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[WHEELCHAIR-BICYCLE MECHANICAL COUPLING; APPENDIX]

APPENDIX INDEX

1. Udstyrsbekendtgørelsen for cykler

Note that equipment Order was amended on 1 November 2012 when the new lamp rules came into force. The text on this page is addressed in relation to the new rules, but you can also find the new order of Legal Information.
Notice of cycles of construction and equipment, etc.
Pursuant to § 50 paragraph. 2-3, § 68 paragraph. 1 and 2, § 70 paragraph. 3, § 83, § 84 paragraph. 1, § 85. 1 and § 118, paragraph. 5 of the Road Traffic Act, see. Legislative Decree no. 735 of 24 August 1992 as amended by Act no. 317 of 17 May 1995, Law no. 1122 of 20 December 1995, Law no. 468 of 10 June 1997, Act no. 292 of 18 May 1998 and Law no. 187 of 30 March 1999:

Chapter 1: Interior

§ 1 A bike and trailer or sidecars shall be so arranged and maintained in such a condition that it can be used without danger or inconvenience.

§ 2 A bicycle shall not be equipped with more than three people. However, there may also be room for one or two children under eight years, as. § 10th

Subsection. 2 A bicycle must not have four wheels. Trailer for a bike for no more than two wheels.

Subsection. 3 wheels must be fitted with tires or other elastic wheel coverings with similar properties.

Chapter 2: Weight and dimensions

§ 3 A bicycle must either laden or unladen have a greater width than 1 m, however, a bike with more than two wheels have a width of up to 1.25 m. Controls and mirrors are not included in the bike's width. For bike with more than two wheels are placed in service before January 1, 1998, the track width between wheels on the same axle, however, be up to 1.25 m and width, however, be up to 1.6 m.

Subsection. 2 In a two-wheeled bicycle handlebar width must not exceed 70 cm. Operating handles and mirrors are not included in the guide width.

Subsection. 3 A bicycle must either load or unload have a greater length than 3.5 m.

§ 4 A trailer for bike must either load or unload have a greater width than 1 m. The total length of the bike and trailer must be laden or unladen does not exceed 3.5 m. The trailer's gross weight must not exceed 60 kg. Is the trailer fitted with drawbar, the total weight shall be up to 100 kg.

Subsection. 2 A bike with a sidecar shall have wider track than 0.8 m. No part of the vehicle or its load must be outside the sidecar wheel. The total length of the bike and sidecar must laden or unladen does not exceed 3.5 m. Side-trailer gross weight must not exceed 60 kg.

Chapter 3: Brakes

§ 5 A bicycle must be equipped with at least two independent braking systems acting on the front and rear. Wheels on the same axle must be braked by the same braking system. A bike that is placed in service before 1 January 1998 may be equipped with only one foot operated coaster brake acting on the rear wheel, unless the bicycle is equipped with more than one person, including bike equipped with special seats for children, or the bike is armed trailers or sidecars.

Subsection. 2. Braking cycle must be done in a safe and effective manner at all speeds and under all load conditions. Inclement weather may not be able to reduce brake operation significantly.

Subsection. 3 When braking system operated by the pedals, the full braking effect could be achieved by depressing the pedal from the horizontal position of the crank arm.

Subsection. 4 Parts of the foot-operated brake system shall withstand an operating force of 100 daN (100 kg). Parts of hand operated braking system must be able to withstand an operating force of 60 daN (60 kg).

Subsection. 5 Goods bike with more than two wheels must also be equipped with a parking brake on the wheels that carry goods loaded. This brake must be able to keep the bike stationary on a slope and must be held in the locked position by a purely mechanical way.

Chapter 4: Lights and reflectors

NB! Please note that per. November 1, 2012 introduced new rules for bike lights. The text below has been updated to fit with the new order.

§ 6 When driving in the daytime, a bicycle be equipped with at least one headlamp emitting white or yellowish light clearly visible from the front for at least 300 meters without being dazzling and visible from the sides. On a bike with more than two wheels, the headlamp shall be placed not more than 0.5 m of the bicycle on the left.

Subsection. 2 When driving in the daytime, a bicycle be equipped with at least one tail lamp emitting a red light to the rear clearly visible for at least 300 meters without being blinding, which is visible from the sides. A bike with more than two wheels must, if it is not more than 1 m wide shall be provided with at least one tail lamp mounted in the centerline of the bike plan or to the left, and if it is more than 1 m wide shall be provided with at least two tail lamps mounted most 0.4 m of the bicycle outermost points and with a spacing of 0.6 m.

Subsection. 3 When driving in the daytime, a trailer for bike be equipped with at least one tail lamp mounted in the trailer median plane or to the left. A sidecar bike to be in the daytime bear at least one position that is located as close to the sidecar rightmost point as possible. Rear light on trailers or sidecars must comply with the rear of the bike.

Subsection. 4 Front and rear light on the bike and trailer or sidecars must comply with § 16 paragraph. 2 or transitional provisions of § 16a.

Subsection. 5 Front and rear light on the bike and trailer or sidecars must be affixed to the vehicle in a manner which ensures that the light does not change the setting during the journey and must be mounted so that the lamp core rays pointing respectively straight forward and straight back. Headlight designed for use on unlit road, should, however, be set by a fall.

Subsection. 6 Headlight emitting white light and rear light on the bike and trailer or sidecars can emit a flashing light. Flashing frequency must be at least 120 times per. minute.

Subsection. 7, a three or four-wheeled bicycle, whose design means that all signals with an arm, see. Highway Code § 32 paragraph. 2 and 4 are not clearly visible, must be equipped with two rear-facing red stop lamps, and one forward and one backward yellow direction indicator lamp on each side.

Subsection. 8 Stop lamps must light immediately when either the front or back wheel brake and must have a brightness that is significantly larger than the tail lights brightness.

Subsection. 9 direction indicator lamps shall be of such intensity that they are clearly visible in sunlight. Direction indicator lamps must have a flash frequency between 60 and 120 flashes per. minute.

Subsection. 10 A bike and trailer or sidecars can be equipped with yellow side marker lamps.

Subsection. 11 A bicycle may be equipped with lamps built into the pedals forward, backward and sideways emit yellow flashing light when the pedals.

Subsection. 12 A bike and trailer or sidecars can not be provided with any other lamps than the foregoing.

Subsection. 13 On a bike with a trailer bicycle must be equipped with rear light.

§ 7 A bicycle must be equipped with at least one white reflector visible from the front. A bike with more than two wheels must be fitted with at least two such reflectors are placed not more than 0.4 m of the bicycle outermost points and with a spacing of 0.6 m.

Subsection. 2 A bicycle must be equipped with at least one red reflector visible from the rear. A bike with more than two wheels must be fitted with at least two such reflectors are placed not more than 0.4 m of the bicycle outermost points and with a spacing of 0.6 m.

Subsection. 3 A bicycle must be equipped with at least two yellow reflectors to move when the bike is running, and which is visible from the rear.

Subsection. 4 A bicycle must be on each wheel being provided with at least one yellow reflector that is visible from the sides, or with white reflective tire or rims.

Subsection. 5.-wheeled trailer for bicycle shall be equipped with at least one white reflector visible from the front, and at least one red reflector visible from the rear. Reflectors must be placed in the trailer median plane or to the left. A two-wheeled trailer to the bicycle must be equipped with at least two white reflectors visible from the front, and at least two red reflectors visible from the rear. Reflectors must be located as close to the trailer outermost points as possible. Sidecar for bicycle shall be equipped with at least one white reflector visible from the front, and at least one red reflector visible from the rear. Reflectors must be located as close to the sidecar rightmost point as possible.

Subsection. 6 A trailer for the bike to be on each side shall be equipped with at least two yellow reflectors visible from the side, or at least one yellow reflector on each wheel, which is visible from the sides. A sidecar bike to be on the right side being provided with two yellow reflectors visible from the side, or at least one yellow reflector on the wheel that is visible from the side.

Subsection. 7 A bike and trailer or sidecars can not be fitted with triangular reflector. Reflections in a couple must be the same.

Subsection. 8 A bike and trailer or sidecars can be equipped with additional reflectors as follows: Fixed, forward-facing reflectors must be white, rear-facing red and reflexes, facing to the side, yellow. Moving reflexes must be yellow.

Subsection. 9 Reflective bike and trailer or sidecars must be labeled in accordance with § 16 paragraph. 4th

Subsection. 10 Notwithstanding paragraphs. 9, the reflex acquired before 1 January 1998 continue to apply. Mandatory reflex acquired before 1 January 1998 must be E or e-marked or labeled by another authentication scheme.

Chapter 5: Signal Device and cyclist pennants

§ 8 A bicycle must be equipped with a clear sounding bell, which shall be located on the handlebar. The bike must not be fitted with other signaling device.

§ 9 A bicycle may be equipped with a little flag mounted on luggage rack or the like over the rear wheel.

Subsection. 2 Flag's stick must be flexible and be positioned so that no part of the rod travels farther than 0.5 m to the left and 0.15 m to the right of the bike's longitudinal axis. The warning device shall be located at the far left of the flag's stick and shall be equipped with a red reflector that is visible from the rear.

Chapter 6: Transport of passengers

§ 10 On a bicycle shall not be carried more people than it was designed for. However, children under 8 years are included on the bike when arranged special seating.

Subsection. 2 Special seating for children must be tailored to the child's weight and height, and there must be shielding wheel like.

Subsection. 3 Children included on a bicycle, must be securely fastened.

Subsection. 4 Carriage of children must not obstruct the driver of the bike in to have full control of the bike or make proper hand signals.

Subsection. 5 The driver of the bike must be 15 years of age.

§ 11 A trailer or sidecar bike to be used to transport up to 2 persons, when each person is arranged special seating with shielding wheel like. Trailer or sidecar total weight and dimensions shall not exceed those specified in Chapter 2 above. There must also carried one child under 8 years old on the bike.

Subsection. 2 persons traveling in trailers or sidecars for bicycle must be tightened securely. However, people who cycle on a special trailer fitted with handles, saddle and pedals (half cycle) not be secured.

Subsection. 3 The driver of the bike must be 15 years of age.

Chapter 7: Connecting the trailer or sidecar to bike

§ 12 The bicycle must be coupled one trailer or one sidecar. Trailer or sidecar be coupled with proper coupling.

Subsection. 2 Sidecar must be positioned to the right of the bike.

Chapter 8: electric bike

§ 13 A bicycle may be equipped with an electric auxiliary engine and should not be fitted with other engines.

Subsection. 2 An electric auxiliary motor must only provide power when the pedaling or the like simultaneously operated. Electric bicycle may be equipped with an electric go-function, so that the bike's electric auxiliary motor can deliver power at a speed of 6 km / h or less, although the pedals or the like not simultaneously be operated when an electrical contact, eg push-button or rotary handle mounted on the handlebars, influenced manually by the driver. Electric auxiliary engine power output shall automatically cease when the influence of the electrical contact on the handlebar ends.

Subsection. 3 An electric auxiliary motor shall have a maximum power of 250 W.

Subsection. 4 An electric auxiliary motor may only deliver power at speeds of 25 km/h or less.

Chapter 9: Cycling

§ 14 During the years under the Road Traffic Act § 37 paragraph. 1 need a bike to be equipped with lamps, see. § 6, reflectors, see. § 7, and bell, see. § 8 thereof.

Chapter 10: Distribution of lighting equipment, etc.

§ 15 parts bike and trailer and sidecars may only be marketed if they comply with §§ 2-5, § 6, paragraph. 1-3, and paragraphs. 6 pcs. 9 and paragraph. 11 and § 9th

§ 16 Lights and reflectors for use by bike and trailer and sidecars may also be marketed and sold in case the lights, reflectors and marketing complies with paragraphs. 2-4.

Subsection. 2 Front and rear light must have a brightness of at least 4 candela measured respectively from the front and right rear, at least 0.4 candela measured 20 degrees to each side and at least 0.05 candela measured 80 degrees to each side. For a battery-powered lamp, lamp except where charging takes place during driving is also the case that it should have a useful life of at least 5 hours. Useful life is the time that the lamp can light with at least the required brightness before the battery / batteries need to be replaced or recharged. The lamp can be set to flash and to shine with a steady light or to have different levels of intensity, the need for life by setting that results in the shortest useful life. The useful life is measured by the on and off intervals, each lasting 2 hours at + 5 ° Celsius and with nominal battery voltage at start time.

Subsection. 3 Battery-powered front and rear lights, except the lamp in which the charging is done while driving, on the light or on the sales packaging clearly labeled with 'Useful life' or 'Run-time' followed by the number of hours and the 'h' or 'hours'. In marketing, for example, in advertisements, brochures or on the internet of such a lamp must use the time stated clearly.

Subsection. 4 White forward, backward red and yellow reflector facing to the side, must be approved in accordance with ECE Regulation. 3 and 'E' mark in Class IA or IVA or approved in accordance with EC Directive no. 76 / 757 / EEC and 'e' mark in class IA or IVA. White reflective tire or rims must be approved according to ECE Regulation. 88 and 'E' mark or approved and labeled in accordance with national standards or rules in another EU or EEA country. Yellow movable rear facing reflectors must be approved according to ECE Regulation. 3 and 'E' mark in Class I, IA or IVA, authorized in accordance with EC Directive no. 76/757 / EEC and 'e' - mark in class I, IA, or IVA or approved and labeled in accordance with national standards or rules in another EU or EEA country.

Transitional provisions:
§ 16a. Rear acquired before 1 November 2012, can still be used, provided it meets the requirements of § 6 paragraph. 2 '

Chapter 11: Penalties and entry into force, etc.

§ 17 Violation of §§ 1-5, § 6, paragraph. 1-5, § 6, paragraph. 6, second paragraph., § 6, paragraph. 7-9 and paragraph. 12, § 7 paragraph. 1-9 and paragraph. 10, second paragraph., § 8, § 9, paragraph. 2, § 10 paragraph. 1-4, § 11 paragraph. 1 and 2, and §§ 12, 13, 15, 16 and 16 shall be punished by a fine.

§ 18 Order comes into force on 1 November 2012.
Subsection. 2 bikes, and trailers and sidecars can immediately arranged in accordance with the notice.
Subsection. 3 Ministerial Order no. 338 of 13 May 1997 on the cycles of construction and equipment, etc. repealed.

Traffic Authority, January 31, 2012
Carsten Falk Hansen / Ib Rasmussen

2. BICYCLE BASIC DIMENSIONS

1. MATERIAL

1.1. Frame Tubes

Cold drawn seamless, or electrically resistance butt welded conforming to IS 2039.

1.2. Liners

Mild steel with sulphur and phosphorus content, each not exceeding 0.060 percent.

1.3. Logs

Mild steel with sulphur and phosphorus content, each not exceeding 0.060 percent; or whiteheart malleable iron casting conforming to Grade WM350 of IS 14329.

2. DIMENSIONS

2.1. Frame Tubes

The frame shall conform to the dimensions specified in Fig. 1, Fig. 2 or Fig. 3. The dimensions of the tubes specified in Fig. 1 shall comply with those given in IS 2039.

2.2. Screw Threads

The dimensions of screw threads on bottom brackets shell for fixed and adjuster cups shall conform to IS 1131, IS 1132, IS 1133 and IS 1134.

3. MANUFACTURE

The tubes shall be fitted squarely to their respective lugs. During brazing, the frame assembly shall be securely held to prevent the relative movement of its members. The tubes shall be so fitted as to be in one plane and the axis of the bottom bracket shall be perpendicular to the plane of the frame.

4. FINISH

The frame shall be free from rust, scale and oily substances. It shall be suitably pretreated and stove–enamelled, spray–painted or otherwise treated to give a good/glossy finish.

5. FRAMES CHARACTERISTICS

5.1. General view

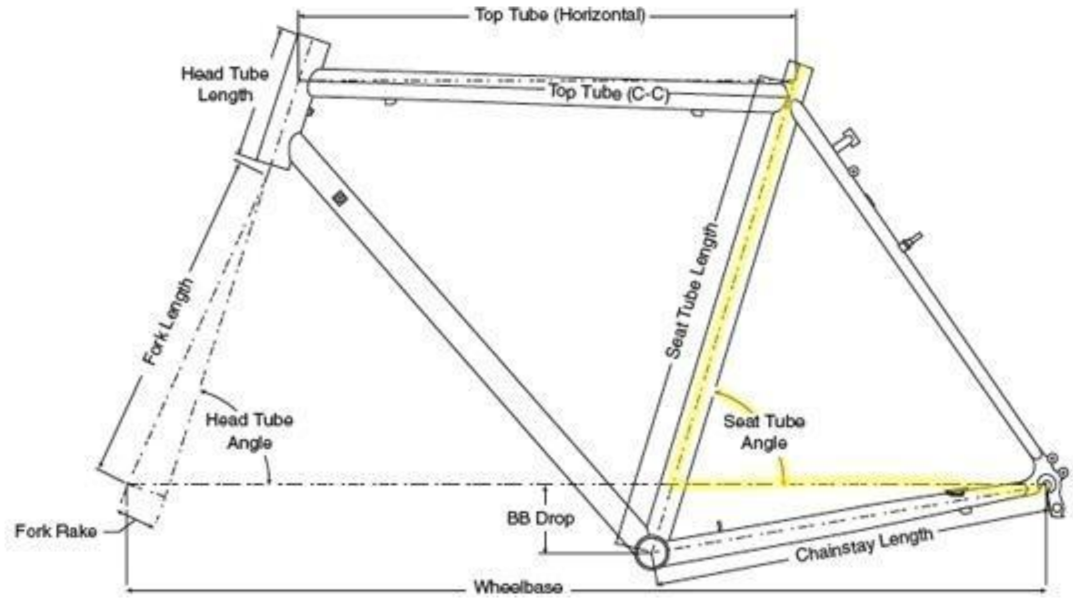
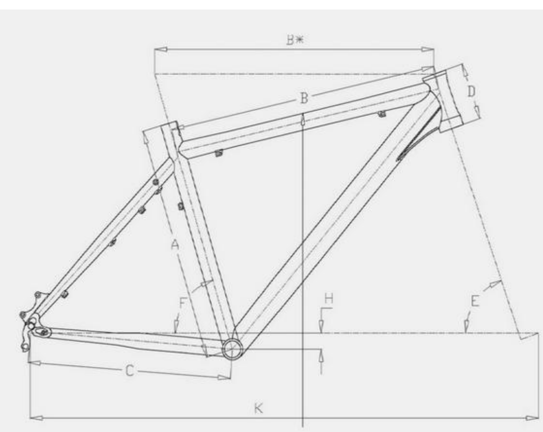


Figure 1. Names of frame's parts and angles.

