 \cdot P_{wheel} + 5 \cdot P_{actuator}$$

$$P_{equip} = 2 \cdot 155\ W + 5 \cdot 550\ W = 3060\ W\ = 3.06\ kW$$

The previous value is a theoretical value, because it is supposed that in any moment all the actuators and engines will work at the same time. Then, a simultaneity factor was applied.

$$a_{sim} = 0.7$$

$$P_{tequip} = P_{equip} \cdot a_{sim} = 3.06\ kW\ \cdot 0.7 = 2.142\ kW$$

NOVIA UNIVERSITY OF APPLIED SCIENCES

Mechanical-Environmental Engineering

Bachelor's thesis:

Exoskeleton: Prototype design

Annex 2: Catalogues

Oscar Teruel Guisado

The degree program of Environmental Engineering
Vaasa/Novia April 2016

Modello ALI4

- Motore a magneti permanenti CE
- Motore A.C. monofase-trifase CE
- Riduttore vite senza fine - ruota elicoidale
- Stelo filettato trapezoidale o a ricircolo di sfere (VRS)
- Asta traslante in acciaio cromato
- Lubrificazione a grasso
- Attuatore IP 65, testato secondo norma CEI EN 60529
  motore C.A. IP55 standard - IP65 a richiesta
  motore C.C. IP44 standard - IP65 a richiesta
- Temperatura di funzionamento -10°C +60°C
- Impiego intermittente S3 30% (5 min) a 30°C*
- Fine corsa, potenziometro ed encoder a richiesta

(*) Per impieghi diversi contattare il Ns. Ufficio Tecnico

Model ALI4

- *Permanent magnet motor CE*
- *Three phase or single phase motor CE*
- *Worm gearbox*
- *Acme lead screw or ballscrew (VRS)*
- *Chrome plated steel push rod*
- *Grease lubricated*
- *Actuator IP65, tested according to rule CEI EN 60529*
  A.C. motor IP 55 standard - IP65 on request
  D.C. motor IP 44 standard - IP65 on request
- *Working temperature range -10°C +60°C*
- *Intermittent duty S3 30% (5 min) a 30°C**
- *Limit switches, potentiometer and encoder on request*

***(*)** For any special duty please contact our technical dept.*

ALI4 - (Vac)

Fmax *Fmax* (N)	Velocità *Speed* (mm/s)	Versione *Version*	Taglia motore *Motor size*	Potenza motore *Motor power* (KW)	Giri motore *Motor speed* (rpm)	Rapporti Riduzione *Gearbox Reduction Ratio*	D vite *Screw D* (mm)	Passo *Pitch* (mm)	Rendimento *Efficiency*	Corsa max (mm) *Max stroke [mm]* ALI4-F	ALI4
2100	93	M01	IEC71	0,55	2800	1.4	18	8	0,31	1000	1040
3900	47	M02	IEC71	0,55	2800	1.4	18	4	0,29	500	770
5300	23	M03	IEC71	0,37	1400	1.4	18	4	0,29	500	660
8600	9	M04	IEC71	0,25	1400	1:10	18	4	0,28	500	520
9400	6	M05	IEC63	0,18	1400	1:16	18	4	0,26	495	495
10000	3	M06	IEC63	0,13	1400	1:30	18	4	0,22	485	485
10000	2	M07	IEC56	0,09	1400	1:50	18	4	0,20	480	480

ALI4-VRS (ballscrew 16x5) (Vac)

Fmax *Fmax* (N)	Velocità *Speed* (mm/s)	Versione *Version*	Taglia motore *Motor size*	Potenza motore *Motor power* (KW)	Giri motore *Motor speed* (rpm)	Rapporti Riduzione *Gearbox Reduction Ratio*	D vite *Screw D* (mm)	Passo *Pitch* (mm)	Rendimento *Efficiency*	Corsa max (mm) *Max stroke [mm]* ALI4-F	ALI4
2500	58	M08	IEC63	0,25	2800	1.4	16	5	0,77	625	825
3100	29	M09	IEC63	0,18	1400	1.4	16	5	0,77	625	825
3400	23	M10	IEC56	0,14	2800	1:10	16	5	0,74	625	780
5000	15	M11	IEC56	0,14	2800	1:16	16	5	0,38	620	620
6000	7	M12	IEC56	0,09	1400	1:16	16	5	0,68	620	620
7500	4	M13	IEC56	0,09	1400	1:30	16	5	0,59	570	570

ALI4-VRS (ballscrew 20x5) (Vac)

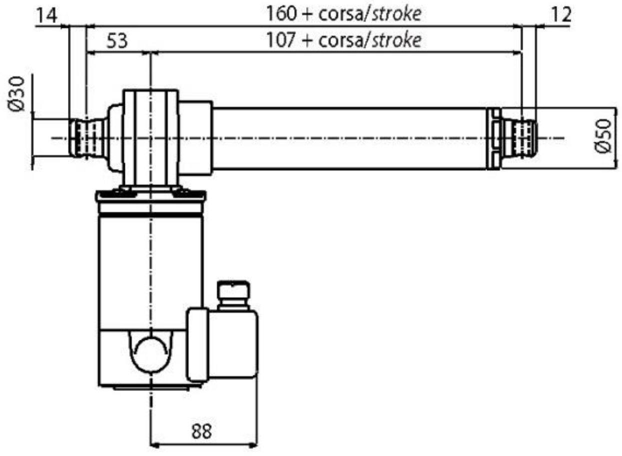
Fmax *Fmax* (N)	Velocità *Speed* (mm/s)	Versione *Version*	Taglia motore *Motor size*	Potenza motore *Motor power* (KW)	Giri motore *Motor speed* (rpm)	Rapporti Riduzione *Gearbox Reduction Ratio*	D vite *Screw D* (mm)	Passo *Pitch* (mm)	Rendimento *Efficiency*	Corsa max (mm) *Max stroke [mm]* ALI4-F	ALI4
3000	58	M32	IEC63	0,25	2800	1.4	20	5	0,77	625	880
3800	29	M33	IEC63	0,18	1400	1.4	20	5	0,77	625	850
4200	23	M34	IEC56	0,14	2800	1:10	20	5	0,74	625	850
6000	15	M35	IEC56	0,14	2800	1:16	20	5	0,38	620	800
7500	7	M36	IEC56	0,09	1400	1:16	20	5	0,68	620	800
9000	4	M37	IEC56	0,09	1400	1:30	20	5	0,59	570	720

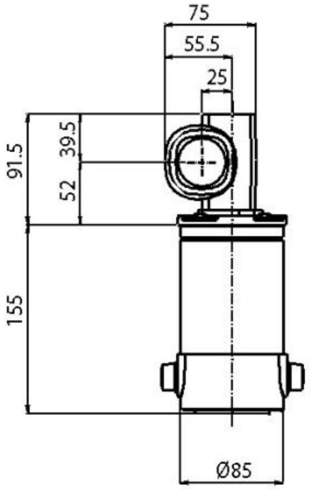
ALI4 24 Vdc

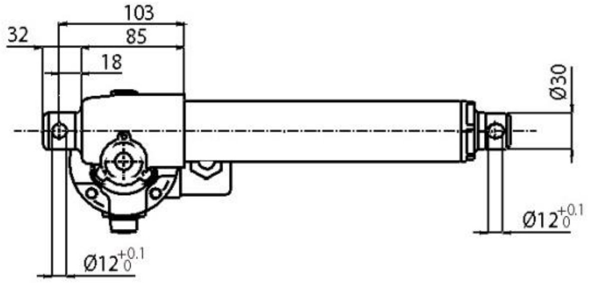
Fmax *Fmax* (N)	Velocità *Speed* (mm/s)	Versione *Version*	Taglia motore *Motor size*	Potenza motore *Motor power* (KW)	Giri motore *Motor speed* (rpm)	Rapporti Riduzione *Gearbox Reduction Ratio*	D vite *Screw D* (mm)	Passo *Pitch* (mm)	Rendimento *Efficiency*	Corsa max (mm) *Max stroke [mm]* ALI4-F	ALI4
600	100	M20	D.85		3000	1.4	18	8	0,31	1000	1040
1100	50	M21	D.85		3000	1.4	18	4	0,29	500	1040
2800	20	M22	D.85		3000	1:10	18	4	0,28	500	905
4100	13	M23	D.85		3000	1:16	18	4	0,26	500	750
6800	7	M24	D.85		3000	1:30	18	4	0,22	500	580
10000	4	M25	D.85		3000	1:50	18	4	0,20	480	480

ATTUATORE SENZA FINE CORSA / *ACTUATOR WITHOUT LIMIT SWITCHES*

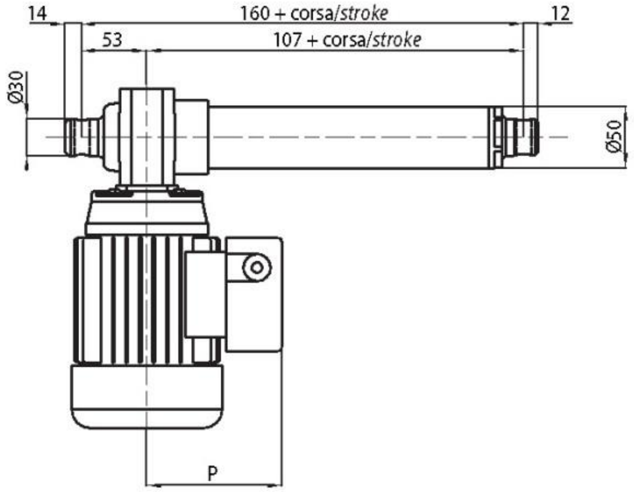
ALI4 - versione C.C. / *D.C. Version*

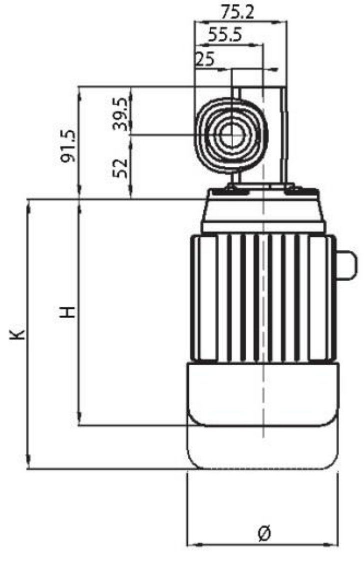


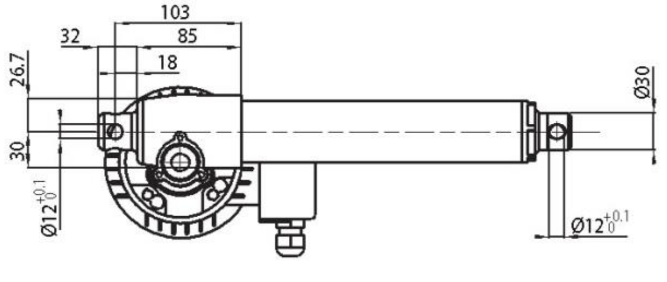




ALI4 - versione C.A. / *A.C. Version*







DIMENSIONI MOTORI C.A. / *A.C MOTORS DIMENSIONS*					
GR. / *SIZE*	VERSIONE / *TYPE*	H	K	Ø	P
56	Standard	168		116	108
	Autofrenante / *Brake motors*		200		
63	Standard	190		129	110
	Autofrenante / *Brake motors*		235		
71	Standard	220		146	121
	Autofrenante / *Brake motors*		267		