According to the person's height and constitution it is possible to find difference frame sizes:



Frame size:	S	M	L	XL	XXL
Seat tube A	420	470	510	560	600
TT B	545	557	575	586	599
TT (eff.) B*	570	590	610	625	635
CS length C	429	429	429	429	435
HT length D	105	110	120	135	155
Steering angle E	70°	70,5°	70,5°	71°	71°
Seat angle F	74°	73°	73°	73°	73°
Seat post dia. G	31,6	31,6	31,6	31,6	31,6
BB drop H	72	70	70	70	70
wheelbase K	1062	1066	1087	1097	1114
stand over L	736	772	784	819	850
max travel front	100	100	100	100	100

Figure 2. Frame sizes.

5.2. Tubes ods

MEN'S BICYCLE FRAME

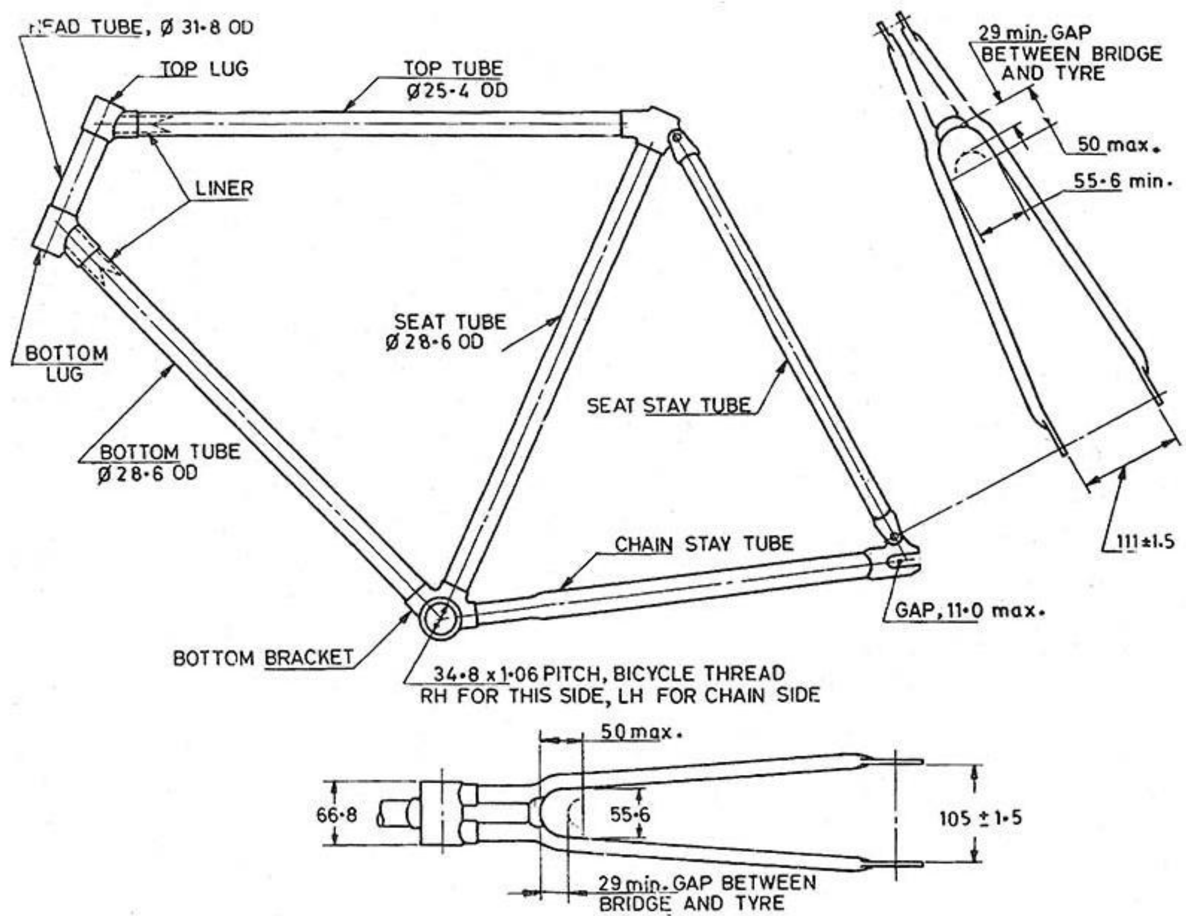


Figure 3. Basic tube's ods in a male bicycle frame. All dimensions in millimeters.

WOMEN'S BICYCLE FRAME

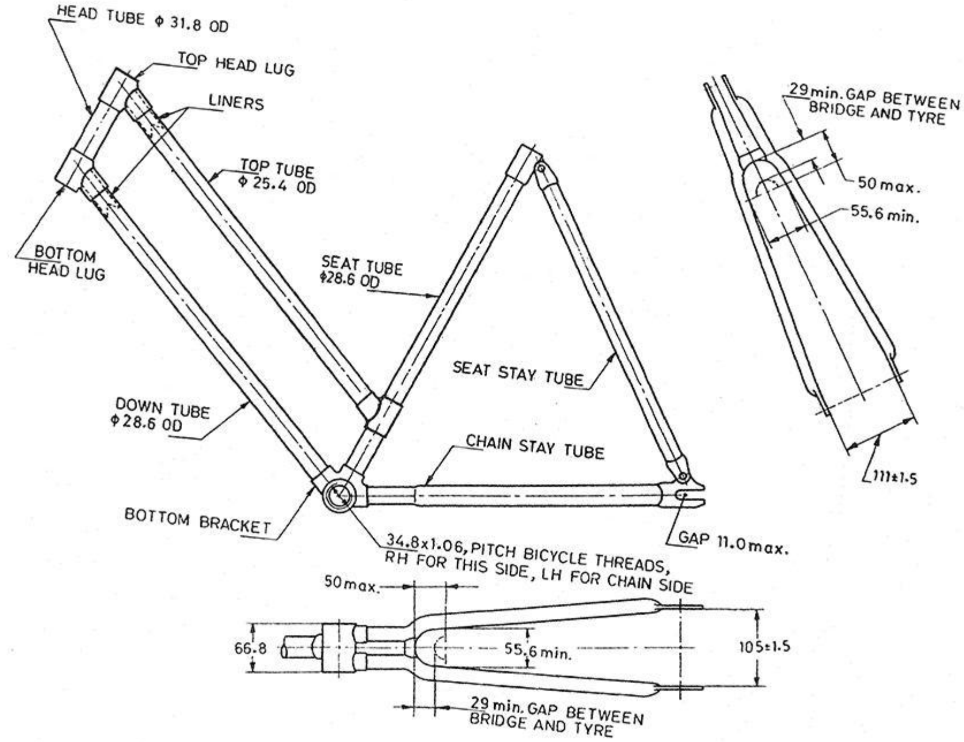


Figure 4. Basic parallel bars bicycle frame. All dimensions in millimeters.

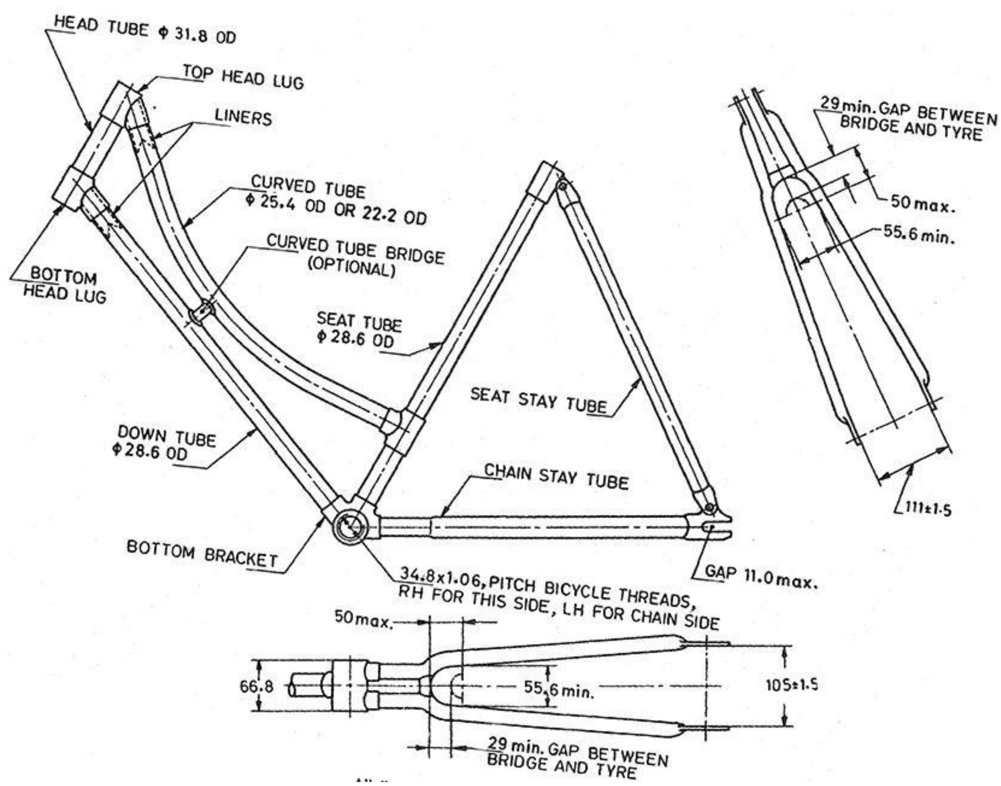


Figure 5. Basic curved bar bicycle frame. All dimensions in millimeters.

REFERENCES

[1] Frame characteristics. August 29, 2014. http://cyclingabout.com/wp-content/uploads/2013/10/wpid-Photo-4-Oct-2013-1227-am.jpg

[2] Tube's ods. August 30, 2014. https://law.resource.org/pub/in/bis/S13/is.623.2008.html

[3] Frame basic dimensions. August 30, 2014. http://twentynineinches.com/wp-content/uploads/2011/01/Revox_geo.JPG

3. DRAFT OF IDEAS

1. TRAILERS

1.1. REAR WHEEL CONNECTION.

1.1.1. REAR WHEEL - WHEELCHAIR FRONT CONNECTION

1.1.1.1. FIRST APPROXIMATION

In this design we have focused on a union between the bicycle's rear wheel and the wheelchair's front part. The mechanism is joined through two fixed pressure clamps with screws to the wheelchair front bars, figure 1.5. and 1.6., and as it can be seen at the figure 1.1. the union at the bike is made at the rear wheel's axle.

The whole design is formed by 4 parts joined through an universal joint, that union transforms the mechanism in articulated and provides a degree of movement between the parts. Moreover, this joint gives a huge advantage when the whole is driven as the bars are not subjected to big efforts (when turns) because it is not a rigid structure. The joint can be seen in the figure 1.4.

Due to the fact that our design is simple and formed by four parts, it makes easier its transport and the assembly of the whole. Also the design supposes no manipulation on the bike what results in a completely adaptable mechanism to electric bikes. Another thing to take into account is that we are talking about a very innovative model due to there are some mechanisms already designed but no one of them has been thought to attach the wheelchair directly to the bike.

Talking about disadvantages the fact that the union is made with bars provokes some remoteness between the wheelchair and the bike so the management of the whole will decrease considerably. There will be big efforts on the bars at the breaking and acceleration moments due to the bars as well. Another point to take into account is the interaction and communication of the driver and the passenger, because of the distance those facts will result affected. Moreover, as we have an articulated joint behind the bike the stability of all the parts it is going to be lower than on the other designs.

Figure 1.1. Complete assembly.

1.1.1.2. FURTHER RESEARCH

As it has been explained in the description of this model the union between the parts is done through two bars attached to the rear wheel's bike and to the front part of the wheelchair.

The joining made at the wheelchair is the one shown in the figures 1.2. and 1.3. It is formed by an elliptic part that in one of its sides contains the bar, which is retained with a screw, and in the other the wheel's axle is attached with a bolt and a washer.

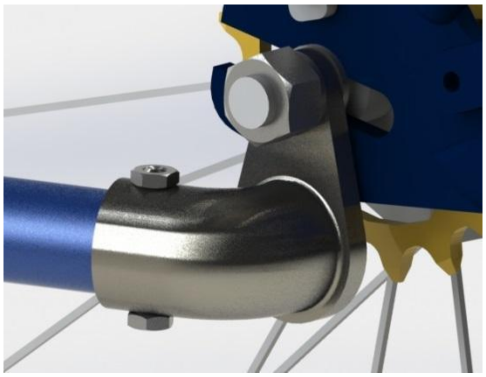


Figure 1.2. and 1.3. Hub attachment piece.

There are different ways to attach the axle to the fork and the frame of the bike but the most common ones are the thru axle and the female axle. Both links use diameters axles of around 14 – 20 mm but there are some other kind of unions which use smaller diameters so the solution would be to build two different kind of pieces; one for the bigger diameters and another for the smaller.

To keep together the two bars (the bar which is linked to the wheelchair and the other which is linked to the bike) it is used a universal joint, showed at the figure 1.4., to give some degree of movement to the mechanism and release it from bigger mechanical efforts.

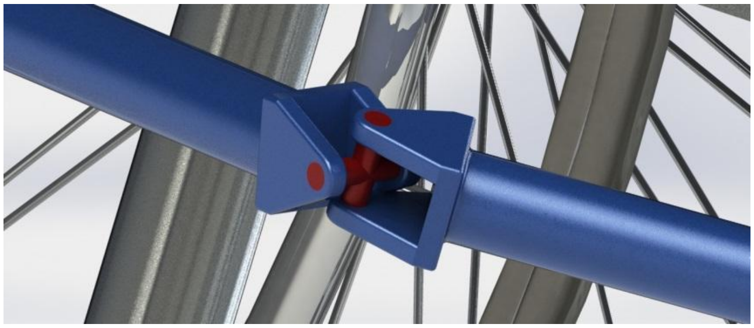
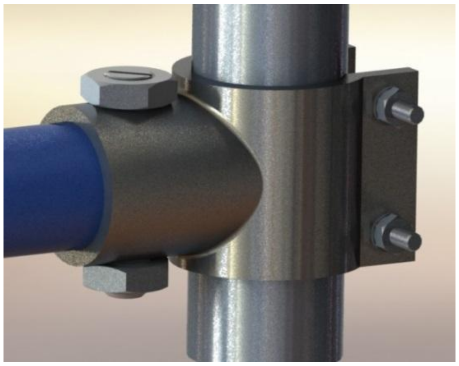


Figure 1.4. Universal joint.

Universal joints are commonly used for the transmission of a shaft's rotation to another shaft which is not linear with the first one. In our design it will be used to minimize the bending moments on the attachment points of the mechanism.

Finally the last union made in this model is at the front part of the wheelchair. The attachment is done by round clamps firmly braced to the wheelchair's bars thanks to two screws. The big advantage of this linking method is that in case of having bars of different diameters the mechanism would be perfectly adjustable to them. However, in the common wheelchair models, the diameter of the canes, spreader bars… oscillate between 7/8''– 1 1/8'' (2.20 – 2.85 cm).



Figures 1.5. and 1.6. Clamps attached to the front part of the wheelchair.

What we are looking for at the time of manufacture the model is to get parts as much resistant and durable as possible, taking into account that they must be light as it will be more helpful for the driver to carry the passenger. So apparently the best choice would be aluminum, it is lighter and more malleable than the steel and presents a high resistance against vibrations thanks to its flexibility. Furthermore aluminum gives to the mechanism an extra protection against the oxidation as it is already covered by a thin layer of rust (because of it is a very oxidisable material and reacts immediately in contact with oxygen). Even if steel is more resistant than aluminum this last is still being the best choice.

1.1.2. REAR WHEEL - WHEELS ATTACHMENT

1.1.2.1. FIRST APPROXIMATION

As you can see this design is quite similar with the anterior one (figure 1.1.), the only difference is the union point of the both parts. In this case the link is made at the rear's wheelchair shaft and the rear's bike shaft. And as in the case above all the joins are the same but the one which is attached to the wheelchair, it can be appreciated in figure 1.7.

When referring to the advantages and disadvantages they are pretty much the same than in the case above as it is a very similar model only changing the attachments at the wheelchair.

The fact that is practically identical to the design before supposes the same advantages and disadvantages.

Figure 1.7. Whole assembly result.