DryLin® T | **Technical Information**

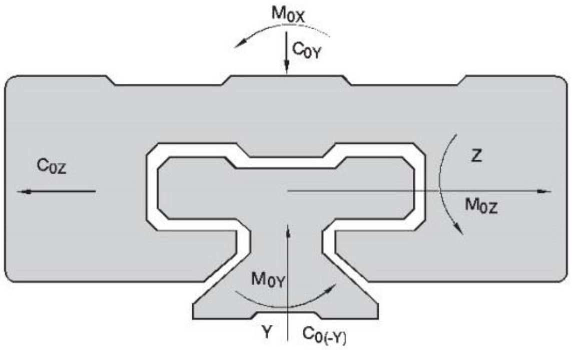
Special properties

- With a low rate of inertia, high accelerations and short term extreme speeds up to 30 m/s are possible
- DryLin®T linear guide systems run dry. Dirt cannot settle in lubricants
- Recommended for use in food, medical, and clean room technologies, as no lubricants are present
- The corrosion resistance of DryLin® T means that it can also be used in wet environments
- High pressure washdown does not damage the system
- Vibration dampening and extremely quiet operation
- The aluminium rail provides good thermal dissipation. The aluminium only retains heat at continuously high speeds
- The combination of anodized aluminium and iglidur® J results in a low initial breakaway force
- DryLin® T is dimensionally interchangeable with standard ball bearing systems

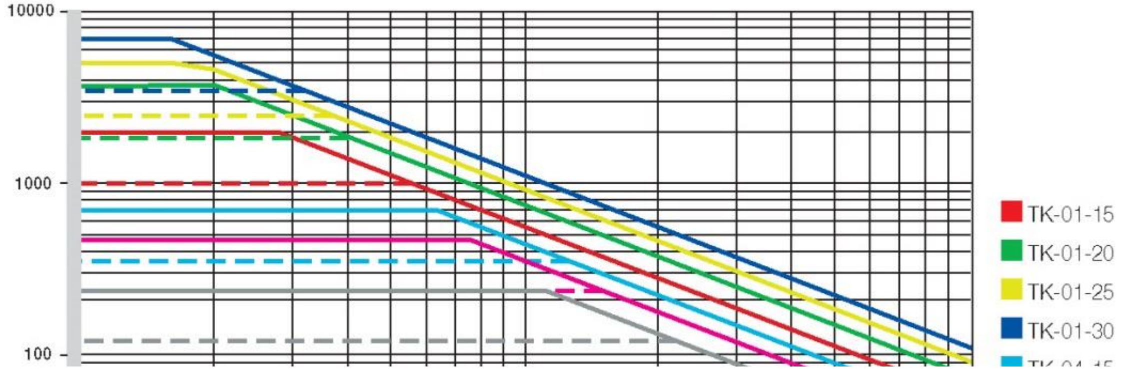
Picture 60.1: DryLin® T in a demanding packaging machine application

Type	C_{0Y} [kN]	$C_{0(-Y)}$ [kN]	C_{0Z} [kN]	M_{0X} [Nm]	M_{0Y} [Nm]	M_{0Z} [Nm]
04-09	0,48	0,48	0,24	3,4	1,8	1,8
04-12	0,96	0,96	0,48	9,2	4,4	4,4
04-15	1,4	1,4	0,7	17	8	8
01-15	4	4	2	32	25	25
01-20	7,4	7,4	3,7	85	45	45
01-25	10	10	5	125	65	65
01-30	14	14	7	200	100	100

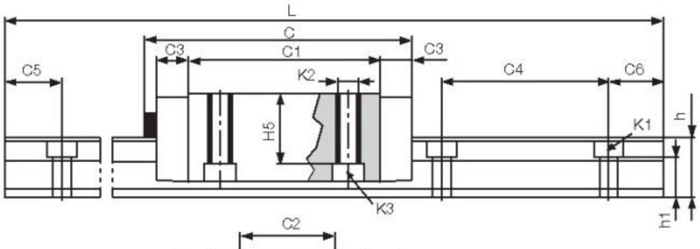
Table 61.1: DryLin® T-01 – Permissible static load capacity



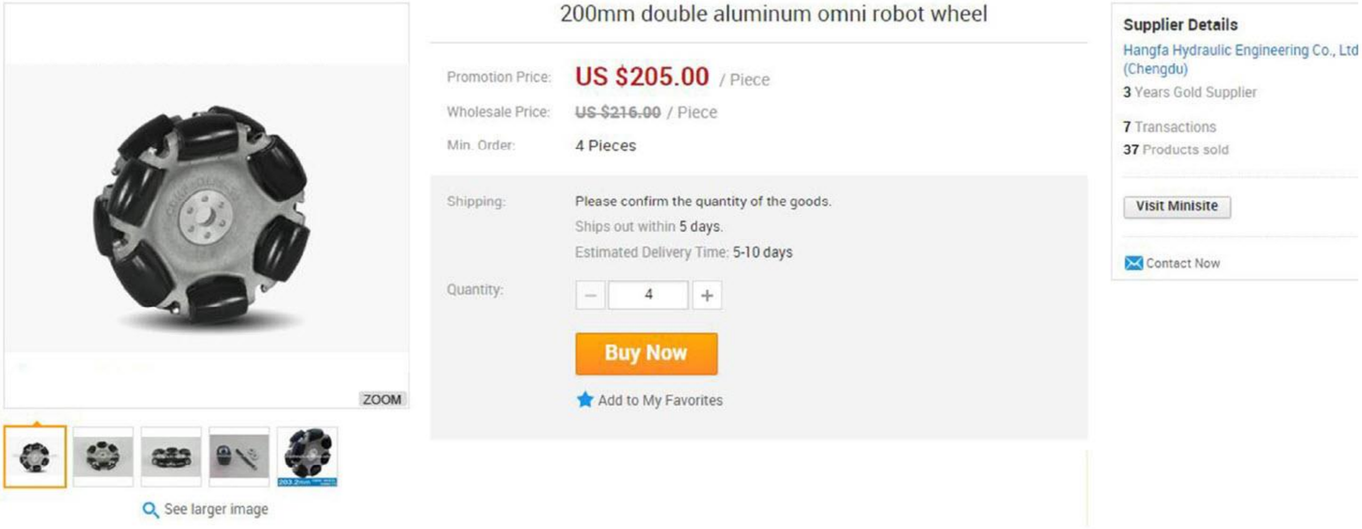
Graph 61.1: Designation of load directions



DryLin® TK-01... | **Adjustable clearance** | mm



HANGFA QLM-20 OMNIWHEEL



200mm double aluminum omni robot wheel

Promotion Price: **US $205.00** / Piece

Wholesale Price: ~~US $216.00~~ / Piece

Min. Order: 4 Pieces

Shipping: Please confirm the quantity of the goods.

Ships out within 5 days.

Estimated Delivery Time: 5-10 days

Quantity: − 4 +

Supplier Details

Hangfa Hydraulic Engineering Co., Ltd (Chengdu)

3 Years Gold Supplier

7 Transactions

37 Products sold

Product Details:

Quick Details

Place of Origin:	Sichuan China (Mainland)	Brand Name:	HANGFA	Model Number:	QLM-20
weight:	2200g	diameter:	203.2mm	wide:	75mm
wheels:	12	bearings:	24	hub material:	aluminum
wheel material:	polyurethane	mount:	M6*6	hole:	20mm
load:	160KG				

QLM-20 Dimensional:

Model Number: QLM-20

Diameter: 203.2mm

Width: 75mm

Number of Rollers: 12

Number of Bearings: 24

Hub Material: Aluminum

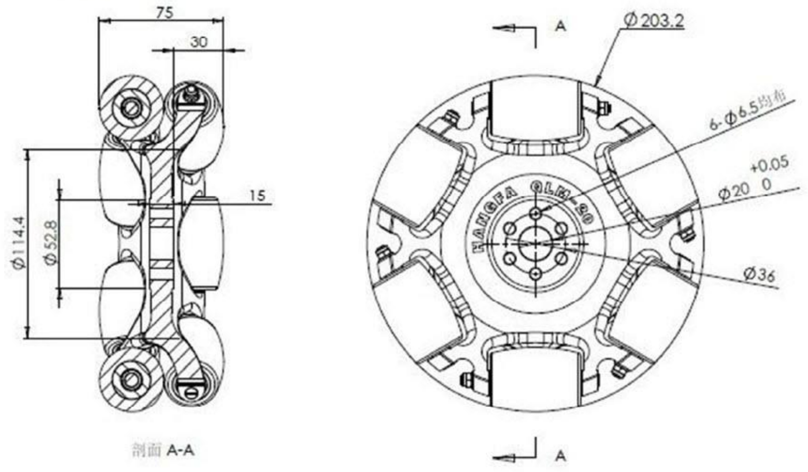
Roller Material: Polyurethane

Hole size: 20

Mount: 6*6mm Key

Weight: 2200g

Load Capacity: 160Kg



The hole size in the middle can be customized as your order .