1.1.2.2. FURTHER RESEARCH

This model is practically identical to the 1.1.1. The only thing that changes is the union on the wheelchair which in this case is made at the shaft of the wheelchair's rear wheel. This is a very complicated union to assembly due to the two elements, wheelchair and bike, have to be manipulated at their rear wheels.

In any case the attachment would be exactly equal as the one made in the 1.1.1. at the bike's rear wheel, an oval part which one of its sides contains the bar joined through a screw and the other side is attached to the wheelchair's rear wheel by bolts, figure 1.8.

Figure 1.8. Joint on wheelchair's wheel hub.

The attachment is more complicated than how it is showed in the picture as for its proper mounting the whole wheel and shaft should be unassembled, this would suppose a big problem for the costumers and also to us because it is tried to design a mechanism the simplest as possible. Regarding the materials would also be aluminum as we have the same requirements in all the designs.

Of course the other designs will not change from the other design i.e. there will be used universal joints to attach the bars and the same part for the attachment at the bike's rear wheel.

1.2. SEATPOST ATTACHMENT

1.2.1. SEATPOST - WHEELCHAIR FRONT ATTACHMENT

1.2.1.1. FIRST APPROXIMATION

At this design the wheelchair and bicycle's unions are made from the seat of the bicycle to the front part of the wheelchair by a curved bar and the bindings, the whole mechanism is formed by four different parts, as it is shown in figure 1.9. The union at the wheelchair is done by a straight bar with two clamps at both sides as at the point 1.1.1. and joined with the linking bar through a reinforcement box which will reduce the flexion efforts as well, the reinforcement is stuck to the bar by a screw. At seat's bike the join is done with a double clamp, one attached to the seat and the other is a part of the linking bar. The clamps give us the advantage to be able to control the height of the mechanism in case we would want to adapt it with different bikes or wheelchairs.

As we have been talking at the other points, the advantages of this model are still being the same due to it is the same kind of model but with different attachments. In case of the forces on the system we could say that the linking bar would be subject to higher efforts than at the other points as compression and traction are focused on it originating deformations at the middle in case of high force.

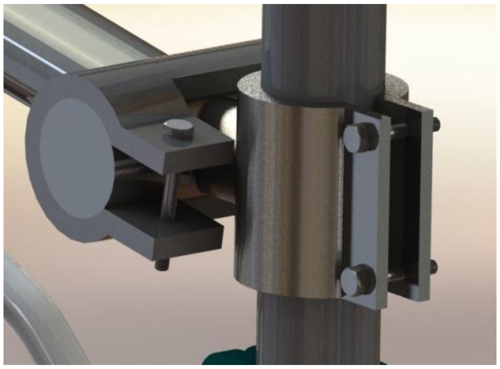
A possible disadvantage would be the number of parts and it is size that could do more difficult transport the whole device and assembly it to the bike (compared with the rest of the designs).

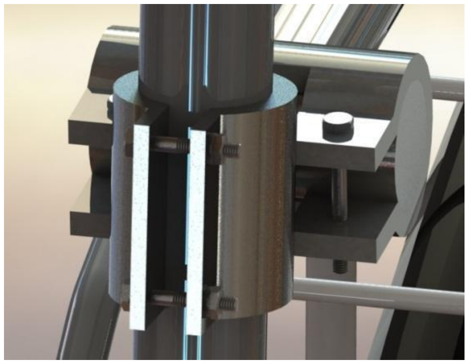
Figure 1.9. Whole Seatpost-Front part assembly.

1.2.1.2. FURTHER RESEARCH

This model tries to imitate a trailer but without it i.e. the wheelchair does the function of the trailer. In this case the union is made by a bar attached to the seat of the bike and to another bar attached to the front part of the wheelchair as in the case 1.1.1. The two bars are joined between them thanks to a box which does the work of contain them and strengthen against the mechanical efforts.

The attachment at the seatpost is done thanks to two round clamps joined between them by screws and nuts. The union between them is made by a round clamp attached to the seat which has an outgoing cylinder where the other round clamp (which is part of the joining bar) goes attached. The material of the frame determines the seatpost diameters, depending on the bike these diameters vary from 21.15 to 32 cm being the average diameter 27,2cm, figures 1.10. and 1.11.





Figures 1.10. and 1.11. Round clamps on the seatpost.

The attachment at the wheel chair is made through another bar, figure 1.12., in this case straight and longer than the other bar, with round clamps in their sides. These clamps are subjected to the wheelchair due to some screws and nuts joined to them. It is pretty similar to the points 11.1. and 1.1.2. but the two clamps of the wheelchair will go fixed together.

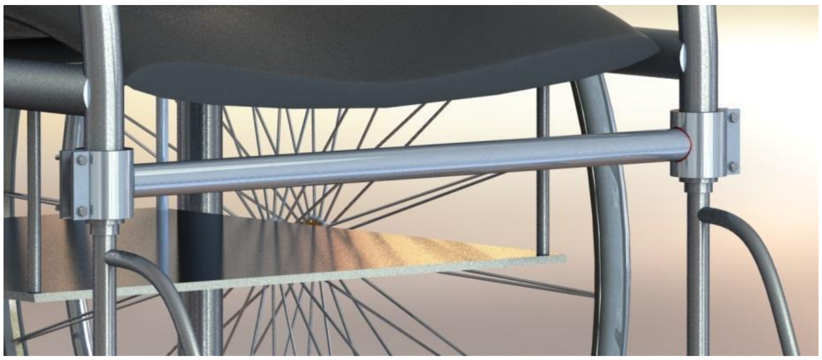


Figure 1.12. Bar for the wheelchair attachment.

The bars will be contained inside this strengthen box which will attach them and protect them from the mechanical stresses. The box will be assembled over the bars and joined by screws and nuts placed in its corners. The larger bar will be fixed to the whole by a screw passing through it thanks to a hole make it for that purpose.

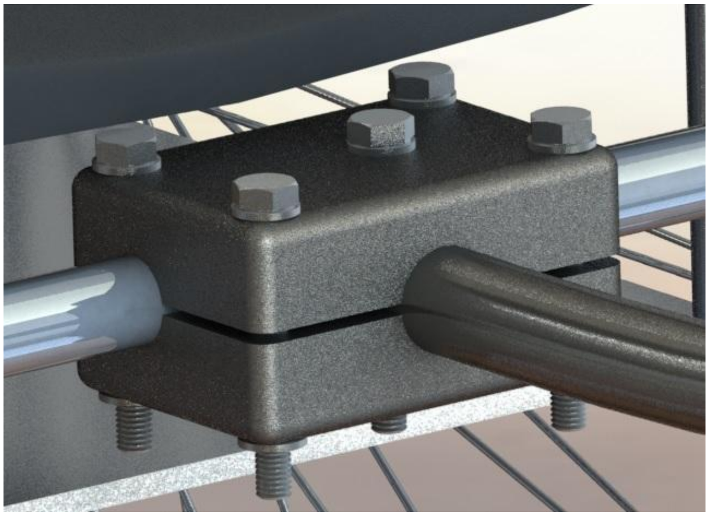


Figure 1.13. Bars attachment.

The material for the attachments will be aluminum as in all the cases before because we are looking for minimize the weight of the mechanisms, taking into account that must be a material which can hold the stresses, and at the same time we want it resistant against the weather.

1.2.2. SEATPOST - WHEELS ATTACHMENT

1.2.2.1. FIRST APPROXIMATION

At figures 1.14. and 1.15. it is showed the design of this topic. In this case the attachment between the two parts is made from the wheelchair's back shaft and the seat of the bike. The union is pretty similar with the point above except that the linking bar is divided in two parts to attach the two sides of the wheels' shaft. As we have been talking about, this design and all above mentioned are pretty innovative because the wheelchair is directly adapted to the bike instead of having a special bicycle or whole mechanism for it purpose.

A considerably disadvantage is the size of the mechanism; if the customer wanted to move the device he would probably have some problems when bringing it somewhere.

Figure 1.14. Seatpost - Wheels attachment.

Figure 1.15. Rear view.

1.2.2.2. FURTHER RESEARCH

The following design is based in the one above but in this case the union is made on the wheelchair's rear wheel. That means that the long bar is divided in three parts, one joined to the seatpost and the other two joined to the wheel's shaft.

The main bar has a horizontal protrude cylinder where the other two bars are fixed by screws and nuts, this prevent that the structure can move, figure 1.16. So the whole can be adjusted thanks to the round clamp of the bike's seatpost. As in the model 1.1.2. the union at the wheelchair is pretty difficult to get due to the shafts of the wheelchair, so once more it is not a very good design to choice.

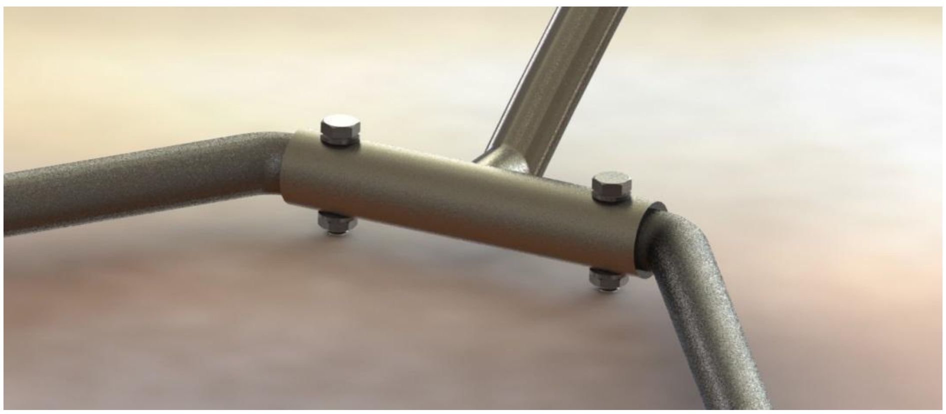


Figure 1.16. Bars attachment.

The design is formed by 4 different parts and some of the very long so it presents a serious problem for its storage. The fact that the bars are long also means big mechanical efforts on them (bending, buckling) as well.
The chosen material as in the other cases is aluminum as well because we are going to have parts pretty big so we need them as light as possible and proportionality strong enough.

1.3. TRAILERS CONNECTIONS

1.3.1. TRAILER ATTACHED TO THE BICYCLE'S REAR WHEEL.

1.3.1.1. FIRST APPROXIMATION

Following the line of this group of solutions and sub-solutions, this kind of load attachment has been thoroughly developed along the past years due to its simplicity and reliable outcomes.

This option's scope includes a huge amount of different combinations between bicycles and wheelchairs. It is, its adaptability grade is one the greatest in the available market nowadays. The attachment is easy, it is just necessary to add a small piece on the rear wheel axle and to that it is possible to assemble and disassemble the complete trailer structure easily. The connection between the trailer and the wheel is through a bar, connected with a pin to the trailer and with this foldable part at the other edge which is added to the small piece previously mentioned also through pin connection. In order to assure the security, it also counts with an extra strip to roll around the bicycle frame in case of failure. A general view of the design it is shown in figures 1.17. and 1.18.

Not only that, it has the great advantage that the steering geometry of the bicycle remains intact after the attachment is made. The bicycle user needs to be aware of the fact that the size of his/her mean of transport is considerably larger, as well as the final assembly weight, factors that can be made up for the ease for that user feels in everyday using.

In spite of having a considerable amount of advantages, this subsolution has also a negative side. For example talking about social aptitudes, it can be said that this solution cannot fulfil the requirements at all. The wheelchair user is just sitting on the trailer and watching his partner's back. It is not easy for them to establish a fluid communication. Moreover, as another inconvenient the large amount of different pieces that involve this solution results a large-scale final device in which the wheelchair it is supposed to be attached. This involve an increment on the price due to difficulties when transporting, larger amount of materials used and more items at the time of maintenance.

To satisfy the security required, it is important to take in mind that it is necessary to ensure that both attachments (trailer-bicycle and trailer-wheelchair) are safe enough.

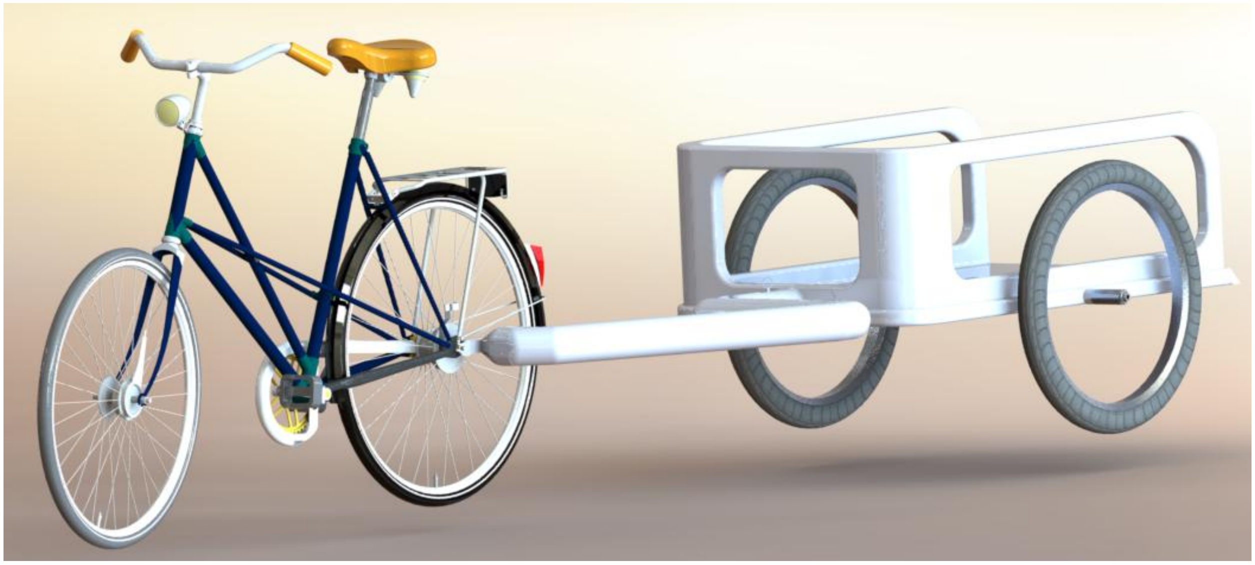


Figure. 1.17. Trailer attached to the rear wheel.

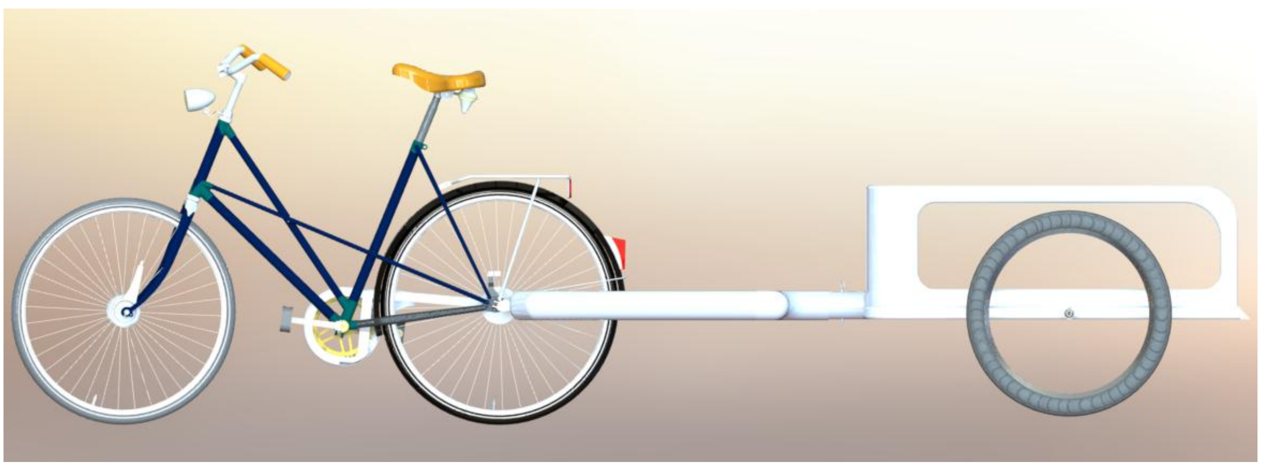


Figure 1.18. Lateral view.

1.3.1.2. FURTHER RESEARCH

ATTACHMENT

In this second trailer design the connection bicycle-trailer takes place on the rear wheel's axle. This one has almost the same behaviour as the one attached to the seatpost but it has a lower final size and easier to storage.

The connection is made thanks to a piece that will be attached on the rear wheel's thru axle, it is the center part of the rear wheel. Nowadays, most of the bicycle that are found in the market are equipped with a quick release that makes easier the installation and removal of the wheel. Anyway, in order to involve also older bicycles, the initial piece of the connection will be attach on the screw that stands out a little bit from the hub.

Common axles are 8, 9, 9.5 or 10 mm in diameter, so it is mandatory for the connection piece that be compatible with all dimensions. Nevertheless, nowadays it is also possible to find axles of 14, 15, 17 and 20 mm, specially on BMX and modern mountain bikes. Due to that, it is mandatory to take both measurements into account and design two different pieces according to the dimensions demanded. Attached to that piece, it is the bar that also connects with the trailer - it connects in the same way as the the connection in Seatpost attachment between the trailer and the bar, (see more information in chapter 1.2.1.2.). Here in figure 1.19. it is showed the piece and its connection.