PM63-50 / PM63-75 / PM63-100 with GB9 gearbox

standard motor-gearbox configured and customised for your application

MOTOR	Permanent magnet DC
SPEED	1500 - 8000 rpm
PROTECTION	up to IP66
POWER	up to 900 Watts
VOLTAGE	12 - 240V DC
INSULATION	Class F
CONSTRUCTION	Ferrite magnets; aluminium end castings; single piece steel body; replaceable carbon brushes; spade connectors
EXTRAS	Ventilated motor with internal fan (IP2x); encoder to RoHS standard; 12V or 24V 2Nm failsafe holding brake

GEARBOX	Worm and wheel
RATIOS	12.5:1, 25:1, 30:1, 60:1, 75:1
EFFICIENCY	up to 95%
MATERIALS	Delrin or phosphor bronze
SHAFT	single or double up to 25mm diameter
CONSTRUCTION	Steel worm shaft; CNC machined aluminium housing; sealed for life - maintenance free; cushioned 1-piece coupling; steel output shaft with 2 ball-bearings
OPTIONS	Stainless steel shaft; black finish; dog clutch

ISO 9001:2000 Certificate No. FM548688

	PM63-50GB9				PM63-75GB9				PM63-100GB9				Gearbox GB9			
	Power (W)	Speed (rpm)	Torque (Nm)		Power (W)	Speed (rpm)	Torque (Nm)		Power (W)	Speed (rpm)	Torque (Nm)		Ratio	Efficiency†	Momentary overload (Nm)	
			Delrin	Bronze			Delrin	Bronze			Delrin	Bronze			Delrin	Bronze
Continuous S1 duty (assuming 24V supply)	200	516	3.5	3.4	247	560	4	3.9	270	515	4.8	4.6	12.5	95%	171	359
	200	438	4.3	4.2	247	424	5.3	5.1	270	380	6.4	6.2	12.5	95%	171	359
	218	303	6.4	6.2	256	334	6.9	6.7	275	300	8.2	8	12.5	94%	171	359
	200	219	8.3	8	247	212	10	9.8	270	190	12.2	11.9	25	90%	192	359
	218	100	*18.3	17.8	256	93	22.9	*22.3	275	103	*24.2	23.6	30	87%	145	160
	218	50	*33.3	*32.5	256	47	*41.5	*39.4	275	51	*40.7	*39.6	60	79%	148	316
	200	30	*47.7	*46.5	247	33	*53.3	*50.6	270	30	*65.5	*63.8	60	76%	104	316
	200	20	*60	*58.3	247	22	*76.3	*74.3	270	21	*86.2	*81	75	70%	104	266
Intermittent duty S3 30% (assuming 24V supply)	318	500	5.8	5.6	356	544	5.9	5.8	380	504	6.8	6.6	12.5	95%	171	359
	318	420	6.8	6.6	356	408	7.8	7.7	380	368	9.3	9	12.5	95%	171	359
	328	288	10.1	10	365	316	10.3	9.8	385	292	11.8	11.5	12.5	94%	171	359
	318	210	13	12.6	356	204	*15	*14.6	380	184	*17.8	17.3	25	90%	192	359
	328	103	*26.3	*25.6	365	90	*33.9	*33.1	385	98	*32.7	*31.8	30	87%	145	160
	328	52	*47.7	*46.5	365	45	*61.6	*60.1	385	49	*59.4	*57.9	60	79%	148	316
	318	33	*69.2	*67.5	356	32	*80.9	*78.9	375	29	*94	*91.6	60	76%	104	316
	308	20	*103.2	*100.7	356	19	-	*106.4	375	19	-	*128	75	70%	104	266

*Gearbox life may be less than 5000 hours. Contact us for application advice. † Maximum theoretical efficiency.

Notes: Designed to operate with PWM controllers.

Graphs are available showing the motor performance throughout the speed range.

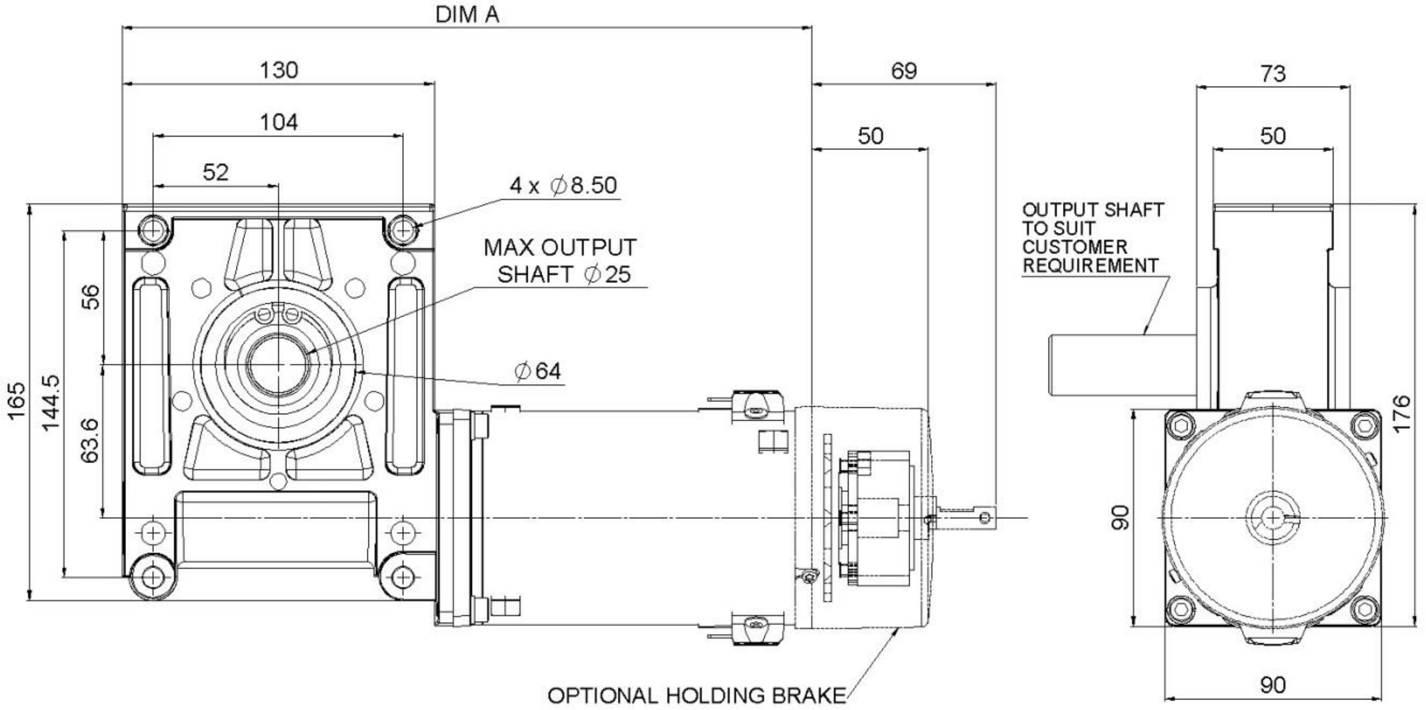
The GB9 gearbox may be coupled with many of our other standard AC or DC motors.

For customers who require in excess of 5000 units per year we offer a totally bespoke design service to fit the application; at zero cost premium. This service enables customers to outline any number of mechanical, electrical, environmental or even aesthetic requirements in order to realise their preferred motor-gearbox solution.

To find out more please contact a member of our sales team on +44 (0)1202 512 575 or visit our website at www.parvalux.com for further information.

drawing for PM63-50 / PM63-75 / PM63-100 with GB9 gearbox

standard motor-gearbox configured and customised for your application



Motor Type	Motor Weight	Gearbox Weight with Delrin	Gearbox Weight with bronze	DIM A	
				Totally Enclosed	Ventilated
PM63-50	3.0 kg	1.1 kg	1.5 kg	290	303
PM63-75	4.0 kg	1.1 kg	1.5 kg	315	328
PM63-100	4.0 kg	1.1 kg	1.5 kg	340	353

EXIT A AS SHOWN
EXIT B IS THE
OPPOSITE HAND

All dimensions are in mm
Many of our drawings are available in 3D format. Please contact us with your requirements

For customers who require in excess of 5000 units per year we offer a totally bespoke design service to fit the application; at zero cost premium. This service enables customers to outline any number of mechanical, electrical, environmental or even aesthetic requirements in order to realise their preferred motor-gearbox solution. To find out more please contact a member of our sales team on +44 (0)1202 512 575 or visit our website at www.parvalux.com for further information.

Trojan
BATTERY COMPANY

J185H-AC DATA SHEET

for Renewable Energy and Backup Power Applications

SIGNATURE LINE

MODEL: J185H-AC with Bayonet Cap

DIMENSIONS: inches (mm)

BATTERY: Flooded/wet lead-acid battery

COLOR: Maroon (case/cover)

MATERIAL: Polypropylene

PRODUCT SPECIFICATION

BCI GROUP SIZE	TYPE	CAPACITY [A] Amp-Hours (AH)							ENERGY (kWh)	VOLTAGE	TERMINAL Type**	DIMENSIONS [B] Inches (mm)			WEIGHT lbs. (kg)
		2-Hr Rate	5-Hr Rate	10-Hr Rate	20-Hr Rate	48-Hr Rate	72-Hr Rate	100-Hr Rate	100-Hr Rate			Length	Width	Height [C]	
SIGNATURE LINE - DEEP-CYCLE FLOODED BATTERIES															
921	**J185H-AC***	146	185	207	225	240	245	249	2.99	12 VOLT	6	15 (381)	7 (178)	14-5/8 (371)	128 (58)

CHARGING INSTRUCTIONS

CHARGER VOLTAGE SETTINGS (AT 77°F/25°C)	
	Voltage per cell
Absorption charge	2.35-2.45
Float charge	2.20
Equalize charge	2.58

Do not install or charge batteries in a sealed or non-ventilated compartment. Constant under or overcharging will damage the battery and shorten its life as with any battery.

TERMINAL CONFIGURATIONS

6	DT	Automotive Post & Stud Terminal
		*Terminal Height Inches (mm)* 29/32 (20) *Torque Values In-lb (Nm)* Bolt: 95 – 105 (11 – 12) AP: 50 – 70 (6 – 8) ST: 120 – 180 (14 – 20) *Bolt Size* 5/16 – 18

* Polyon™ Case

OPERATIONAL DATA

Operating Temperature	Self Discharge	Specific Gravity
-4°F to 113°F (-20°C to +45°C). At temperatures below 32°F (0°C) maintain a state of charge greater than 60%.	Up to 4% per week	The specific gravity at 100% state-of-charge is 1.280

CHARGING TEMPERATURE COMPENSATION

To the Voltage Reading -- Subtract 0.005 volt per cell (VPC) for every 1°C above 25°C or add 0.005 volt per cell for every 1°C below 25°C.

EXPECTED LIFE VS. TEMPERATURE

Chemical reactions internal to the battery are driven by voltage and temperature. The higher the battery temperature, the faster chemical reactions will occur. While higher temperatures can provide improved discharge performance the increased rate of chemical reactions will result in a corresponding loss of battery life. As a rule of thumb, for every 10°C increase in temperature the reaction rate doubles. Thus, a month of operation at 35°C is equivalent in battery life to two months at 25°C. Heat is an enemy of all lead acid batteries, FLA, AGM and gel alike and even small increases in temperature will have a major influence on battery life.

A. The amount of amp-hours (AH) a battery can deliver when discharged at a constant rate at 77°F (25°C) and maintain a voltage above 1.75 V/cell. Capacities are based on peak performance.

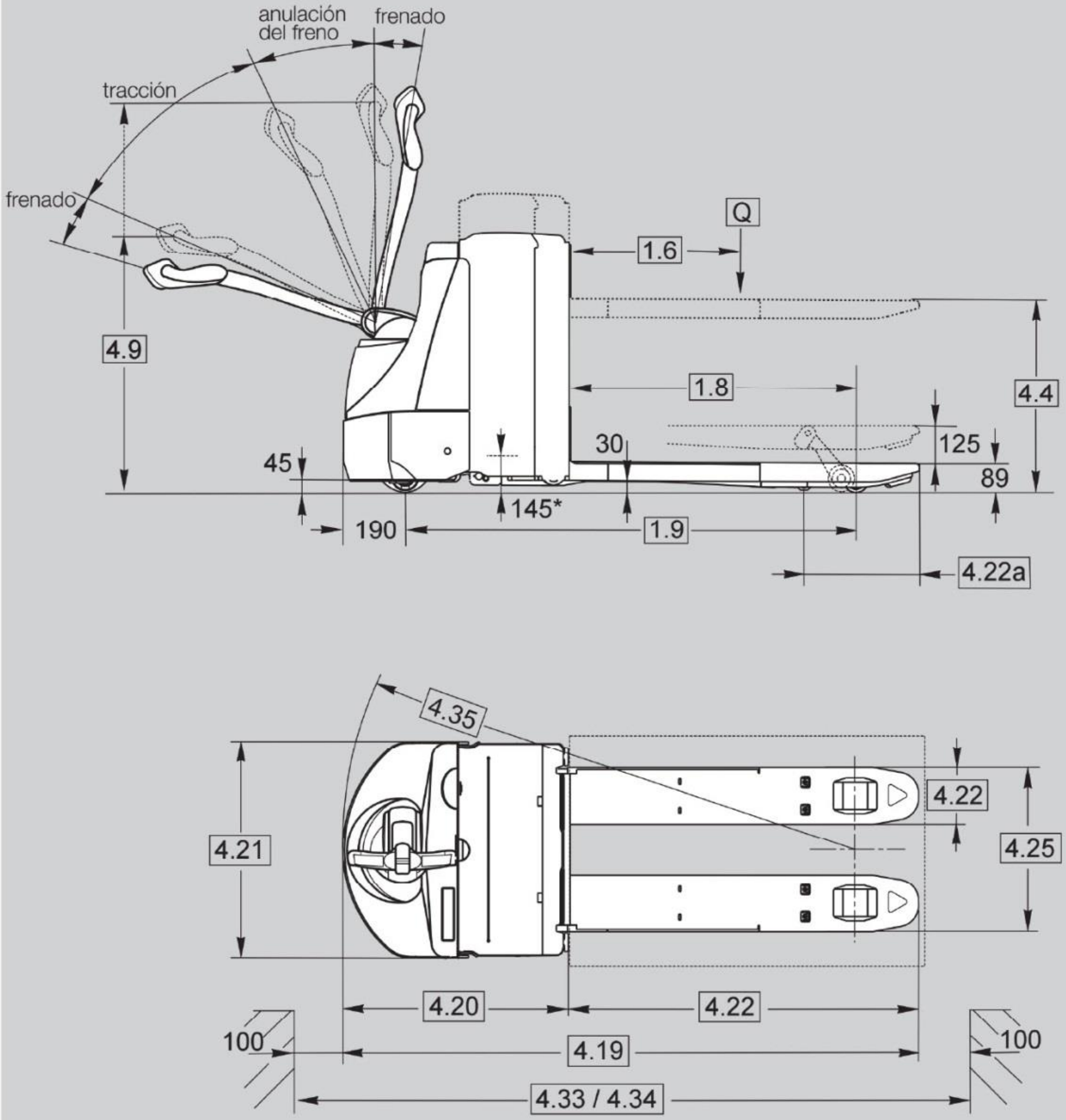
B. Dimensions are based on nominal size. Dimensions may vary depending on type of handle or terminal.

C. Dimensions taken from bottom of the battery to the highest point on the battery. Heights may vary depending on type of terminal.

** Additional terminals available.

Trojan's battery testing procedures adhere to both BCI and IEC test standards.

Made in the USA



* altura de extracción de la batería

Serie WP 3000 Especificaciones

Información general	1.1	**Fabricante**				Crown Equipment Corporation	
	1.2	**Modelo**				WP 3080-2.0	
	1.3	**Alimentación**				eléctrica	
	1.4	**Conductor**				acompañante	
	1.5	**Capacidad de carga**	transpaleta	Q	t	2,0	
			apilador	Q	kg	800	
	1.6	**Centro de la carga**		c	mm	600	
	1.8	**Distancia hasta la carga**	patas de carga elevadas/bajadas	x	mm	900 / 940	
	1.9	**Batalla**	patas de carga elevadas/bajadas	y	mm	1343 / 1399	1443 / 1499
Pesos	2.1	**Peso**	sin batería		kg	490	535
	2.2	**Carga por eje**	con carga delante / detrás		kg	947 / 1696 (968/1702)	982 / 1765
	2.3		sin carga delante / detrás		kg	495 / 148 (516/154)	562 / 185
Neumáticos	3.1	**Tipo de ruedas**				Vulkollan	
	3.2	**Tamaño de ruedas**	delante		mm	Ø 250 x 85	
	3.3		detrás		mm	Ø 82 x 110	
	3.4	**Otras ruedas**	ruedas estabilizadoras		mm	Ø 90 x 50	
	3.5	**Ruedas**	cantidad (x = tracción) del. / det.			1x + 2/2	
	3.6	**Ancho de vía**	delante	b_{10}	mm	478	
	3.7		detrás	b_{11}	mm	370	
Dimensiones	4.3	**Elevación libre**		h_2	mm	536	
	4.4	**Altura de elevación**		$h_2 + h_{13} + h_5$	mm	750	
	4.6	**Elevación inicial**		h_5	mm	125	
	4.9	**Altura brazo timón**	en pos. conducción mín. / máx.	h_{14}	mm	780 / 1197	
	4.15	**Altura de las horquillas**	bajadas	h_{13}	mm	89	
	4.19	**Longitud total** [2] [3]	patas de carga bajadas	l_1	mm	1799	1899
	4.20	**Long. unidad tracción**	patas de carga elev./bajadas	l_2	mm	665 / 649	765 / 749
	4.21	**Anchura total**		b_1	mm	712	
	4.22	**Dimensiones horquillas**		AxAxF	mm	60 x 186 x 1150	
	4.22a	**Longitud punta horq.** [3]			mm	393	
	4.25	**Ancho entre horquillas**		b_5	mm	540	
	4.32	**Distancia hasta el suelo**	centro de la batalla	m_2	mm	30	
	4.34	**Ancho pasillo trabajo ***	palé 800x1.200 largo, patas de carga elev./bajadas	Ast	mm	2034 / 2050	2134 / 2150
	4.35	**Radio de giro** [1]	patas de carga elevadas	Wa	mm	1534	1634
Rendimiento	5.1	**Velocidad de desplazamiento**	con / sin carga		km/h	5,5 / 6,0	
	5.2	**Velocidad de elevación**	con / sin carga		m/s	0,11 / 0,17	
	5.3	**Velocidad de descenso**	con / sin carga		m/s	0,15 / 0,13	
	5.8	**Pendiente máx. superable**	con/sin carga, rég. 5 min.		%	10 / 25	
	5.10	**Freno de servicio**				eléctrica	
Motores	6.1	**Motor de tracción**	régimen a S2 60 min.		kW	1,5	
	6.2	**Motor de elevación**	régimen a S3 15 %		kW	1,3	
	6.3	**Batería**	según DIN 43535			no, A	B
		Tamaño máx. comp. batería		FxAxA	mm	146 x 660 x 591 (683)	212 x 624 x 627
	6.4	**Tensión de la bateria**	capacidad nominal K5		V/Ah	24 / 150 (200)	24 / 250
	6.5	**Peso de la batería**			kg	153 (180)	212
	8.1	**Tipo de controlador**	tracción			transistor	

[1] Patas de carga bajadas +56 mm
[2] Patas de carga elevadas +16 mm
[3] Horquilla de 1.200 mm de longitud +50 mm

* El cálculo Ast se aplica a las horquillas de 1.150 mm y 1.200 mm de longitud,

con compartimento para batería de 200 Ah (opcional), utilizar los valores entre paréntesis

NOVIA UNIVERSITY OF APPLIED SCIENCES

Mechanical-Environmental Engineering

Bachelor's thesis:

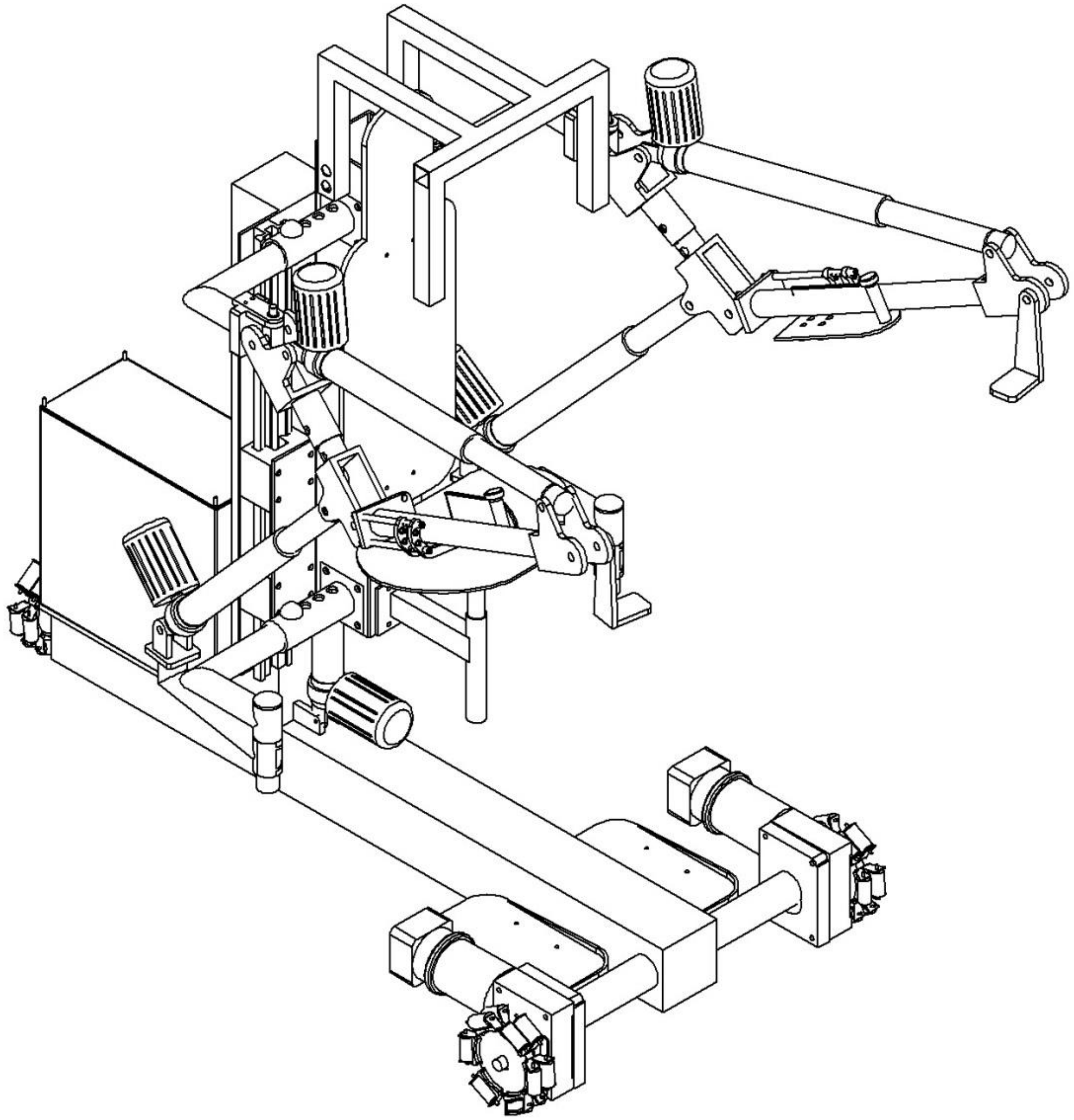
Exoskeleton: Prototype design

Annex 3: Construction drawings

Oscar Teruel Guisado

The degree program of Environmental Engineering
Vaasa/Novia April 2016

Table of contents



Exoskeleton design

	Date	Author
Name	30/04/2016	Oscar
Surname		Teruel Guisado

YRKESHÖGSKOLAN NOVIA

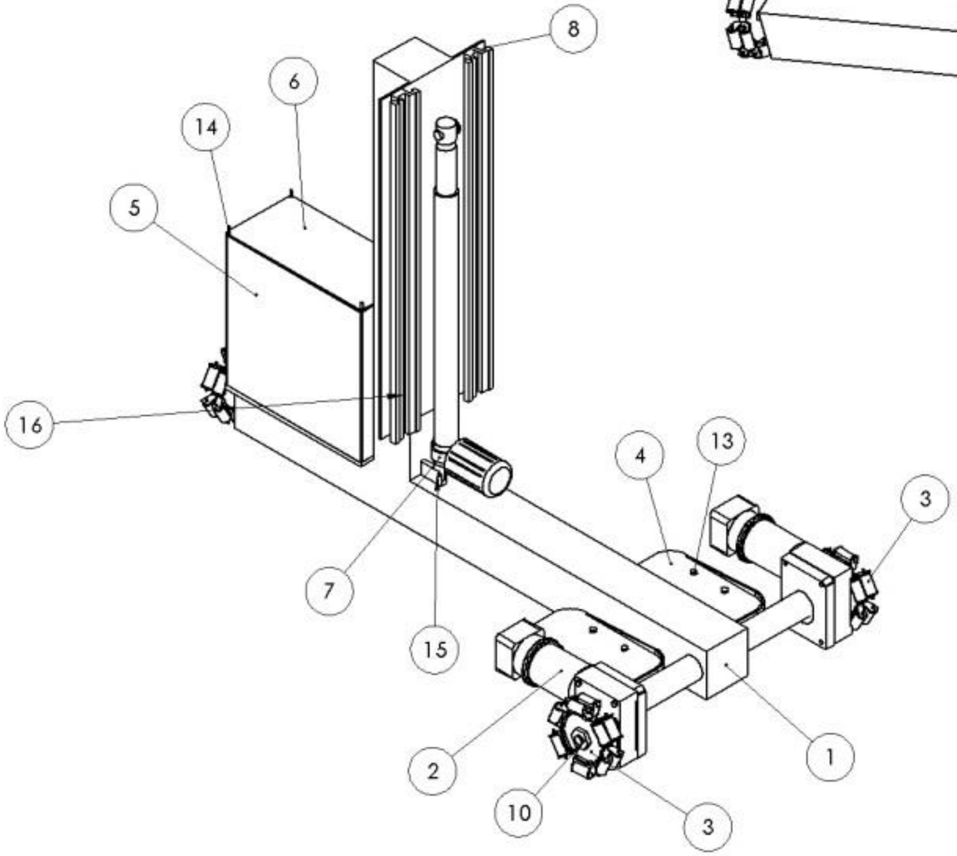
Novia University of Applied Sciences

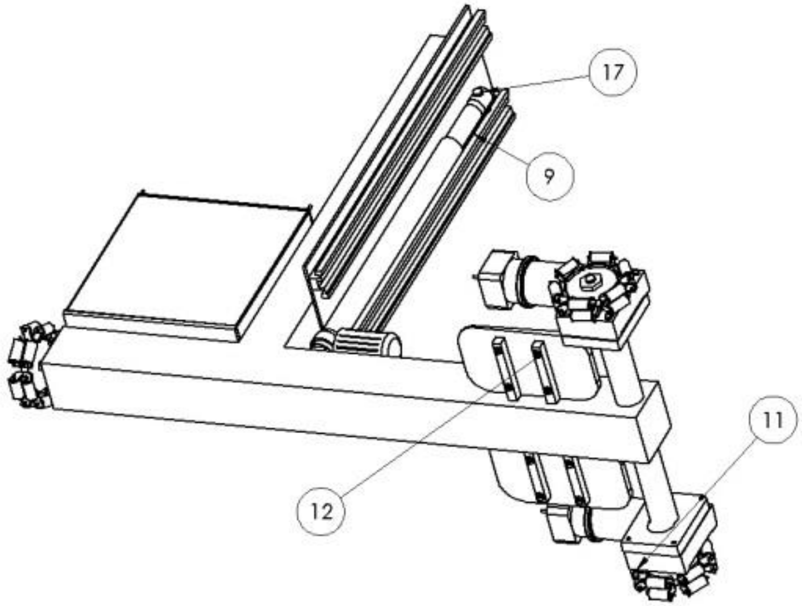
Mechanical-Environmental Engineering

SCALE
1: 10

Final assembly

Sketch num: 1





ITEM NO.	PART NUMBER	QTY.
1	Lb_weldedbase	1
2	Lb_engine	2
3	Lb_wheel HANGFA QLM-20 MECANIZED	3
4	Lb_footrest	2
5	Lb_boxbattery	1
6	Lb_battery_tape	1
7	Lb_actuator guide	1
8	Lb_guideback	2
9	Lb_actuatorcilinder	1
10	Lb_M20 hembra	1
11	Lb_m8,5 macho	8
12	Lb_M6 hembra	8
13	Lb_M6 macho	8
14	Lb_screwedbold M6_battery	4
15	Lb_bolt actuator	1
16	Lb_M8 bolt guide	28
17	Lb_M40 actuator	1

EXOSKELETON DESIGN: LOWER BODY

	Date	Author
Name	30/04/2016	Oscar
Surname		Teruel Guisado

NOVIA

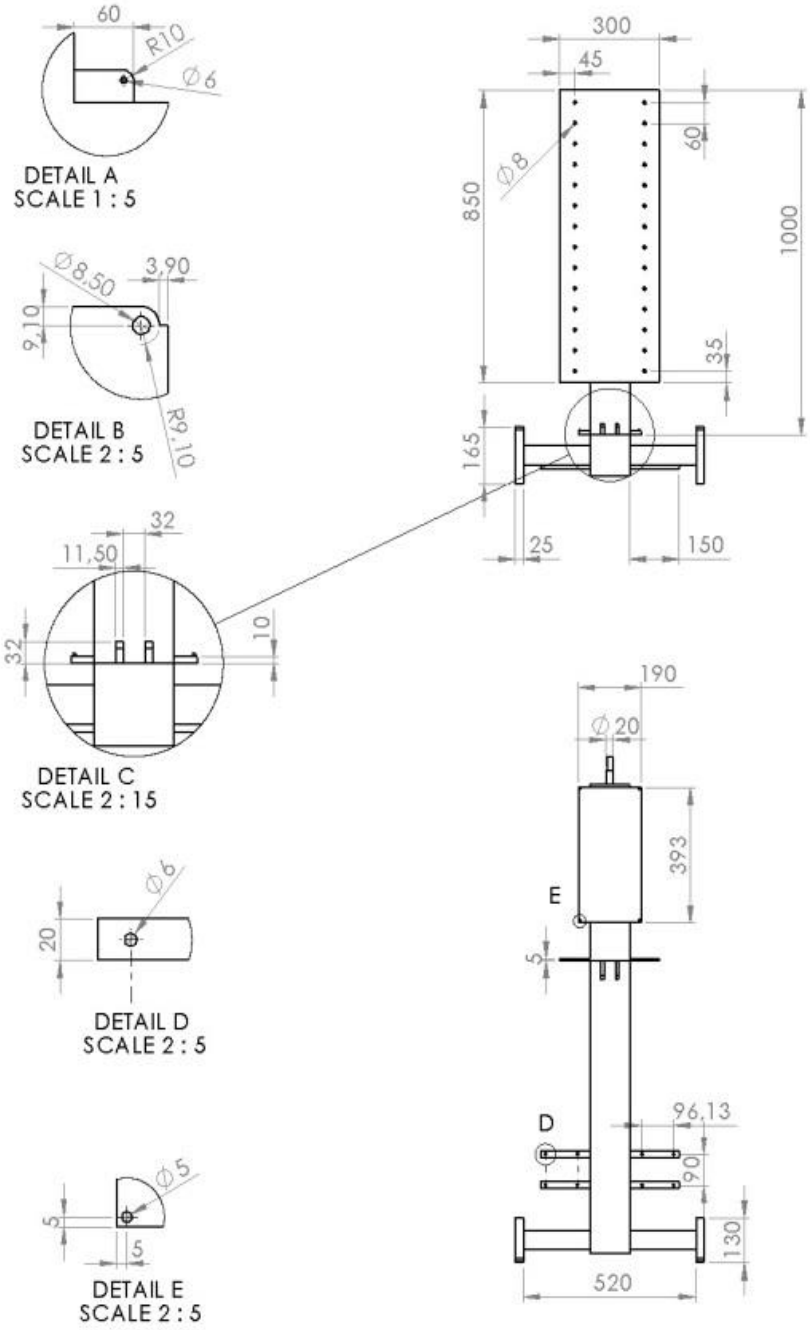
Novia University of Applied Sciences

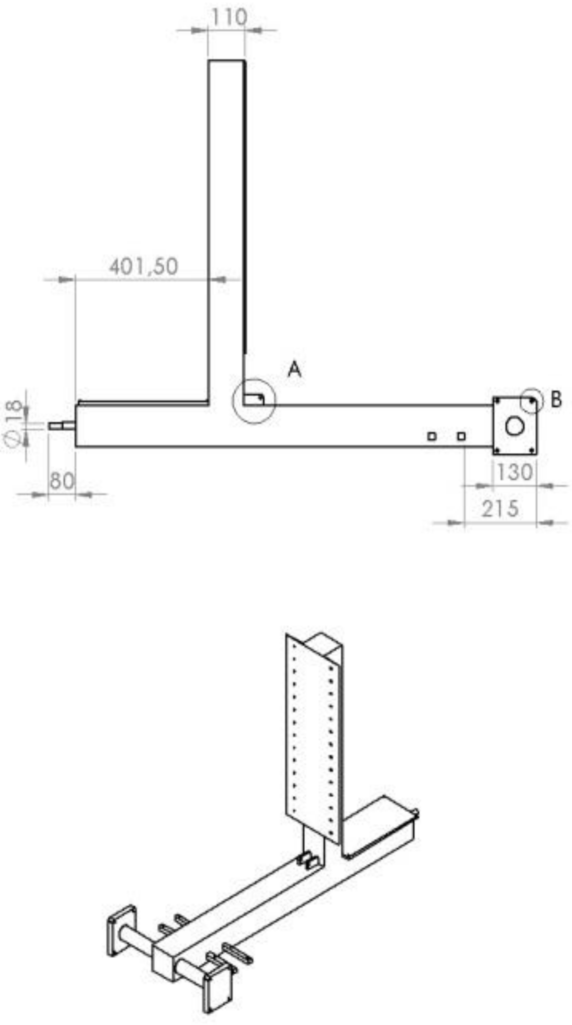
Mechanical-Environmental Engineering

SCALE 1:10

Subassemly: Lower body

Sketch num: 2





EXOSKELETON DESIGN: LOWER BODY

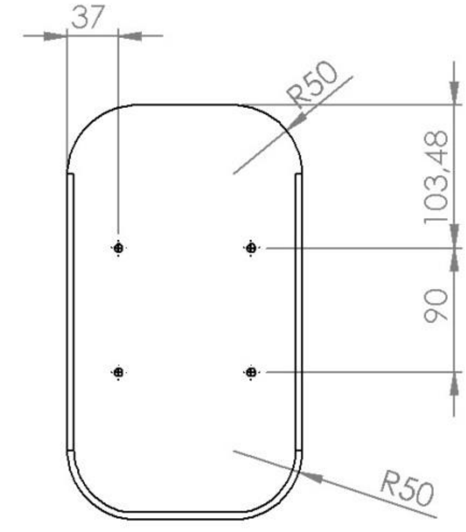
	Date	Author
Name	30/04/2016	Oscar
Surname		Teruel Guisado