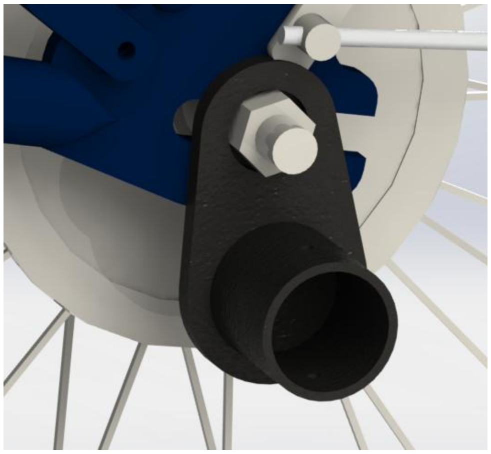


Figure 1.19. Attachment piece on rear wheel's axle.

Then, attached to it through a pin and a security string it is the bar. The final part of the bar (the one that makes the curve) is completely flexible, red part that is made in plastic. This fact makes possible for the trailer to get a better position regarding the bicycle, not to be completely rigid facilitates the attachment method.

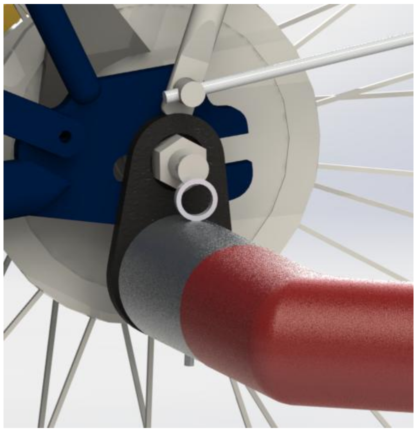


Figure 20. Bar attached to the rear wheel.

The other parts of the bar, it is the pin and the bar itself, are made in aluminium. A good quality material regarding resistance, weight and life expectation can fulfil the basic requirements that this mean of transport can show from the beginning. Also, it is not a really expensive material, and thanks to its natural protective layer, it will resist perfectly outside conditions. The complete bar assembly is shown in the figure 1.21. below.

Figure 1.21. Upper view from the attachment.

TRAILER

The trailer has the same dimensions and characteristics as the one used on design 1.3.2. explained below: Trailer attached to the bicycle's seatpost.

The connection between the bar and the trailer is also made through a pin that get through both shaft and hub.. For more security the both also count with a string that join the two parts, even though it is not appreciable on the figure bla bla bla.

There is one important issue that has to be taken into account. The trailer connection must be completely in the center and the trailer must be located with its longitudinal symmetry plan in line with the bicycle's main line. That is because in that way a symmetrical force distribution is reached, the trailer does not tends to apart to one side and it is easier for rider to control the whole assembly, especially in case like this one that a considerably large load is being carrying. Due to that, the aluminium bar has this particular shape.

CONCLUSION

The final assembly has similar aspect to the previous one, as it can be appreciate on figure 1.22.

Figure 1.22. Final assembly.

The behaviour is similar to the seatpost attachment, regarding adaptability, security, foldability, etc. but it has a clear advantage. When you attach the trailer to the back part of the frame (rear wheel's axle), the leaning of the bicycle does not steer the trailer as much as it could happen with the seatpost hitch. In this design, the attachment point is moved to a lower height which provides a little more stability. For example, the possible effect in seatpost connection of losing the contact point with the ground for the front wheel will not happen in this one. On the other side, there are some disadvantages. Due to the fact that is a rigid bar only located in one of the bicycle sides it can limit the turning tight.

The connection is easier in this trailer, just that small piece that can remain with the bicycle causing no problems when normal using of it. Apart from that, the size is not as big with the same versatility and adaptation capacity. The number of required pieces is greatly reduced, which can also derive in less maintenance in a first look.

Regarding more abstract characteristics, it is not an innovative product to the customer and it is not the most attractive one taking the social aptitudes as a main point. On the other hand, it suppose an easy way to attach a trailer to the bicycle and quite easy to drive, since the bicycle remains as usual.

1.3.2. TRAILER ATTACHED TO THE BICYCLE'S SEATPOST.

1.3.2.1. FIRST APPROXIMATION

This type of trailer attachment has been not as deeply developed as the wheel's attachment. In a first look it is possible to have an impression of its huge size, which provokes a really complicated transportation and storing, which are ones of the major disadvantages, (for a first idea it is possible to take a look to figure 1.23.). Nevertheless, if it is also possible to work with a foldable device, some transportation final characteristics will be considerably improved.

On the other hand, this attachment is quite comfortably to get ready. It provides enough stability for the trailer and also a good mobility - because of its free degree of freedom that allows it to turn around a vertical axis; and it is only necessary to add a piece around the seat's shaft and the rest of the trailer is added through it using a typical screw connection, consequently the adaptability is one of the good points of this sub-solution.

The versatility is huge but it is also mandatory to be aware of the adverse conditions that it carries: a lot of different materials and several items which are involved; a big size; a considerable increment of the final weight, although it is really easy to steer as there is no modifications on the wheel frame and it finally works as a normal bicycle; or the price rise in comparison with other designs, now that the production and logistics will take more time and concern.

As a final conclusion, in a first view for a plausible buyer it seems like a large device in which you can carry a wheelchair user in your back with barely communication between each other and with some difficulties to storage when not using. In contrast, it is also attractive for the amount of wheelchairs that is possible to be adapted.

Figure 1.23. General view of the attachment.

1.3.2.2. FURTHER RESEARCH

ATTACHMENT

The main point in order to get a conclusion about a design is available or not is to find a viable attachment that could reach the main goal: an adaptation between wheelchairs and bicycles ready to use.

In this case, the attachment is thought to be made between the seatpost and a specific trailer. Depending on the different material used in the frame, different seatpost diameters are required in order to optimize the ride quality and the strength of the tubes.
According a statistical study on a 276 different seatpost diameters according to different brands, they can vary from 21,15 to 32 centimeters, with an average of 27,18cm and a mode of 27,2cm.

This aspects affects directly the attachment design, it has to be adjustable in order to cover all possible diameters. It is optimal to use an adjustable round clamp that is possible to be firmly closed with a couple of screws, since the difference between the maximum and the minimum is not as significant in order to look for different devices.
For an easy turning behaviour, it is mandatory to have freedom to move around Z-axis - the axis which perpendicular to the floor. The connection has a degree of freedom on Z-axis thanks to three different little devices that complete the assembly. The design can be seen in figures 1.24. and 1.25.

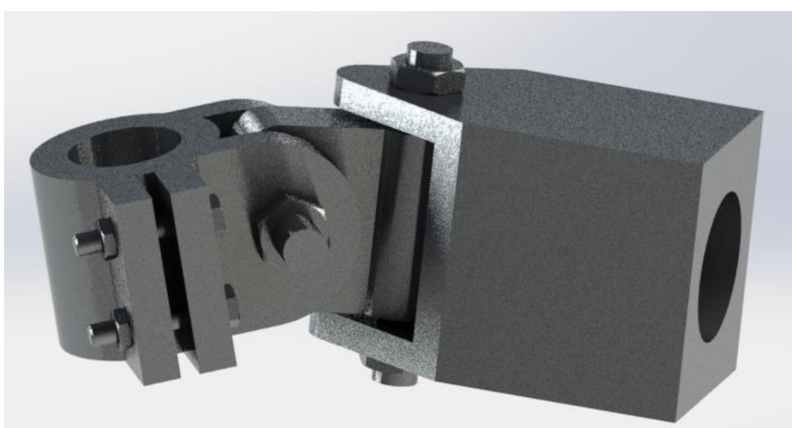


Figure 1.24. Seatpost attachment.

Figure 1.25. Attachment in an explosion view.

As it can be seen this assembly provides a two-rotational movement (around axis Y and Z) between the bar and the seatpost, in order to make easier the complete movement of the device.

A good material choice for the bar is aluminium. Due to its low density is it viable for such a device that is moving thanks to physical effort, also it has good tensile, compression and flexural strengths enough to stand the efforts that can appear when using the device. Not only that, it is a considerably cheap material that is also really easy to mechanize.

TRAILER

The trailer itself has to be a light and resistant device. It has to be large enough to carry the wheelchair in an appropriate way, so its maximum dimensions reach 825 x 1100mm. It basically consists in a plastic flat base with four attachments for the lateral bars. This kind of attachment allows the whole structure to be foldable which makes easier the storage of the trailer. Here, in figures 1.26. and 1.27. are shown the connection and the whole trailer final appearance.

Figure 1.26. The bar and the trailer are joint through screw and nut assembly.

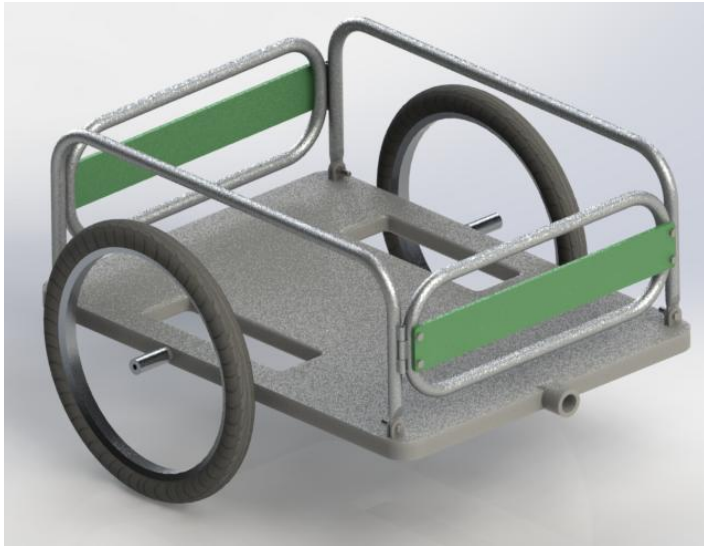


Figure 1.27. Trailer view.

The base is made in Polyvinylchloride, PVC, a hard and rigid plastic (in its rigid form because it can be also found in a flexible form) with high mechanical properties that increase with the molecular weight and decrease with the temperature. The rigid form is also known as having strong resistance against chemicals, sunlight, and oxidation from water, which makes it an excellent choice for such a device.

The lateral bars and the doors, are made in aluminium, which thanks to its natural protective layer can resists perfectly the outside conditions. Also, it is a light material which does not add extra weight to the final device and for the bicycle user.

The main advantage in this design is the storage, it can be easily folded turning into a considerable small piece - comparing with the expanded trailer. In the figure 1.28., it is shown the possible fold position.

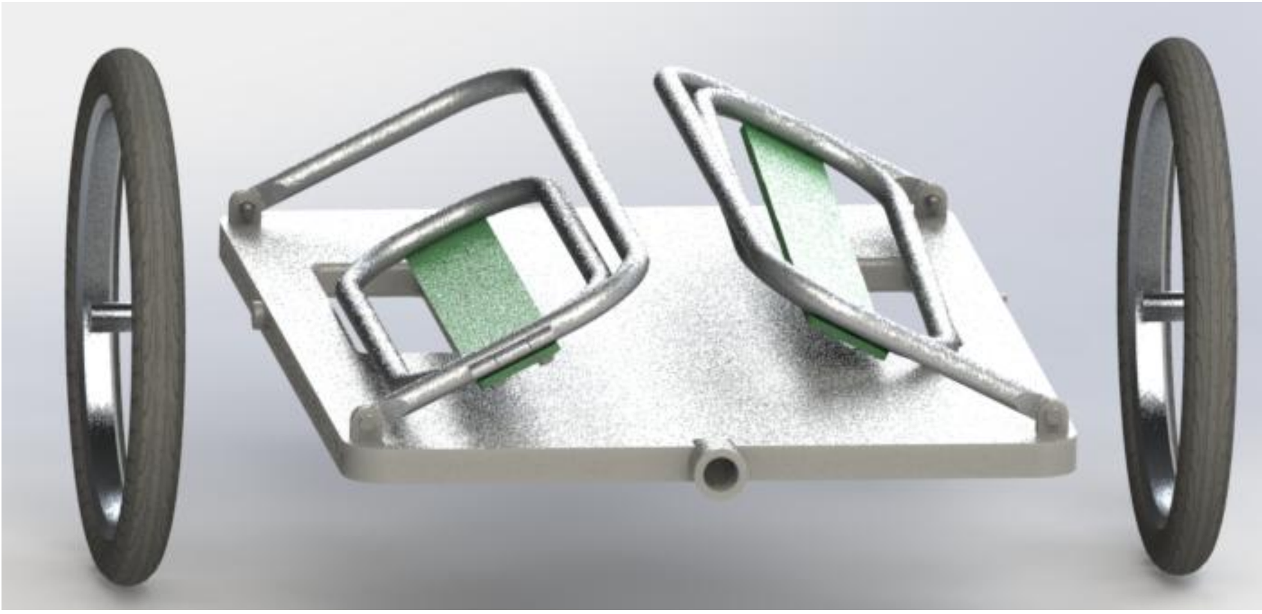


Figure 1.28. Fold trailer.

According to the Danish Bicycle legislation approved on the 31st of January, 2012, both rear wheels in the trailer turn according the same drive axle, that also counts with a specially brake system that will keep the device steady when it is stopped.

The connection between the bar and the seatpost is made basically through a pin that get through both shaft and hub, same connection as bar - trailer itself. For more security the both also count with a string that join the two parts.

Regarding the wheelchair, there are also two holes in the base that are made, indeed, to the correct placement of the wheelchair that is also fasten by seat belts to it. And finally, to make easier also the wheelchair’s mounting it has ramp at the bottom.

CONCLUSION

As a final result of the whole assembly it can be seen the figure 1.29. showed below.

Figure 1.29. Final view from the assembly.

Besides the technical characteristics, this idea also can be clearly measured according the basic criteria mentioned in chapter 7.

It is really common seeing this kind of trailer in everyday life riding in the streets. That is because its good functionality. The bicycle remains the same steering geometry and brake system with the unique difference that it is carrying a load behind it. It is really easy for the bicycle user to control the whole assembly and allow him to drive it as an usual bicycle. Nevertheless, it also has some disadvantages. When the bicycle leans back or forwards, the trailer can feel steered to right and left due to roll-steer interaction. However, when riding, the whole assembly remains is pretty stable, the pull of the trailer will be trying to stand the bike back upright but for example in braking situation, the trailer will try to push the bicycle over. This effect maybe will not be noticed with a light load but, with the expected weight in this trailer the bicycle user will require some effort to be undercontrolled. Not only that, regarding acceleration and hard climbing, all the trailer load will subject a put backwards force on the seatpost. The riders must take this fact into account and control it, if not some wheelies and a front wheel not touching the ground can be possible consequences. On the contrary, it can also suppose a problem when braking. When stopping all the load will try to keep going forwards due to the inertia it has, which can make the bicycle skip a little.

Furthermore, the final assembly is considerably big and also not as lighter as desired. The attachment method is not really difficult to connect and being foldable make it easier for storage and transportation. The stability is good and any kind of wheelchair can be perfectly attach to the trailer with a good safety grade.

To sum up, this design can be chosen as a good option taking into account the good functioning and behavior that the buyer can expect. However, the human factor and sociability that are expected to this kind of mean of transport are really low in here, and because that a less attractive design.

2. FRONT LOCATION

2.1. WHEELCHAIR AS FRONT WHEEL (I)

2.1.1. FIRST APPROXIMATION

The following designs are probably the simplest ones of the whole design list and their principal scope is to improve the social aptitudes that the device can offer to the customers and doing them as simple as possible at the same time. The main point of this design is to replace the front wheel of the bike to attach it directly to the wheelchair as it can be seen in the figure 2.1.

The union is made through a bar placed at the down back part of the wheelchair which has to clamps on its sides (to fix it with the wheelchair) and it is placed where the shaft of the front wheel would be. This attachment is really simple and makes the whole quite small and very stable. Moreover the mechanism is only formed by one par so it is supposed to be a very simple building device and portable. Also this design is planned to get closer the driver and the passenger so it is perfect for the interaction of both.

In the other hand we have the disadvantages of the model. The distribution of forces in this design causes big bending efforts when turning on the fork as the distance between the two arms is small and when the whole is stopped it is required to do a bigger force to move it.

Figure 2.1. General view of the attachment.

2.1.2. FURTHER RESEARCH

The scope of these models is to improve the social skills of the mechanism, being the passenger in front of the driver will increase the interaction between them. In this first model we have substitute the front wheel for a bar which will join the wheelchair and the bike.

As it can be seen at the figure 2.2, the union is made through a bar which has round clamps in its sides and is attached to the bike in the fork, where the shaft would be assembled.

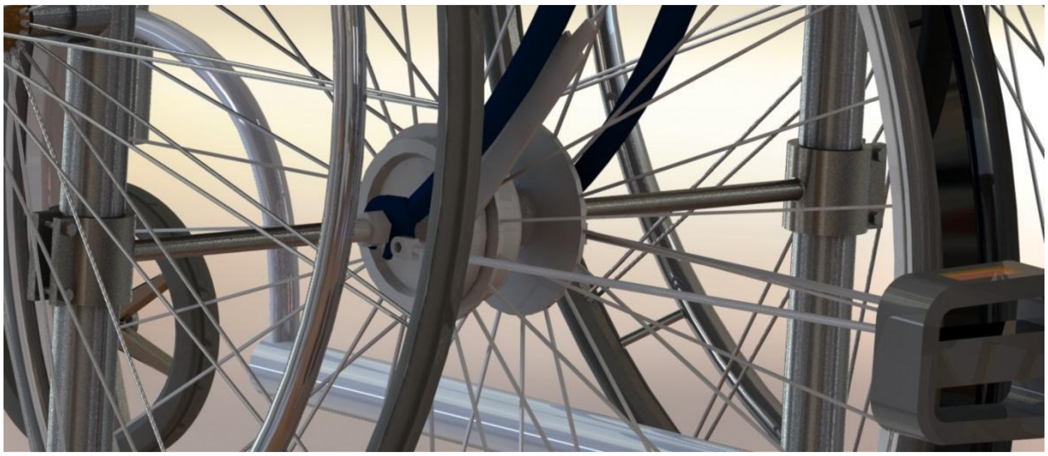


Figure 2,2, Wheelchair attachment point.

This union provides to the bike a lot of stability due to it is subjected directly to the wheelchair and also the whole gives to the users a huge degree of interaction. Another point to take into account in the advantages is that this design only needs one part so it will be very easy to storage and transport. On the other hand there will be some problems, for example the fork would be subjected a big torque efforts as the distance between the two arms is small so to turn the wheelchair when load will be difficult since the driver would have to do a lot of force.

This bar will be subjected to higher efforts than in the rest of the designs so the material chosen for it will be steel. As it is known steel is heavier than aluminum (approx. three times more) but it will not be any problem due to the mechanism will be only formed by one part.

2.2. WHEELCHAIR AS FRONT WHEEL (II)

2.2.1. FIRST APPROXIMATION

The next model has some similarities with the one above and shares the same goals but in this case the attachment is done from the steering of the bike to the upper back part of the wheelchair through two bars settled at the sides of the steering, figures 2.3.

In this design the front wheel's bike is also removed but now the bike is held by the bars attached to the wheelchair so the whole keeps the same stability than in the model above. Compared with the case before the distribution of forces are much better because we reduce the bending effects on the bars, and the fact that the bars are considerably distanced will make easier to move the wheelchair when stopped and when moving.

Figure 2.3. Front view of the assembly.

2.3. WHEELCHAIR AT FRONT WITH THE WHOLE BICYCLE

2.3.1. FIRST APPROXIMATION

The last model for the front location designs is the one shown in the figures 2.4. and 2.5. In this one the attachment is made exactly equal than in the case before but without removing the front wheel of the bike so the bars will be longer in this mechanism. As we have said what is tried to reach in these models is a big capacity of interaction for the costumers that is why we are trying to place the wheelchair at the front side.

The union is made as the case above, two bars with clamps at its sides fixed at the steering's bike and to the wheelchair. The advantage of this model over of the point 2.3 is that is not necessary to remove the front wheel of the bike doing is assembly easier. But the fact of doing the bars longer results in bigger bending and buckling efforts on them so mechanically the other design would be better.

Figure 2.4. General view.

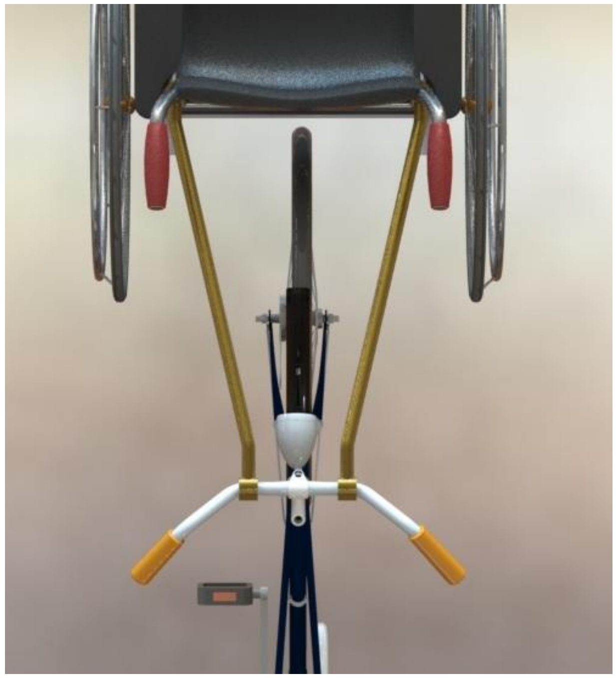


Figure 2.5. Upper view from the attachment.

2.4. TRAILER AS FRONT WHEEL

2.4.1. WHOLE BICYCLE

2.4.1.1. FIRST APPROXIMATION

The main aim of this sub-solution is to get a significant adaptability at the same time the wheelchair will be located on the front part of the bicycle in order to improve it social aptitudes, both communication and comfort for the disabled person. It can be appreciate on figures 2.6. and 2.7.

Taking into account the fact that mounting a wheelchair in a device that includes also its own wheels is not the optimal option, it improves the “cycling” experience for the passenger. Regarding adaptability, it also can be considered as a good-graded one. As it is a trailer any kind of wheelchair can be attached to it, being always aware of the special necessities of every user and the security measures required. Anyway, the whole assembly will not reach really high velocities so it will be easier to keep safe with some ropes to attach the whole structure. Nevertheless, the attachment continues to be more complex regarding trailer-bicycle connection.

As it was said, the assembly is quite more complicated than others. It is necessary to fix an appreciable large device in the front on the bicycle and, at the same time, ensure that the steering geometry remains functional. As it is known, the steering of a ride bicycle is not the same as the one from a steady bicycle, and this have to be taken into account as the time of adding several pieces where the bicycle steering geometry it is located.

The stability will increase but as consequence of adding two extra wheels, which means more materials purchasing and longer production and consequently a price increment, also promoted by transportation of logistics that these large devices causes.

This design would improve social aspects for both users which is the base of innovation in this idea. However, not everything can be based on that. This idea also has quite different disadvantages, which the main one resides in simplicity. This attachment it is not easy to make and neither is transport and storage, reasons which can make the buyer think about buying it or not.

Figure 2.6. Front view.

Figure 2.7. Lateral view. Need to make clear lower attachment (Further Investigations).

2.4.1.2. FURTHER RESEARCH

ATTACHMENT

The main goal of this ideas, it is the trailer located on the front part of the bicycle, is to improve the social characteristics of this assembly. It is thought to be used to carry a disabled people and in most of the cases it will be an enjoyable ride for two people that know each other and if its better if they can communicate in an easy way. The stability reached when putting the trailer in front is, indeed, sensible good thanks to its three contact points to the ground.

In this case the device steering requires a little more of consideration. Now, it is a normal bicycle with its usual steering geometry to which it is attached a trailer to the front part. If the handle turns right, the trailer will be forced to move to the right side, but if there is no kind of transmission between that turn and the trailer axle turn, the wheels will not start to turn at the same time. It is completely mandatory to install some kind of steering method in order to be able to drive this assembly in an appropriate way.

Regarding the fact that it is the bicycle's steering geometry the one that controls the movement, it has to remains intact - fact that was thought as one advantage of the design in the first place. With the front wheel spinning around the front axle, it is impossible to find a viable and easy way to install a transmission mechanism from the handle's turn to the trailer's axle one. Because of that, it is thought that the bicycle's front wheel has to be remove in order to reach a achievable whole. This front wheel removal determines an empty fill in order to build the transmission. Once the wheel is removed, it is also mandatory to think about how the empty fork will remain and how it should be attached to the trailer, as well as the handle.
In this mechanism, the movement has to be transmitted to the front wheels that will act as steered wheels. Because of that, it is really important to notice how it is the most appropriate way to build it according to the Ackermann condition (ANEXUS) for a correct steering behavior. Not only that, it has to be considered the fact that the steering from a normal bicycle is not the same as the one of a tricycle, it does not just steer thanks to leaning the bicycle.

The turn that is made by the bicycle's handle has to be transmitted to the front wheels for a correct behaviour.

There is a double point attachment. On one side, the higher back part of the trailer is attached with clamps to the bicycle's handle and, on the other side, the empty fork is attached on the lower part.

This clamp bars, figure 2.8., are made in aluminium and they just simply consist in a clamp welded to a metallic bar which ends in a 10mm-radius threaded point. The bar is attached to both, trailer and bicycle, through a common screw-nut joint, that is pretty easy to install and remove and it also offers a really good resistance. The point of attachment with the handle bar is shown on the figure 2.9.

Figure 2.8. Bar designed for the attachment

Figure 2.9. Clamps attached to the handlebar.

The attachment with the fork is more complicated. The final part of the fork will transmit the turns to the wheels. It is attached to a bar in which are also connected two cables. Since the bicycle fork is not completely perpendicular to the ground, the steering has to be done through cables. When the device is turning right, through this cables it will be transmitted to the front wheels' axle and it will move appropriately - it will be deeper developed if this design is chosen as the optimum one.

TRAILER

The trailer is set in a frontal position and due to that it has different characteristics from others ones.

First of all, the back gets higher than in other designs. That is because there is an attachment between the handle and the back and the closer the better. If longer bars are installed, a larger amount of stresses and forces can appear over when them when riding and its failure would be easier to reach. Also, when more different curves, turns, etc. the amount of stresses in that certain zones considerably increase, making that zones weaker.

The back part present a number of apertures with the same size really close to each other, as it can be seen on the figure 2.10. This step is made in order to increase the adaptability. It is, the bar are completely rigid, but not all handlebars has the same height and characteristics and with this little step it is possible to choose the most efficient height and width for everyone.

Figure 2.10. Back view of the adjustable plate.

The rest of the structure is similar to the trailers mentioned in previous aparts. The flat part are made in rigid PVC and the bars in aluminium. Thanks to that the trailer is not as heavy as it could be and easier for the rider to use it. It also counts with a little ramp, also made in PVC, that can be used as both ramp and door. It makes easier for the wheelchair to reach the adequate position in the trailer. As a final view of the trailer it can be seen figure 2.11.

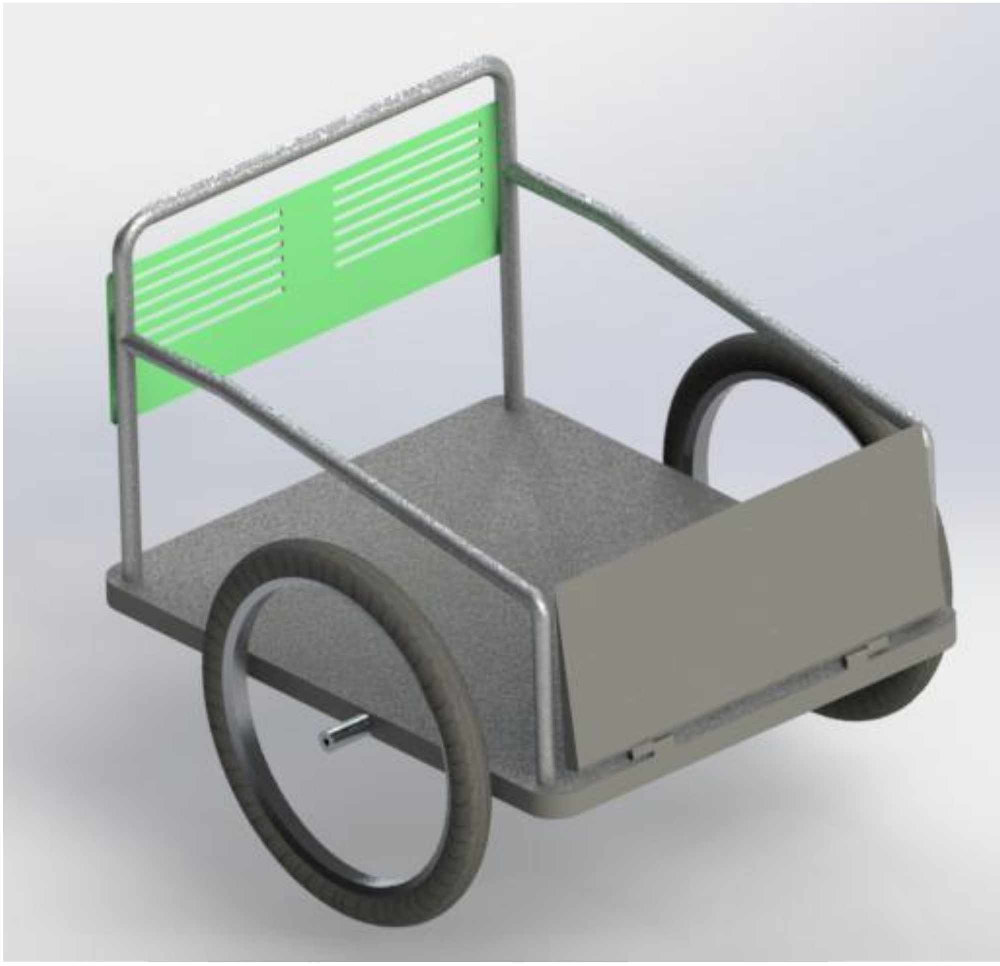


Figure 2.11. Final view of the front trailer.

CONCLUSION

Locating the trailer in the front part, instead of in the back as it commonly see, brings both advantages and disadvantages. The final appearance is shown in figure 2.12.

Figure 2.12. Final assembly.

On one side, thanks to its adaptable clamps and back it almost viable for every kind of bicycle. Everyone but electric ones, which have the electric motor connected with the front axle. Nevertheless, when attached it provides good stability and comfort riding. The riding experience is more enjoyable to the wheelchair's user now that he/she is in the front and he/she also can communicate better with the bicycle driver.

On the other side, one considerable disadvantage is the fact that this kind of devices are really “bad climbers”. The bicycle user has to do a great effort when starting the uphill and it is also really hard to keep going on with all the load located in front of you. Because of that, this design is appropriate for flat zones. Not only that, the attachment is easy to fix, but still is quite annoying to remove the front wheel in order to be able to ride.

The whole assembly reaches as maximum dimensions of 2,60 m length and 0,985 m width, following the Danish Legislation for bicycles, being just the trailer 1 x 0.82 m. It also count with three different brakes: one for the front axle; one for the rear wheel, which remains for the normal bicycle construction; and one that only keep the trailer steady when stopped. It is made of relatively cheap and light materials, easy to mechanize and with good lifetime expectation.

2.3.2. DIVIDED BICYCLE

2.3.2.1. FIRST APPROXIMATION

This design reaches the same goal as its group's partner, but a huge difference can be appreciate easily. In this case, the wheelchair would be located as the front on a trailer but, the bicycle is thought not to be a common bicycle at all. Take a look to figure 2.10.

This solution involves such a most extensive design process now that it is necessary to designs both parts, the trailer and the adaptable bicycle just for it. This can bring both advantages and disadvantages.

Firstly, the disadvantages. It is true that it can cover a huge amount of different wheelchairs but it cannot fulfil a normal bicycle adaptation. The constraint of having to design two different but related items leads to suppose a huge increment on the final prize, also including materials, production and transportation. This characteristic makes the device less attractive for possible buyers and affects to the final goal.

On the other hand, it can have also a positive side. Its versatility is not very large, but it can allow the designer to work specifically on a special attachment, specially prepared for this device which can provide a huge grade of safety and simplicity. In this case, it is thought to join them by a simple shaft-hub connection. In order to prevent an accident due to unexpected failure, it can be assurance with a pin across both shaft and hub and an extra band.

In order to improve the final design and improve its versatility, it is possible to design an extra device with which would it be also viable to use it as common bicycle. Now that the transmission is made with the rear wheel that is the one that rears the assembly, it would be only necessary to change the front part. With this, the versatility improves, but also the price a really certain amount of money, because also the steering geometry of the bicycle mode is different from the other one.

Figure 2.10. Basic view from the attachment with wheelchair.

2.3.2.2. FURTHER RESEARCH

In the first place, it requires the full design and develop of two different components: the trailer and the adaptable bicycle. It derives in an outsize price increment. Not only, it is absolutely impossible to use a normal user bicycle, the buyer also have to pay for a specially designed trailer in where the wheelchair it is attached.

The steering geometry does not require so much effort at others, in here it is not necessary to think about a special connection a correct functioning, it is just specifically designed for this certain device. In contrast, the size, transporting and storing diminish viability. Normal users will not be interested on buying such a complicated device if it is possible to acquire one to attach to his/her everyday bicycle.
One alternative to make it more attractive would be to build an adaptable front bicycle part which could be adaptable to the back already made - with another price increment.
Even though the social aptitudes and comfort get to really good grades, it is not viable to build such a design. The simplicity and adaptability are much more valuable characteristics.

3. BACK LOCATION

3.1. TRAILER TRICYCLE

3.1.1. FIRST APPROXIMATION

This design is quite similar to the front trailer, but located in the back part of the bicycle as a common tricycle. It also counts with two different items: the trailer itself and the bicycle part. See figure 3.1.

There are various transmission methods that can be found nowadays. Nevertheless, in common bicycles the transmission is made between the rear wheel and the crankset through a chain.

This sub-solution follows this scheme but, instead of one rear wheel there are two. Because of that, the movement is transmitted from the pedals and crankset to the back wheels' joint axle. This concept involves a huge reduction regarding adaptability. The fact that it is a trailer allows a lot of different wheelchairs to be attached, but the number of possible bicycles it is nule. You just cannot simply attach the back part of a bicycle easily to a trailer and even less be able to connect the chain as if a normal bicycle it was. Due to that, it was thought to design and build a special adaptable bicycle. Build a front part of the bicycle, being focused on a good transmission and stability.

This design involves a double chain connection that connects also a gear shift in order to make easier the riding comfort. One of the chains is surrounding the axle and connects with the gear shift and the second one connects the gear shift with the crankset. Ones of the main goals of designing such a device are simplicity and adaptability. Matters that are hardly reached according this device.