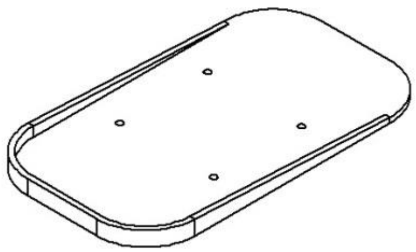
Novia University of Applied Sciences
Mechanical-Environmental Engineering

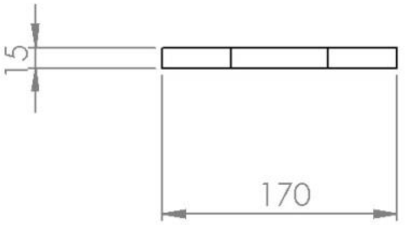
SCALE
1:20

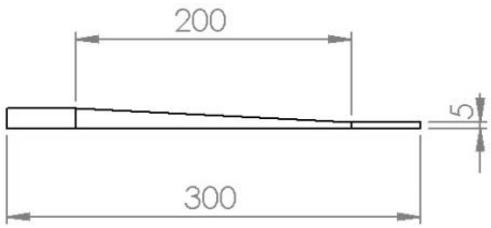
WELDED BASE

Sketch num: 3



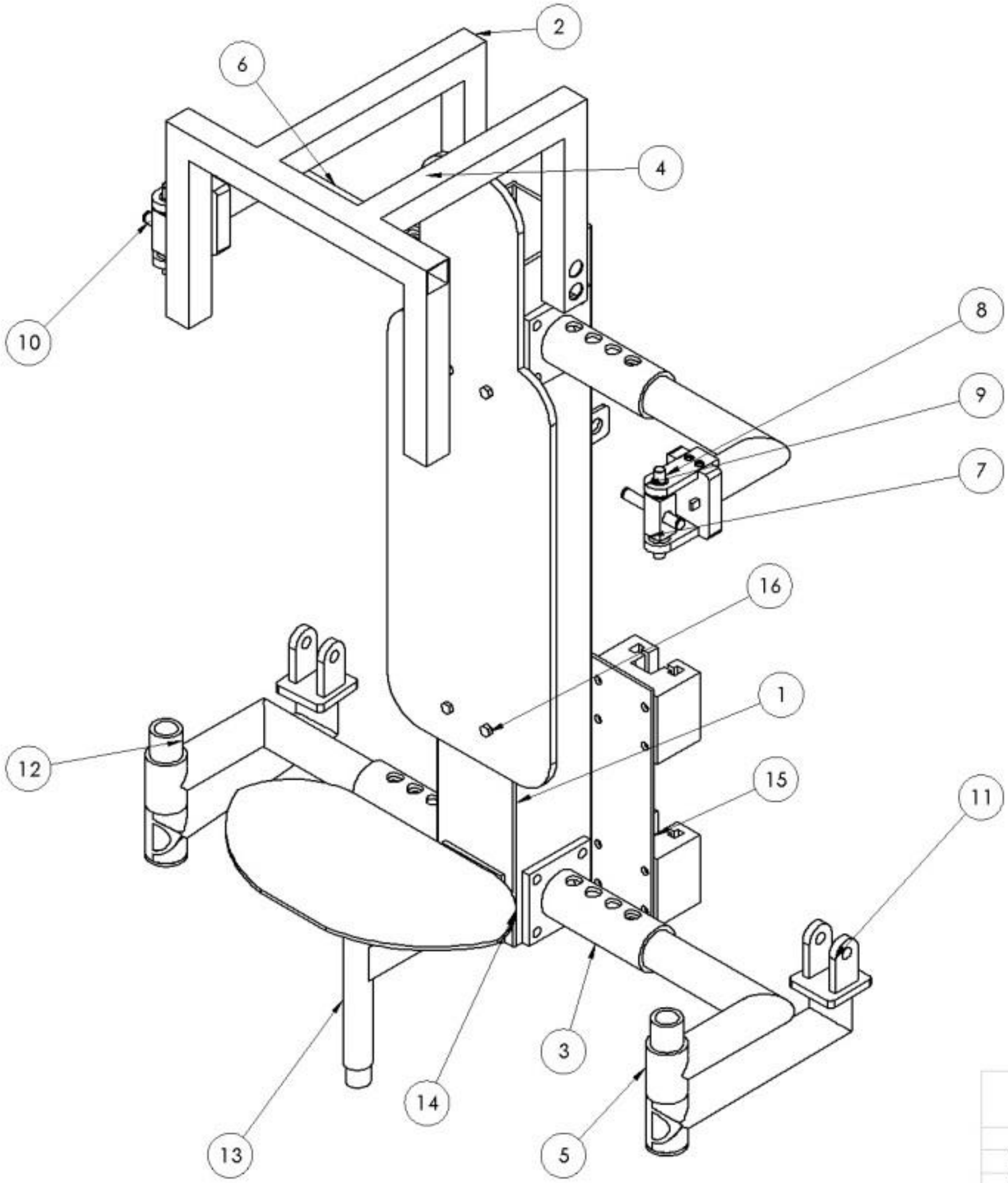






EXOSKELETON DESIGN: Lower body

	Date	Author	NOVIA	**Novia University of Applied Sciences** Mechanical-Environmental Engineering
Name	30/04/2016	Oscar		
Surname		Teruel Guisado		
SCALE 1: 5	Subassembly: Footrest			Sketch num: 4



ITEM NO.	PART NUMBER	QTY.
1	C_column	1
2	C_securitystructure	1
3	C_tubularprofile	4
4	C_backsupport	1
5	C_retactablestructuresupport	2
6	C_retractableshoulderstructure	2
7	C_Cooperhub	4
8	C_rotatorycylinder	2
9	C_independentear	2
10	C_shoulderbolt	2
11	C_reticularprofiles_supportfork	2
12	C_cupperhub_tape	2
13	C_seatsupport	1
14	C_seat	1
15	Lb_skate	4
16	Lb_M6 macho	4

EXOSKELETON DESIGN: Chest

	Date	Author
Name	30/04/2016	Oscar
Surname		Teruel Guisado

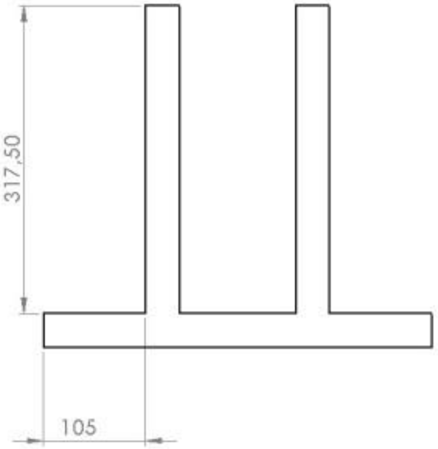
NOVIA

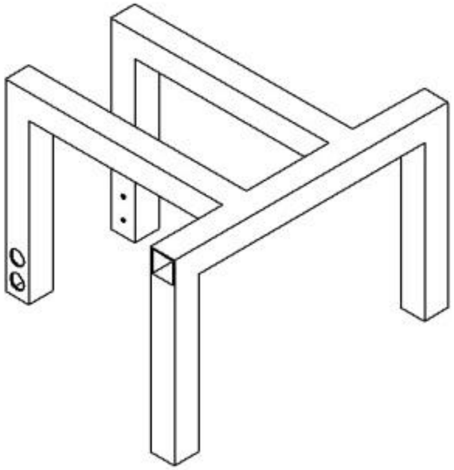
Novia University of Applied Sciences
Mechanical-Environmental Engineering