It gets stability and a good functionality carrying the load backward and permits the rider to comfortably steer thanks to its reduced size and to its not really extra weight added comparing to a normal tricycle. Anyway, the insignificant adaptability causes a mandatory bought of an specific device, putting completely away the possibility of using your own bicycle to carry out the same task.

As a matter of fact, also the production and materials makes a negative impact in this design. The prize is increased due to the specific construction required and followed by the different amount of materials that could be required in order to build the whole "bicycle"-trailer assembly.

Figure 3.1. Trailer as tricycle.

3.1.2. FURTHER RESEARCH

In contrast with its predecessor, the “tricycle”, this design does not involve a wheelchair. Instead of that, it is thought to build a special trailer and attach it as it was a normal tricycle but, not a trailer in where the wheelchair is attached, it is a trailer that consists in a some kind of chair for the disabled people in order to reduce the final size of the assembly. This measure had introduce because it was thought that the removal and installation of the rear wheel is quite annoying and in some cases even complicate.

The attachment is made through a front part of a bicycle frame and the specific trailer, which involves also a connection for the chain in order to transmit the movement of the crankset. Although, as the two previous ones, it is not one of the best choices when price and versatility enter in the field of consideration.

This trailer simply consists in a seat with two wheels. In order to be adaptable for every kind of users, it has a large back and armrest in both sides, all including also the security measures for the user to be safe. It is attached to the partial bicycle through a serie of bars by simply pin connection secured with strings in case of failure. With this mechanism, it is easy to comfort the trailer’s user and then attach it to the bicycle.

It could be decided to be developed in other fields, but not in this one that the major versatility and social aptitude are fixed as main goals.

3.2. THE “TRICYCLE”

3.2.1. FIRST APPROXIMATION

This design it is based in the same idea as the trailer tricycle. It has only one main difference: the trailer is now the wheelchair itself, it can be seen in figure 3.2.

In a first thought it can suppose a considerable decrease in the price. If you put the wheelchair instead of a whole trailer specifically designed for this task you will earn a lot of money on materials, for example. However, it is not that simple to build an adequate attachment between the front part of the bicycle and a common wheelchair.

The movement transmission is not as simple as it was installing a trailer, where you can connect the chain with a common axle to both rear wheels. With this design the transmission is a little bit more complicated. The first idea it is to attach both device, but the certain method will be studied and evaluated further in advance. The rest of characteristics are really similar to the previous design mentioned above.

As the design 3.2. the idea is to build a half bicycle to be adaptable to a wheelchair, which also involves the problem that the versatility is considerably low and not attractive to a common buyer. It is a pretty stable device, with a not very large size and easy to steer for the bicycle user. Although, the difficulty that goes with the kind of attachment could reduce the positive size of this kind of attachment.

Figure 3.2. Wheelchair as “tricycle” location.

3.2.2. FURTHER RESEARCH

This idea has the aim to put a normal wheelchair as a bicycle's rear wheel. In here resides a complicated issue. How to make the transmission from the crankset to the wheelchair's rear wheels.

There is two options then, making a front wheel transmission just leaving the wheelchair behind or build some kind of mechanism to transfer the crankset turning to the wheelchair's rear wheels. This second one it is really hard to be reached. In most of common wheelchairs each wheel turns independently from the other one. Even keeping one steady and turn the other is made to turn the whole chair to one direction or the other. Taking that into account, that option gets absolutely dismissed.

Regarding the first one, from a general point of view is not either consider as a perfect option for such a device that is expected to reach. It is possible to build a front transmission, just putting the chain inverse as it is normally set but, at the same time it is found the same problem as it was talked in 2.4.2. (Divided bicycle for Front Trailer Location). It suppose to build a specific connection for a specific design instead of trying to look for simpler and universal options.

A common customer will not look for a device that it is not easy to storage and it is designed specifically for riding with the wheelchair attached, or a specially back designed bicycle part. Even though, it is an appropriate device, referred to functionality and handling, it is not as appropriate talking about simplicity, adaptability and versatility. According to that and the difficulty added with the movement transmission, it is because it is decided not to deeper developed this idea.

4. SIDECAR

This following two designs are completely different from the ones before. Instead of locating the wheelchair/trailer in the front part or in the back part, the aim of this devices is to put the wheelchair/trailer on one side of the bicycle in order to improve the social aptitudes and make more comfortable for both user the bicycle riding experience.

4.1. WHEELCHAIR AS SIDECAR

4.1.1. FIRST APPROXIMATION

In order to reach that goal mentioned above, it has been thought about this typical motorcycle sidecars but adapted to a common bicycle. In this case, concretely the wheelchair is acting as the actual sidecar, see figure 4.1. A common wheelchair is not prepared for such quick rides so the wheel's properties have to be meticulously measured and checked in order to know if the process is viable or not.

Regarding the assembly, the wheelchair is attached to the frame through a couple of metallic bars. One of them is attached to the lowest part of the chair and the other one is fixed above next to the wheelchair's handle through adjustable clamps. This bars are completely rigid and fixed in order to secure the wheelchair's attachment. As the sidecar is located on the side instead of backwards or forwards, it has a considerable influence on final device's centre of gravity location and the weight is not symmetrically distributed as in common bicycles.

Because of this reason while steering a little effect can be felt by the bicycle's user. When it starts moving it is the bicycle the one that makes the force. This initial force causes in the sidecar a traction force which pushes the sidecar backwards and to the right. It provokes a little displacement which has to be compensated with the handle turning into the left. This effect has to be compensated every moment by the driver.

Initially, it seems like a really good and innovative design taking into account the easy going social aspect and its stability. In contrast, it also have some cons that have to be noticed. As it was mentioned the unequal force distribution and its derivative effects. Also, the traction forces would affect differently both wheelchair's wheels and bicycle's wheels and it is necessary to prepare the first ones to higher velocities, different surfaces and mobility that normal common wheelchairs are not used to. Moreover, it exists another considerable disadvantage: the extra width that the sidecar adds. It can make the assembly to width to some paths.

Figure 4.1. Wheelchair attached as sidecar.

4.1.2. FURTHER RESEARCH

This first one installs a common wheelchair as the sidecar. The major issue that brings this design is how to make it viable for the greatest possible number of bicycles and wheelchairs. Because of that, the attachments are adaptable and removable.

Since the attachment is now located on one side, it is important to take into account the different forces that affects the device which is not now symmetrical at all. One of the main differences from the past devices can be notice while steering the bike. Specially when accelerating, the trailer/wheelchair will try to turn the whole assembly to the right (take into account that the trailer/wheelchair must be located in the right side according to the Danish Bicycle Legislation approved in January, 2012). This issue has to be managed by the bicycle driver, who has to able to compensate it with his/her own hands. Nevertheless, it will be further developed if necessary.

ATTACHMENT

This attachment is basically based on various rigid aluminum bars that join the bicycle frame to the wheelchair. These bars are attached to both items by adaptable clamps, made in aluminium to reduce the total weight of the assembly. This clamps are closed by normal hexagonal screw - nut joint. In order to be able to join a great number of devices, these bars can be extended to various fixed lengths, with a mechanism similar the one that is used in medical crutches.

It is mandatory to decide which are the optimal points for making the connections and how many they should be. Also, common wheelchairs normally can remove one of their wheels easily, a fact that could be advantageous for a smoother driving experience. The front little wheels are characterized by rolling kind of freely. This fact can suppose a great disadvantage due to friction and incorrect behaviour.

In a general point of view, this idea opens a new “field” of study. There is not very common to see a sidecar attached to a bicycle and even less see a wheelchair attached to a bicycle. Because of that and the good social grade that can be reached for both users it is considered a good idea to be developed. Moreover, it is easy to remove and install for a normal user, has a little number of pieces involved and provides really good stability for the whole assembly.

4.2. WHEELCHAIR SIDECAR

4.2.1. FIRST APPROXIMATION

This last sub-solutions follows the same pattern as the previous one, "Wheelchair as sidecar" but, instead of being the wheelchair the sidecar itself, there is a trailer acting as it. Check figure 4.2. on the next page for a first idea.

The connection is fixed in the sidecar, it is built with it, and the difficulty resides in the bicycle-bar connection. It has to be adaptable enough, that can be reached by adaptable clamps.

It is easier to find the appropriate wheels, materials and design. The rest of the characteristics are similar to the previous explained in "wheelchair as sidecar".

Figure 4.2. Especial trailer designed for being a sidecar.

4.2.2. FURTHER RESEARCH

ATTACHMENT

This “trailer” adaptation has almost the same advantages and disadvantages as the wheelchair placed as sidecar. The main difference lies on the fact that in here is mandatory to look for new materials, a new structure and an extra wheel to be able to make the assembly.

This trailer is not a common trailer just for attach the wheelchair. It is thought to be an specific trailer adapted for disable people, they will be directly seated on the trailer, instead being the wheelchair on the trailer. It can be considered a great disadvantage if you take the common wheelchair attached as an example. It supposes a considerably price increment due to the new item design and manufacturing, which involves production, materials and logistics. The attachment will be made in the same way as the one above, at the end they are just the same idea but one requires to be manufactured and the other one simply does not.

One advantage is although present in this design. Since it is an specific design, the trailer can be produced in a way that would be easier to make the attachment with more kind of bicycles. In here, it is only necessary to think in a versatile attachment to the bicycle - if the trailer is already produced with a developed attachment incorporated.

Considering that the simplest the better, it is thought that between this two last designs it much more worthy to developed an attachment between a common wheelchair and a bicycle, instead of designing a specific trailer for the same task.

CRITERIA	USE			FUNCTIONALITY					HANDLING			MAINTENANCE			PRICE			INNOVATION	SECURITY	ESTHETICS
Criterion	Practicality	Social aptitudes	Transportation	Size	Assembly	Adaptability	Nº pieces	Stability	Steering	Weight	Force Distribution	Standard maintenance	Expectation until 1st failure	Maintenance time	Production	Materials	Logistics			
WEIGHT	0,45	0,35	0,2	0,1	0,25	0,25	0,2	0,2	0,4	0,3	0,3	0,35	0,45	0,2	0,35	0,35	0,3	1	1	1
6.1. TRAILER																				
Wheelchair front-Bike seat	6	2	7	6	7	8	7	7	8	8	8	7	7	7	8	8	8	4	7	7
Wheelchairfront-bike wheels	6	2	7	6	7	8	7	7	7	8	8	7	7	7	8	8	8	4	7	7
Wheelchair wheels-bike seat	6	2	6	4	6	8	7,5	7	8	8	8	7	7	7	8	8	8	4	7	7
Wheelchair wheels-Bike wheels	6	2	7	5	6	8	7,5	7	7	8	8	7	7	7	8	8	8	4	7	7
Seat-trailer	4	2	2	3	6	8	5	7	8	5	7,5	6	6	6	5	6	5	2	7,5	6
Wheels-trailer	4	2	2	4	7	8	5	7	7	5	7,5	6	6	6	5	6	5	2	7,5	6
6.2. FRONT PART LOCATION																				
Wheelchair at front	6	5	7	5	6	7	8	7	5	6	7	7	6	8	8	8	8	7	6	6
Wheelchair as front wheel (I)	7	6	7	7	7	7	8	7	5	7	7	6	6	8	8	8	8	7	7	6
Wheelchair as front wheel (II)	6	6	7	7	6	7	8	7	5	7	7	7	6	8	8	8	8	7	7	6
Trailer as front wheel- 1 part	6	6	3	5	5	4	5	5	5	5	7	6	7	6	6	6	6	6	7	6
Trailer as front wheel- 2 parts	7	7	2	5	6	6	3	8	7	5	8	6	7	5	5	6	6	6	8	6
6.3. BACK PART LOCATION																				
"Tricycle"	6	7	6	8	0	5	5	8	8	7	7	5	5	6	3	6	8	7,5	4	7
Trailer "tricycle"	6	7	6	8	3	2	5	8	8	7	7	5	5	6	5	5	6	7,5	7	8
6.4. SIDECAR																				
Wheelchair as sidecar	9	9	9	8	8	9	9	8,5	7	8	6	8	8	8	9	8,5	8	9	9	7
Sidecar	7	9	6	8	7	6	6	8,5	7	7	6	6	7	7	7	7	6	9	9	8

CRITERIA	USE	FUNCTIONALITY	HANDLING	MAINTENANCE	PRICE	INNOVATION	SECURITY	ESTHETICS
WEIGHT	0,15	0,20	0,20	0,05	0,10	0,10	0,15	0,05
6.1. TRAILER								
Wheelchair front-Bike seat	4,8	7,45	8	7	8	4	7	7
Wheelchairfront-bike wheels	4,8	7,25	7,6	7	8	4	7	7
Wheelchair wheels-bike seat	4,6	7,475	8	7	8	4	7	7
Wheelchair wheels-Bike wheels	4,8	7,275	7,6	7	8	4	7	7
Seat-trailer	2,9	6,85	6,95	6	5,35	2	7,5	6
Wheels-trailer	2,9	6,75	6,55	6	5,35	2	7,5	6
6.2. FRONT PART LOCATION								
Wheelchair at front	5,85	6,75	5,9	6,75	8	7	6	6
Wheelchair as front wheel (I)	6,65	6,85	6,2	6,4	8	7	7	6
Wheelchair as front wheel (II)	6,2	6,95	6,2	6,75	8	7	7	6
Trailer as front wheel- 1 part	5,4	4,75	5,6	6,45	6	6	7	6
Trailer as front wheel- 2 parts	6	5,85	6,7	6,25	5,65	6	8	6
6.3. BACK PART LOCATION								
"Tricycle"	6,35	5,7	7,4	5,2	5,55	7,5	4	7
Trailer "tricycle"	6,35	5,25	7,4	5,2	5,3	7,5	7	8
6.4. SIDECAR								
Wheelchair as sidecar	9	8,4	7	8	8,525	9	9	7
Sidecar	7,5	6,8	6,7	6,65	6,7	9	9	8

CRITERIA	TOTAL	E.BIKEPLUS
6.1. TRAILER		
Wheelchair front-Bike seat	6,76	7,26
Wheelchairfront-bike wheels	6,64	7,14
Wheelchair wheels-bike seat	6,74	7,24
Wheelchair wheels-Bike wheels	6,65	7,15
Seat-trailer	5,66	6,16
Wheels-trailer	5,56	6,06
6.2. FRONT PART LOCATION		
Wheelchair at front	6,45	6,95
Wheelchair as front wheel (I)	6,78	6,78
Wheelchair as front wheel (II)	6,75	6,75
Trailer as front wheel- 1 part	5,75	5,75
Trailer as front wheel- 2 parts	6,39	6,39
6.3. BACK PART LOCATION		
"Tricycle"	6,09	6,09
Trailer "tricycle"	6,47	6,47
6.4. SIDECAR		
Wheelchair as sidecar	8,28	8,78
Sidecar	7,48	7,98

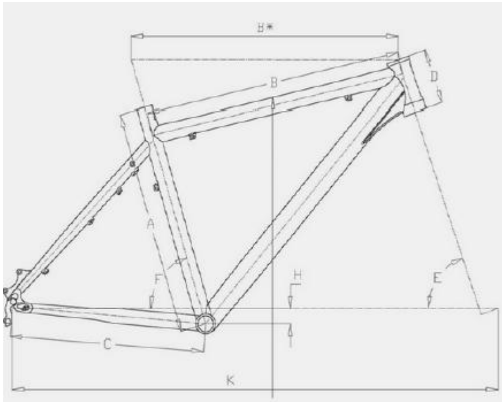
CRITERIA	USE			FUNCTIONALITY					HANDLING			MAINTENANCE			PRICE			INNOVATION	SECURITY	ESTHETICS
Criterion	Practicality	Social aptitudes	Transportation	Size	Assembly	Adaptability	Nº pieces	Stability	Steering	Weight	Force Distribution	Standard maintenance	Expectation until 1st failure	Maintenance time	Production	Materials	Logistics			
WEIGHT	0,45	0,35	0,2	0,1	0,25	0,25	0,2	0,2	0,4	0,3	0,3	0,35	0,45	0,2	0,35	0,35	0,3	1	1	1
6.1. TRAILER																				
Wheelchair front-Bike seat	6	3	4	6	6	8	6	7	7	7	7	6	5	6	7	7	8	4	6	7
Wheelchairfront-bike wheels	5	3	5	6	5	8	4	5	4	6	5	6	7	6	7	7	8	4	6	6
Wheelchair wheels-bike seat	4	3	4	5	4	8	2	7	6	5	6	6	5	6	5	7	8	4	6	7
Wheelchair wheels-Bike wheels	5	3	5	4	5	8	3	4	4	5	5	6	7	5	6	7	8	4	5	5
Seat-trailer	2	3	1	3	5	8	4	5	5	3	7	5	4	3	3	4	4	2	7,5	6
Wheels-trailer	2	3	1	4	6	8	4	5	5	3	7	5	4	3	3	4	4	2	7,5	6
6.2. FRONT PART LOCATION																				
Wheelchair at front	5	5	5	5	7	7	6	5	4	5	6	6	4	7	6	6	7	7	5	5
Wheelchair as front wheel (I)	7	6	7	6	7	6	7	7	4	6	4	7	4	7	7	7	7	7	4	7
Wheelchair as front wheel (II)	6	6	7	6	7	7	6	7	5	6	7	7	6	7	7	7	7	7	6	6
Trailer as front wheel- 1 part	3	6	2	4	4	4	5	6	5	2	7	4	7	3	4	4	3	6	8	6
Trailer as front wheel- 2 parts	5	7	1	4	5	6	3	7	7	3	8	4	7	3	3	4	4	6	8	8
6.3. BACK PART LOCATION																				
"Tricycle"	5	7	5	8	1	4	5	7	6	6	6	5	5	6	3	6	8	7	8	7
Trailer "tricycle"	6	6	6	7	4	1	5	6	5	4	5	5	5	6	5	5	6	5	8	6
6.4. SIDECAR																				
Wheelchair as sidecar	7,5	8	6	6	6	8	7	8	7	7	7	7	5	7	8	7	7	7	6,5	7
Sidecar	6	8	3	3	6	8	6	8	7	5	7	5	7	5	4	4	5	7	8	8

CRITERIA	USE	FUNCTIONALITY	HANDLING	MAINTENANCE	PRICE	INNOVATION	SECURITY	ESTHETICS
WEIGHT	0,15	0,20	0,20	0,05	0,10	0,10	0,15	0,05
6.1. TRAILER								
Wheelchair front-Bike seat	4,55	6,9	7	5,55	7,3	4	6	7
Wheelchairfront-bike wheels	4,3	5,3	4,9	6,45	7,3	4	6	6
Wheelchair wheels-bike seat	3,65	5,5	5,7	5,55	6,6	4	6	7
Wheelchair wheels-Bike wheels	4,3	4,85	4,6	6,25	6,95	4	5	5
Seat-trailer	2,15	5,5	5	4,15	3,65	2	7,5	6
Wheels-trailer	2,15	5,6	5	4,15	3,65	2	7,5	6
6.2. FRONT PART LOCATION								
Wheelchair at front	5	5,75	4,9	5,3	6,3	7	5	5
Wheelchair as front wheel (I)	6,65	6,15	4,6	5,65	7	7	4	7
Wheelchair as front wheel (II)	6,2	6,7	5,9	6,55	7	7	6	6
Trailer as front wheel- 1 part	3,85	4,85	4,7	5,15	3,7	6	8	6
Trailer as front wheel- 2 parts	4,9	5,55	6,1	5,15	3,65	6	8	8
6.3. BACK PART LOCATION								
"Tricycle"	5,7	4,95	6	5,2	5,55	7	8	7
Trailer "tricycle"	6	4,1	4,7	5,2	5,3	5	8	6
6.4. SIDECAR								
Wheelchair as sidecar	7,375	7,35	7	6,1	7,35	7	6,5	7
Sidecar	6,1	7,1	6,4	5,9	4,3	7	8	8

CRITERIA	TOTAL	E.BIKEPLUS
6.1. TRAILER		
Wheelchair front-Bike seat	6,12	6,62
Wheelchairfront-bike wheels	5,34	5,84
Wheelchair wheels-bike seat	5,38	5,88
Wheelchair wheels-Bike wheels	4,94	5,44
Seat-trailer	4,62	5,12
Wheels-trailer	4,64	5,14
6.2. FRONT PART LOCATION		
Wheelchair at front	5,48	5,98
Wheelchair as front wheel (I)	5,78	5,78
Wheelchair as front wheel (II)	6,38	6,38
Trailer as front wheel- 1 part	5,22	5,22
Trailer as front wheel- 2 parts	5,89	5,89
6.3. BACK PART LOCATION		
"Tricycle"	6,11	6,11
Trailer "tricycle"	5,45	5,45
6.4. SIDECAR		
Wheelchair as sidecar	7,04	7,54
Sidecar	6,64	7,14

4. BARS DIMENSIONING

According to the bicycle standardized dimensions it is possible to calculate a range of values that the bars must satisfied to be viable for different frame size bicycles. There are some fixed dimensions according to different sizes that are shown in figure XX for usual urban bicycles.



Frame size:	S	M	L	XL	XXL
Seat tube A	420	470	510	560	600
TT B	545	557	575	586	599
TT (eff.) B*	570	590	610	625	635
CS length C	429	429	429	429	435
HT length D	105	110	120	135	155
Steering angle E	70°	70,5°	70,5°	71°	71°
Seat angle F	74°	73°	73°	73°	73°
Seat post dia. G	31,6	31,6	31,6	31,6	31,6
BB drop H	72	70	70	70	70
wheelbase K	1062	1066	1087	1097	1114
stand over L	736	772	784	819	850
max travel front	100	100	100	100	100

Figure 4.1. Common dimensions for sizes from S to XXL.

According to that, it is possible to calculate the lengths and orientations of the different bars that can fulfill the requirements for the attachment. There are three different bars that have to be dimensioned according to the different parts of the frame and the wheelchair structure.

Bar 1. Connection wheelchair hub to bicycle hub.

This bar makes the most important connection because it is the one in charge of establish the distance between the bicycle and the wheelchair. In order to allow an enough space for the bicyclist to have access to the pedals, the length of the bar is thought to be 250 mm. The location is shown in figure 4.2.

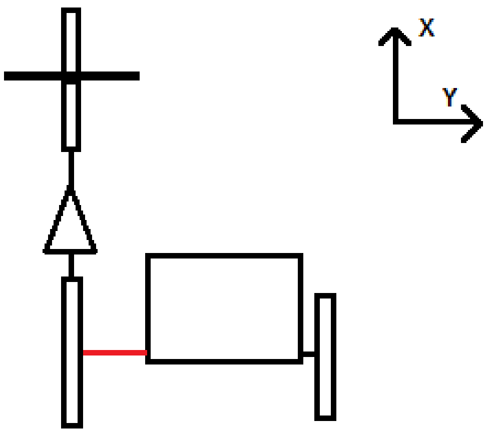


Figure 4.2. View from above of bar 1.

For most of the attachment that will be made, the diameters of the bicycle's rear wheel and the wheelchair's rear wheel will not be the same, which implies that the bar has to be inclined some degrees. In order to avoid this setback, the connection pieces that attach the bar with the different hubs have different attachment points, according to most commons rear wheel diameters, to get a straight attachment, which also helps referred to momentum and forces effects.

Bar 2. Bicycle seatpost to wheelchair upper point.

This connection is made between the seatpost tube of the bicycle with the upper part of the wheelchair, concretely on the tube just below the handles. It is and straight connection, that keep a 90º angle with the vertical line. In order to dimension it, it is necessary to take a look to the dimensions that are shown in figure 4.1. and to the upper view of the final assembly, figure 4.3.

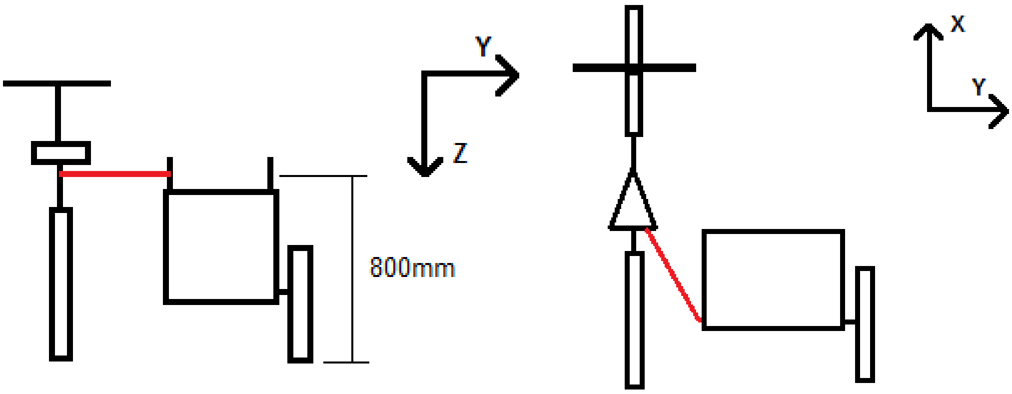


Figure 4.3. View from the back and view from above of bar 2.

These 800 mm height of the attachment are fixed according to a normal wheelchair's most common dimensions. In order to get the final dimension, following the frame dimensions from figure XX, it is necessary to calculate the distance from the rear wheel hub to the seatpost in horizontal. It is calculated for sizes S, L and XXL to get a range instead of just a dimension.

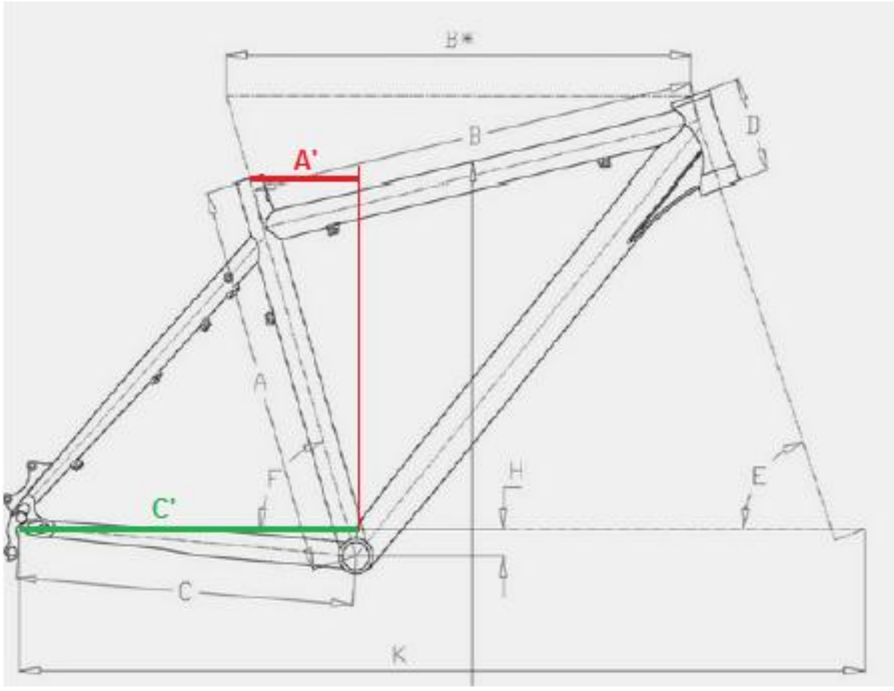


Figure 4.4. Distances required for bar 2 calculations.

$$d_{required} = C' - A' = C \cdot cos\beta - A \cdot sen\alpha \quad (4.1)$$

In where:

- $\alpha = 90º - F$
- $\beta = sin^{-1}(\frac{H}{C})$

So for the different sizes, the final length is calculated according to equation (4.1):

$$d_S = 429 \cdot \cos\left(sin^{-1}\left(\frac{72}{429}\right)\right) - 420 \cdot \sin(90 - 74) = 307 \text{ [mm]}$$

$$d_L = 429 \cdot \cos\left(sin^{-1}\left(\frac{70}{429}\right)\right) - 510 \cdot \sin(90 - 73) = 274 \text{ [mm]}$$

$$d_{XXL} = 435 \cdot \cos\left(sin^{-1}\left(\frac{70}{429}\right)\right) - 600 \cdot \sin(90 - 73) = 254 \text{ [mm]}$$

Since this distance is already calculated, it is possible to calculate the total length following the Pitagoras Theorem, as it is shown in figure 4.5.

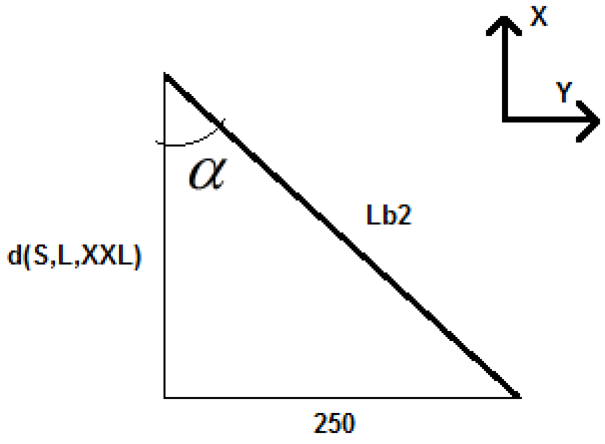


Figure 4.5. View from above of bar 2, Pitagoras theorem application.

$$L_{B2,S} = \sqrt{250^2 + {d_{S,L,XXL}}^2} \tag{4.2}$$

$$L_{B2,S} = \sqrt{250^2 + 307^2} = 396\ [mm]$$

$$L_{B2,S} = \sqrt{250^2 + 274^2} = 371\ [mm]$$

$$L_{B2,S} = \sqrt{250^2 + 254^2} = 357\ [mm]$$

Taking into account all the results from equation (4.2), the telescopic bars must have an available range from 350 to 400 mm.

Bar 3. Bycicle's headtube to wheelchair's lower point.

This connection has to be studied according to two different planes: XY and YZ. It is inclined in both of them, so it is necessary to take both inclinations into account. A 3D approximation it can be seen on figure 4.6., which are the distances that have to be calculated in order to get the final length.

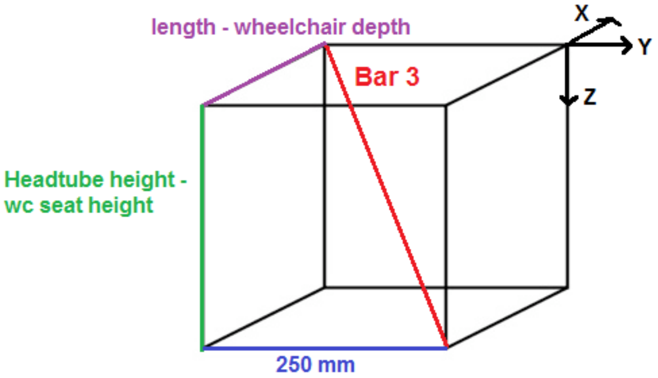


Figure 4.6. 3D view from bar 3.

First of all, it is calculated the distance on the X axis. In order to get it, it is calculated the total length of the bicycle frame and from it, it will be subtracted the wheelchair's depth to get an approximate distance, as it can be seen on the view from above, see figure 4.7.

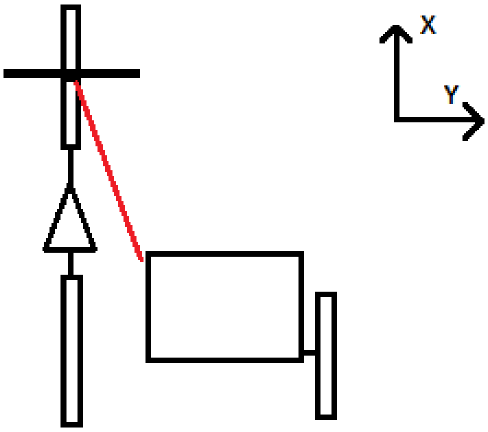


Figure 4.7. View from above of bar 3 and distance which is being required.

Referring another time to figure 4.1., there is a geometric relation to measure the total length of the frame, as follows in equation (X.P):

$$Bicycle\ length = C \cdot \cos\left(sin^{-1}\left(\frac{H}{C}\right)\right) + B^{*} - (A + 80) \cdot \sin\,(90 - F) \tag{4.3}$$

It is easy to explain the 80 which is added to the A distance. There is a little difference between the B* line and the top of the seat tube on the frame. This factor is added in order to compensate it and reach the final dimension in a common line. Following (4.3) the total lengths for the different sizes are:

$$Tot_S = 429 \cdot \cos\left(sin^{-1}\left(\frac{72}{429}\right)\right) + 570 - (420 + 80) \cdot \sin(90 - 74) = 855\ [mm]$$

$$Tot_L = 429 \cdot \cos\left(sin^{-1}\left(\frac{70}{429}\right)\right) + 610 - (510 + 80) \cdot \sin(90 - 73) = 860\ [mm]$$

$$Tot_{XXL} = 435 \cdot \cos\left(sin^{-1}\left(\frac{70}{435}\right)\right) + 635 - (600 + 80) \cdot \sin(90 - 73) = 865\ [mm]$$

And now, according to geometry again and taking into account that a usual wheelchair for an average adult has 41 cm depth, the distance measured along the horizontal axis on the frame from the head tube to the contact point with the wheelchair projection on that axis for S, L and XXL sizes are:

$$d_{X,S} = 855 - 410 = 445\ [mm]$$
$$d_{X,L} = 860 - 410 = 450\ [mm]$$
$$d_{X,XXL} = 865 - 410 = 455\ [mm]$$

At this point, there is only the distance on the Z axis left. The connection is made on the bar that is located just below the seat and continues until the caster wheels. Because of that, as a reference dimension of an average adult wheelchair seat height is taken as reference to approximate the calculations. This distance is standardized on 20" and 21", so it is taken 520 mm as closer value between those two. Regarding the bicycle, the head tube height can be calculated as the B distance on figure 4.1. plus the wheel radius, approximately 300 mm. The final position can be shown on figure 4.8.

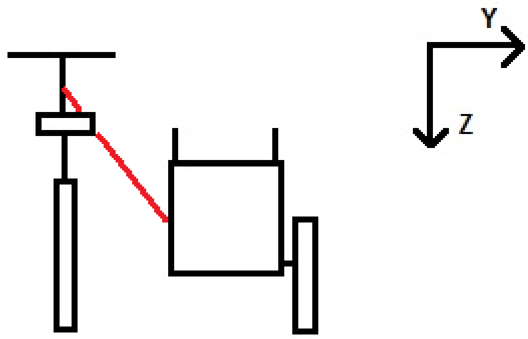


Figure 4.8. View from the back of bar 3.