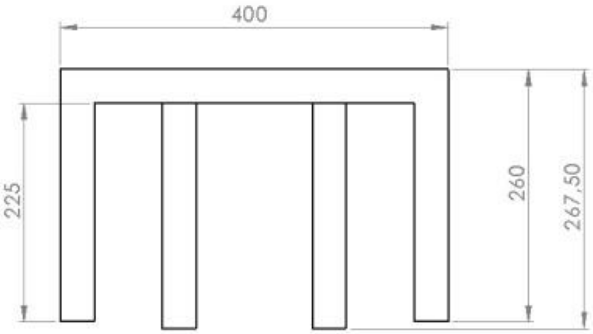
SCALE 1:5

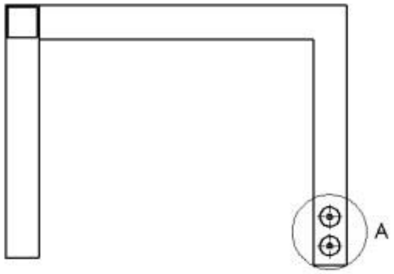
Subassembly: Chest

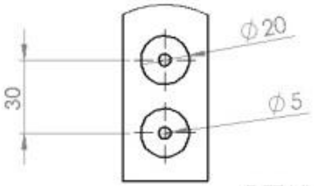
Sketch num: 5







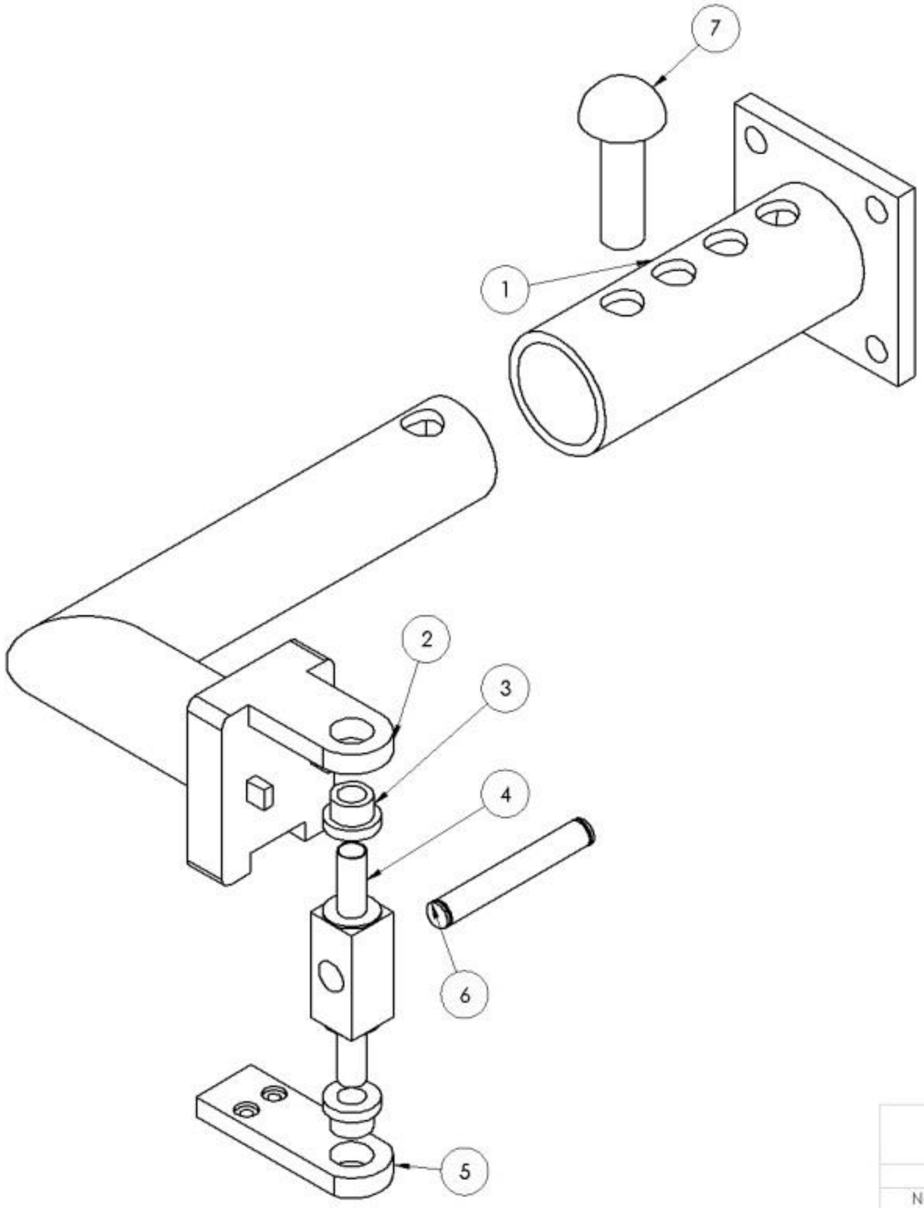




DETAIL A
SCALE 1 : 2

EXOSKELETON DESIGN: CHEST

	Date	Author	NOVIA	Novia University of Applied Sciences
Name	30/04/2016	Oscar		Mechanical-Environmental Engineering
Surname		Teruel Guisado		
SCALE 1:5	SECURITY STRUCTURE			Sketch num: 6



ITEM NO.	PART NUMBER	QTY.
1	C_tubularprofile	1
2	C_retractableshoulderstructure	1
3	C_Cooperhub	2
4	C_rotatorycylinder	1
5	C_independentear	1
6	C_shoulderbolt	1
7	C_M14 bolt	1

EXOSKELETON DESIGN: Chest

	Date	Author
Name	30/04/2016	Oscar
Surname		Teruel Guisado

NOVIA

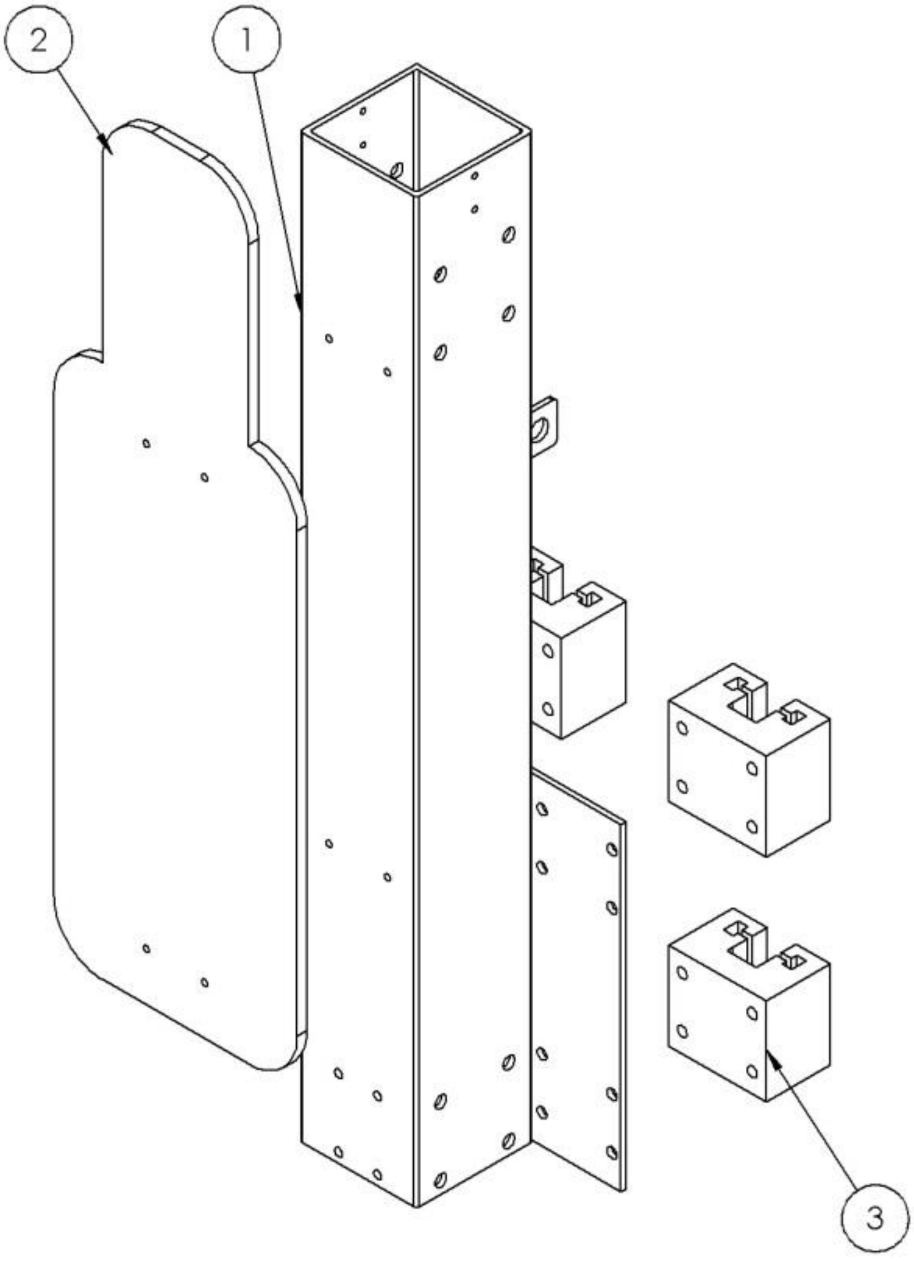
Novia University of Applied Sciences

Mechanical-Environmental Engineering

SCALE 1:2

Subassembly: Shoulder structure

Sketch num: 7



ITEM NO.	PART NUMBER	QTY.
1	C_column	1
2	C_backsupport	1
3	Lb_skate	4

EXOSKELETON DESIGN: Chest

	Date	Author
Name	30/04/2016	Oscar
Surname		Teruel Guisado

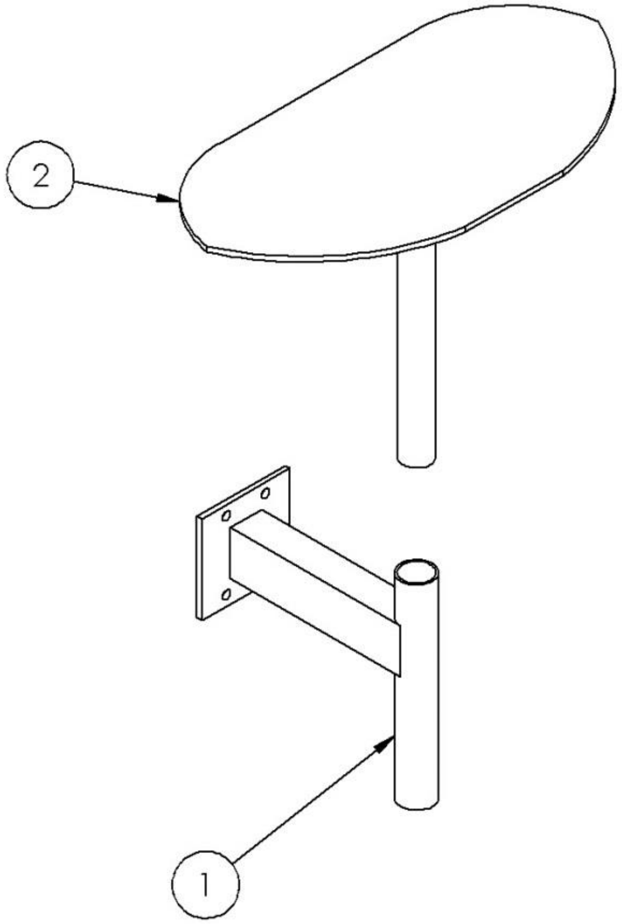
Novia University of Applied Sciences

Mechanical-Environmental Engineering

SCALE
1: 5

Subassembly: Column structure

Sketch num: 8



ITEM NO.	PART NUMBER	QTY.
1	C_seatsupport	1
2	C_seat	1

EXOSKELETON DESIGN: Chest

	Date	Author
Name	30/04/2016	Oscar
Surname		Teruel Guisado

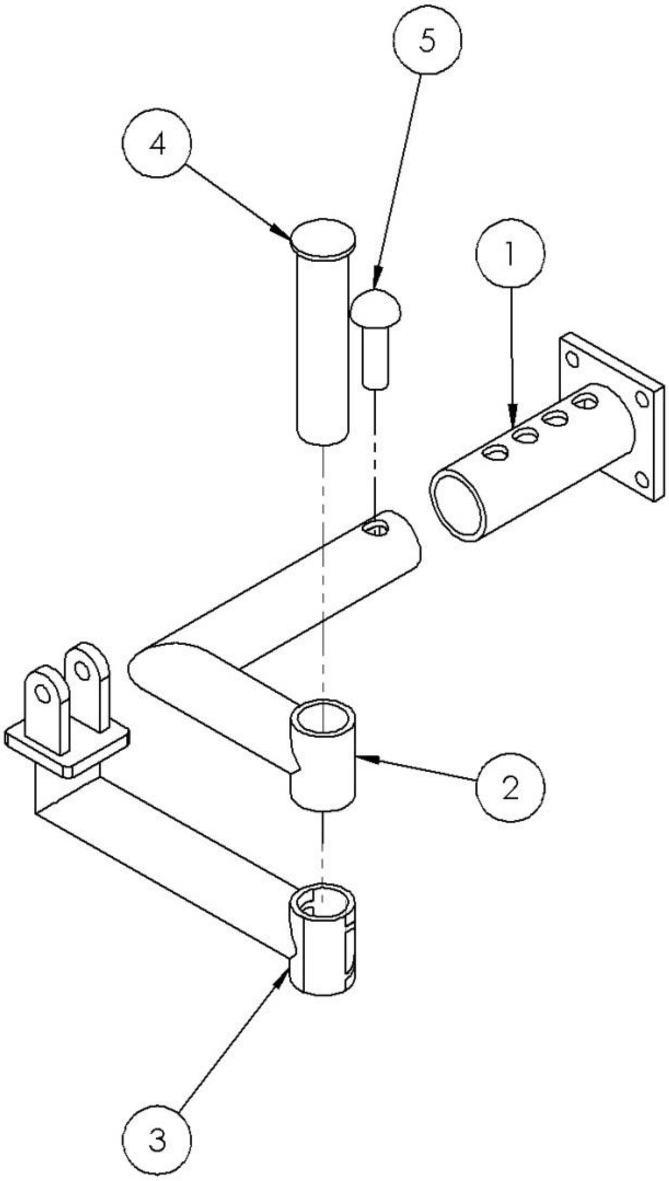
Novia University of Applied Sciences

Mechanical-Environmental Engineering

SCALE
1: 5

Subassembly: Seat

Sketch num: 9



ITEM NO.	PART NUMBER	QTY.
1	C_tubularprofile	1
2	C_retactablestructuresupport	1
3	C_reticularprofiles_supportfork	1
4	C_cupperhub_tape	1
5	C_M14 bolt	1

EXOSKELETON DESIGN: Chest

	Date	Author
Name	30/04/2016	Oscar
Surname		Teruel Guisado

YRKESHÖGSKOLAN NOVIA

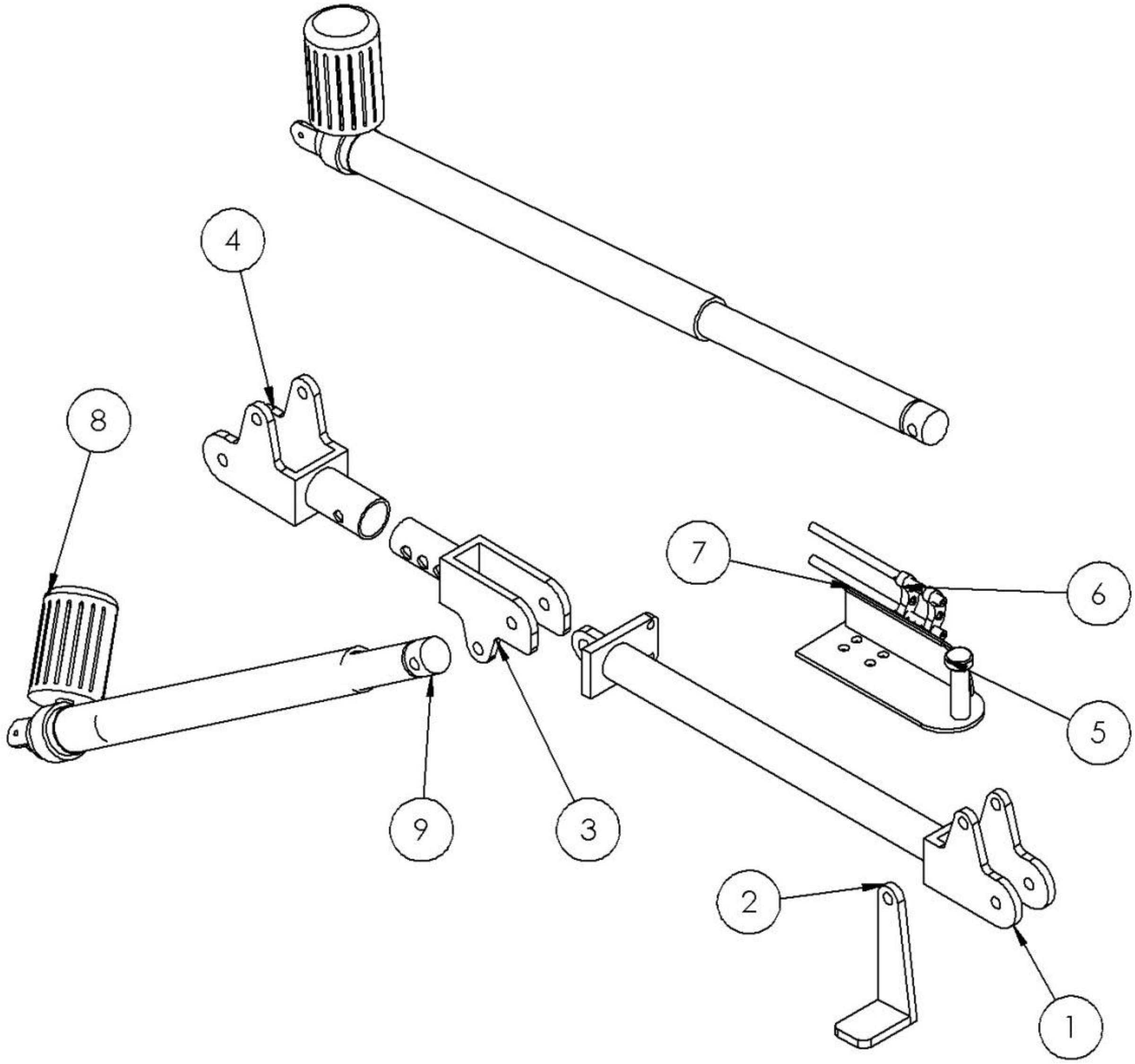
Novia University of Applied Sciences

Mechanical-Environmental Engineering

SCALE 1: 5

Subassembly: Support structure

Sketch num: 10



ITEM NO.	PART NUMBER	QTY.
1	A_forearm	1
2	a_sowel	1
3	A_kneecap_elbow arm	1
4	A_kneecap_shoulderarm	1
5	a_armrest	1
6	a_guidehitch	2
7	a_guide	2
8	A_actuator guide	2
9	A_actuator cilinder	2

EXOSKELETON DESIGN: Arms

	Date	Author
Name	30/04/2016	Oscar
Surname		Teruel Guisado

YRKESHÖGSKOLAN NOVIA

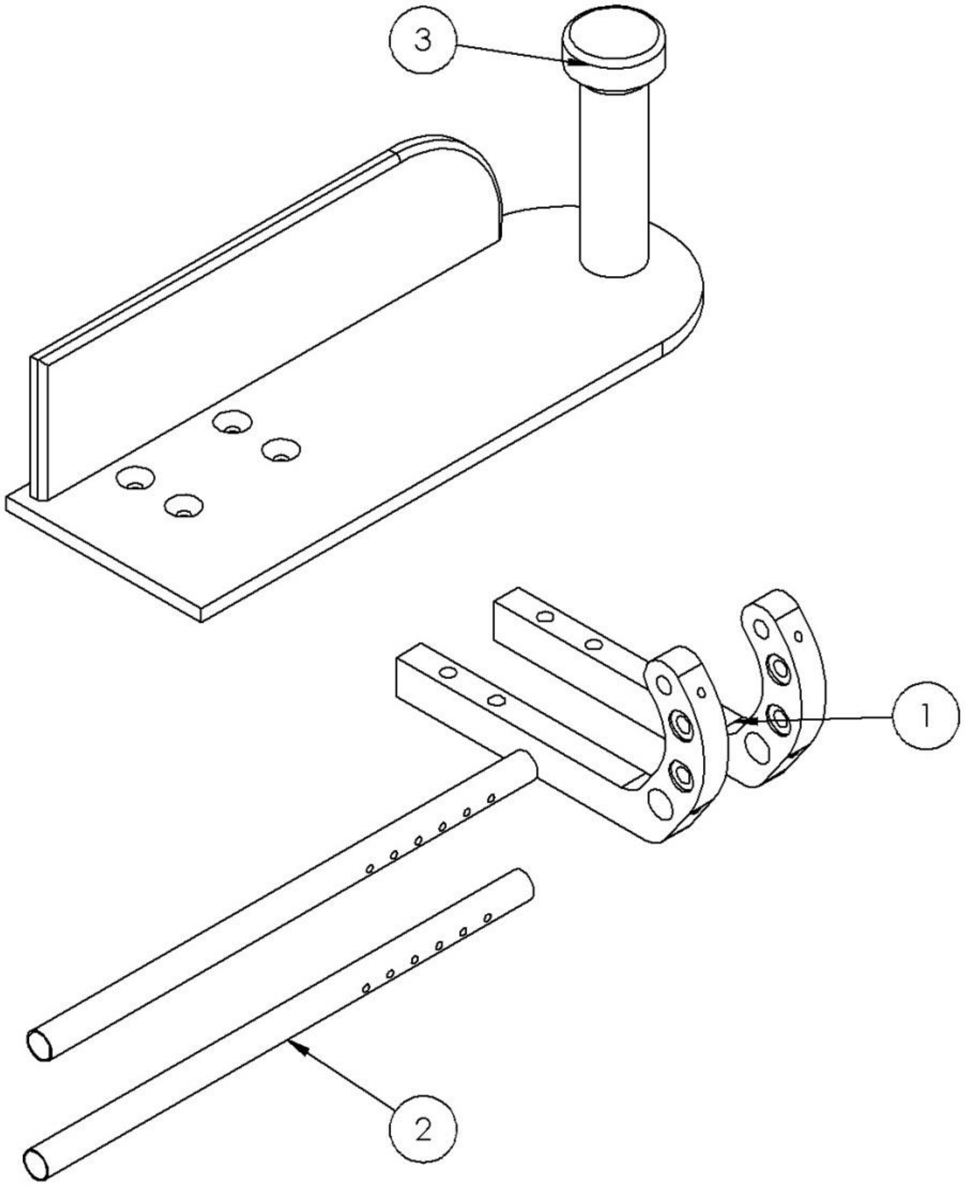
Novia University of Applied Sciences

Mechanical-Environmental Engineering

SCALE 1: 7

Subassembly: Arm

Sketch num: 11



ITEM NO.	PART NUMBER	QTY.
1	a_guidehitch	2
2	a_guide	2
3	a_armrest	1

EXOSKELETON DESIGN: Arm

	Date	Author
Name	30/04/2016	Oscar
Surname		Teruel Guisado

Novia University of Applied Sciences

Mechanical-Environmental Engineering

SCALE 1: 2

Subassembly: Forearm support

Sketch num: 12