According to figure 4.8., the distance on the Z-axis is the head tube height minus the wheelchair seat height. Thus, it can be calculated as:

$$d_Z = (B + wheel\,radius) - \ seat\ height \tag{4.4}$$

$$d_{Z,S} = (545 + 300) - 520 = 325\ [mm]$$
$$d_{Z,L} = (575 + 300) - 520 = 355\ [mm]$$
$$d_{Z,XXL} = (599 + 300) - 520 = 379\ [mm]$$

With these calculations, it is possible to calculate the total length for the three sizes with equation (4.5).

$$L_{B3} = \sqrt{{d_x}^2 + {d_y}^2 + {d_z}^2} \tag{4.5}$$

$$L_{B3,S} = \sqrt{445^2 + 250^2 + 325^2} = 606\ [mm]$$
$$L_{B3,L} = \sqrt{450^2 + 250^2 + 355^2} = 626\ [mm]$$
$$L_{B3,XXL} = \sqrt{455^2 + 250^2 + 379^2} = 642\ [mm]$$

In order to ensure the correct behavior, the range of dimensions will cover from 600 to 650 mm.

5. RESISTANT STUDY

It is necessary to study the responses on the assembly in order to choose the adequate materials and dimensions. In order to get an approximate behavior, the forces that will appear on the assembly when moving can be simulated and studied statically.

The forces have to be considered on two planes, XY and YZ, according to the coordinate system commonly used in mechanics, as it is shown in the figure 5.1.

Figure 5.1. Axis used on the cases.

In addition, it is necessary to calculate the different bar lengths to get a valid study. These dimensions have been calculated on Appendix 4 according to different urban bicycle frame sizes. The longest bars have been chosen in order to get the results for the most unfavorable situations. In summary, these lengths are:

- Bar 1: 250 mm.
- Bar 2: 400 mm.
- Bar 3: 650 mm.

In order to be able to approximate the behavior of the three dimension system, there have been made some assumptions according to each one of the bars.

- Bar 1 is assumed to be the positioning one and it is the only bar that is not build as telescopic. As it has been named on the report, the left rear wheel finally remains in the final assembly and the conflictive point (QR-axle) does not have to stand excessive efforts. For the calculations, this connection is considered to be from the bicycle rear wheel’s axle to the wheelchair’s right rear wheel, see figure 5.3, for plane YZ. In any case it is supposed to be just supported, which means that is in charge of transmitting forces on vertical and axial directions.

- Bar 2 is assumed to transmit forces on the axial direction only. It does not play an important role regarding the forces and stresses. This one plays a role more related with positioning regarding the bar 1.

- Bar 3 is assumed to transfer the momentum caused by the wheelchair tilt, which separates the caster wheels from the ground. To get easier calculations, it is assumed to have a ball connection on the wheelchair said and cantilever beam on the bicycle side.

Once that all assumptions are explained, it is possible to see in detailed how the studies are made, in both planes XY and YZ. It is considered only the wheelchair on motion, due to it is the heaviest body of the assembly and could provoke worse reaction than the bicycle.

In addition, some forces are considered to be applied on the wheelchair, bicycle or whole assembly center of gravity. Due to that, it is also necessary to calculate their exact location in order to keep going on,

In this study has been considered a wheelchair seat width for average adults, 457,2 [mm], plus the wheels, the overall width can be considered around 65 centimeters. The wheelchair overall height is around 1 meter and it is considered the seat depth around 600 [mm]. Regarding the bicycle, its highest part (the seat) reaches around 800 [mm].

Considering each device separately, both of them have an own center of gravity. It is assumed that both users are also on the bicycle and on the wheelchair, and the approximate result that will be taken as reference can be seen on the following figures, in both plane XZ and YZ:

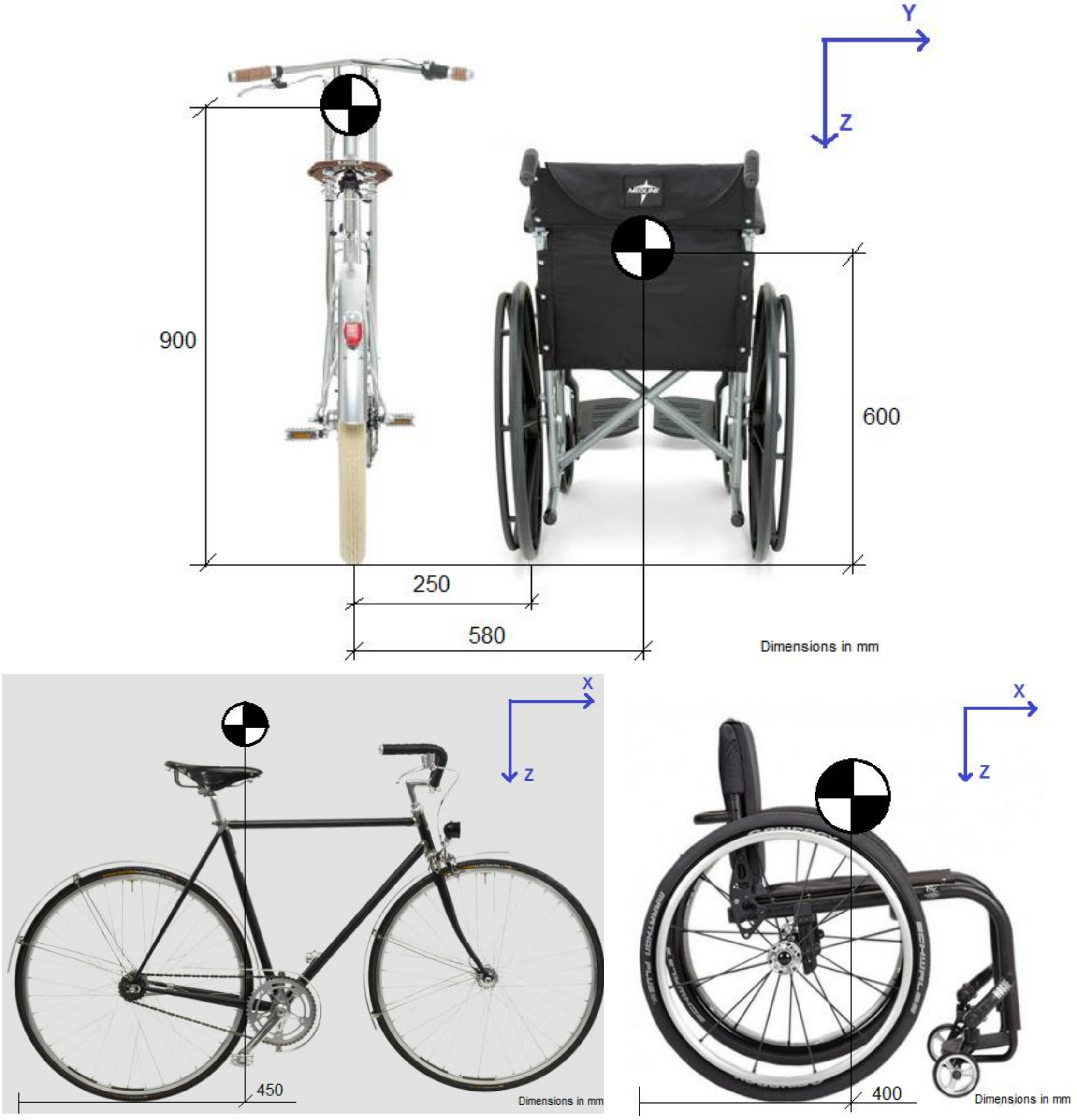


Figure XX. Location of the separate devices' centers of mass.

At this moment that both centers of mass are defined it is possible to find the final common centre of mass' coordinates of the whole assembly through equations (8.1), (8.2) and (8.3). (Coordinates origin is taken where the bicycle's touch the ground at the end of the bicycle):

$$x_{CM} = \frac{x_{CM1} \cdot m_1 + x_{CM2} \cdot m_2}{m_1 + m_2} \quad \text{(x.1)}$$

$$y_{CM} = \frac{y_{CM1} \cdot m_1 + y_{CM2} \cdot m_2}{m_1 + m_2} \quad \text{(X.2)}$$

$$z_{CM} = \frac{z_{CM1} \cdot m_1 + z_{CM2} \cdot m_2}{m_1 + m_2} \quad \text{(x.3)}$$

If the weight of both users is 68 [kg], Danish weight average, the wheelchair weights 15 kg and the bicycle 12,5 [kg], everything multiplied by a safety factor of 1.5. The common centre of mass' coordinates are according the equations above:

$$x_{CM} = \frac{450 \cdot (68 + 12{,}5) \cdot 1{,}5 + 400 \cdot (68 + 15) \cdot 1{,}5}{(68 + 12{,}5) \cdot 1{,}5 + (68 + 15) \cdot 1{,}5} = 423[mm]$$

$$y_{CM} = \frac{0 \cdot (68 + 12{,}5) \cdot 1{,}5 + 580 \cdot (68 + 15) \cdot 1{,}5}{(68 + 12{,}5) \cdot 1{,}5 + (68 + 15) \cdot 1{,}5} = 295[mm]$$

$$z_{CM} = \frac{900 \cdot (68 + 12{,}5) \cdot 1{,}5 + 600 \cdot (68 + 15) \cdot 1{,}5}{(68 + 12{,}5) \cdot 1{,}5 + (68 + 15) \cdot 1{,}5} = 750[mm]$$

Bar 1

The reactions on the bar are calculated considering the forces applied on the wheelchair's CoG. The diagram in plane XY is showed on figure 5.2.:

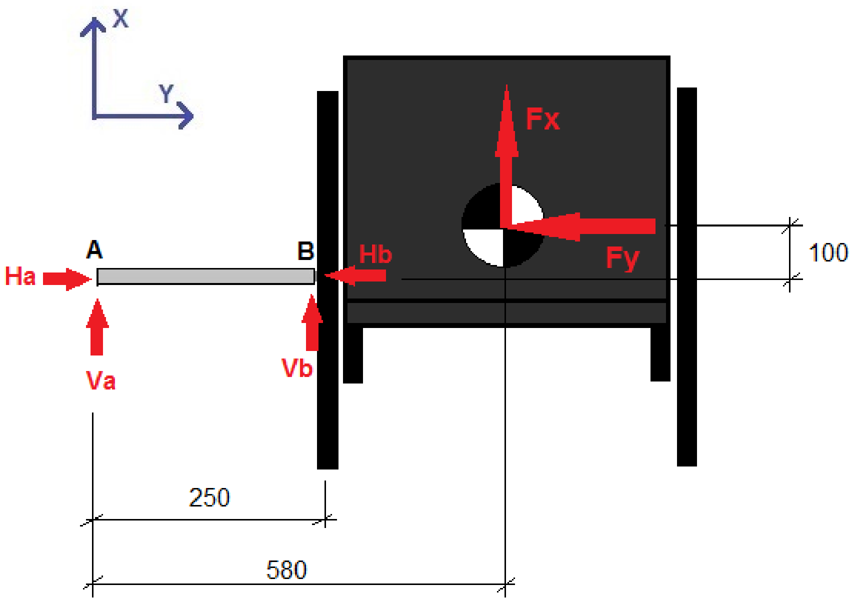


Figure 5.2. Free body force diagram (1).

As it can be seen, this type of support presents reaction on both vertical and horizontal axis. It is represented the worst case, the wheelchair is accelerating and also it has left directed load, action that compresses the bar.

To simulate an extreme situation, it is considered an acceleration of 2 times gravity and the applied forces are, according the Newton's Law, eq. (5.2):

$$F_Y = F_x = m \cdot a = (m_{wheelchair} + m_{user}) \cdot SF \cdot 2g = (68 + 15) \cdot 1.5 \cdot 2g = 2450[N] \quad (5.2)$$

Global equilibrium;

$$\sum F_y = 0 \rightarrow H_A - H_B - F_Y = 0 \rightarrow H_A - H_B = F_Y \quad (5.3)$$

$$\sum F_x = 0 \ \rightarrow V_A + V_B + F_x = 0 \rightarrow V_A + V_B = -F_x \quad (5.4)$$

And due to the boundary conditions of this kind of support, it is known that:

$$\sum M_A = 0 \rightarrow \ V_B \cdot 0{,}25 + F_x \cdot 0{,}58 + Fy \cdot 0{,}1 = 0 \rightarrow V_B = -6664[N] \quad (5.5)$$

Applying this value to equation (5.4):

$$V_A = 4214[N]$$

Despite the fact these supports do not allow a moment reaction on the sides, the bar is still subjected to momentum around the Z-axis due to the shear forces. The momentum reached on the middle of the bar reaches 281, 75 [N·m] (5.6).

$$M_{AB} = V_A \cdot L_{AB} - F_y \cdot 0{,}1 = 4214 \cdot 0.125 - 2450 \cdot 0.1 = 281{,}75[N \cdot m] \quad (5.6)$$

Regarding the axial forces, the bar is being affected by a horizontal load due to the effects of the centrifugal forces when turning. The dimension found for this bar can hold the compression load as it can be seen after the second bar study so there is no point in checking the buckling resistance. This load is only taken into account in the plane XY so in the plane YZ it is not necessary to be considered.

In figure 5.3., it is shown the plane YZ. Since both of the rear wheels remains when attaching the assembly, the wheelchair and its user's weights relies on both wheels, distributed equally, so the bending moment that used to affect on point C disappears.

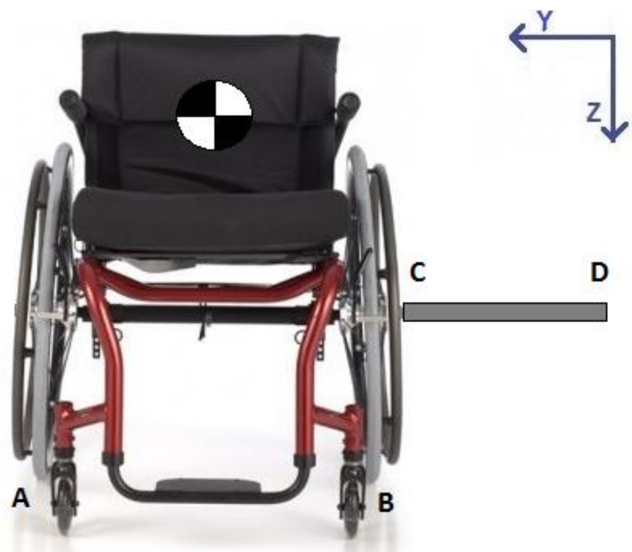


Figure 5.3. Free body force diagram (2).

Since this condition is fulfilled, the only bending moment that can affect the bar will be the one provoked due to forces on plane XY, which are explained below.

The axial load and the bending moment affect the whole beam compressing and bending it. In order for the beam to stand those stresses and forces it has to be true that:

$$\frac{\sigma_y}{\gamma_s} \geq \frac{N}{A} + \frac{M_z \cdot y}{I_z} + \frac{M_x \cdot z}{I_x} \qquad (5.6)$$

In this case we can suppose that mechanical effort realized by the axial forces is zero because:

$$A = \frac{\pi}{4} d^2 \ \ ; \ \ I = \frac{\pi}{64} \cdot d^4$$

Since they are inversely proportional then:

$$\frac{N}{A} \lll \frac{M_z \cdot y}{I_z}; \frac{M_x \cdot z}{I_x}$$

To sum up, the condition must be fulfilled. If the adequate values are included in the equation (5.6);

$$\frac{258 \cdot 10^6}{1.5} \geq \frac{281.75 \cdot \frac{d_e}{2}}{\frac{\pi}{64} \cdot ({d_e}^4 \_ {d_i}^4)}$$

In order to calculate the appropriate diameter, it is necessary to study the different efforts that it has to stand. In this case, the more restrictive will be M_x due to the fact that is considerably bigger than the other one and will be more involved in the diameter restrictions. Resolving the inequation (5.6), the minimum diameters required for standing the moments are:

- $d_e = 26\ [mm]$
- $d_i = 13\ [mm]$

*Formulas from:

- [33] *Apéndice B. Dimensionamiento y comprobación de secciones*. October 15, 2014. http://ocw.bib.upct.es/pluginfile.php/5495/mod_resource/content/1/B-dimensionado-comprobacion_v1.pdf

Bar 2

In the following sketch, figure 5.9., there are shown the axial forces on the bar (this time represented only by sketches because the location of the wheelchair and bicycle are clear enough), which acts compressing it.

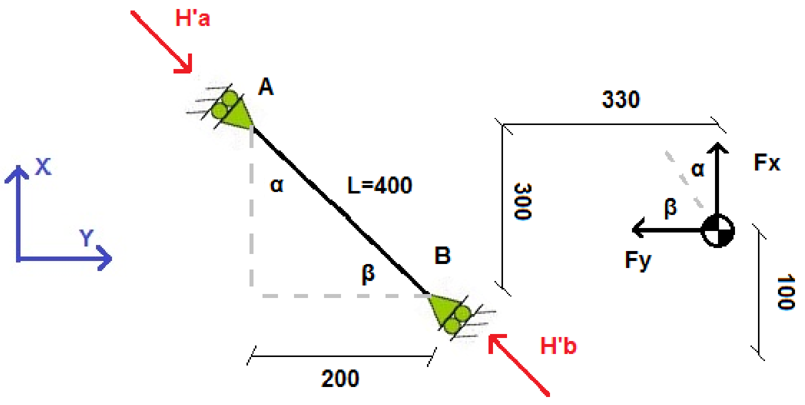


Figure 5.9. Free body diagram (3).

The angles are known due to geometrical relations as:

$$\alpha = \sin^{-1}\left(\frac{250}{400}\right) = 38.7[º] \quad (5.7)$$

$$\beta = \sin^{-1}\left(\frac{300}{400}\right) = 51.3[º] \quad (5.8)$$

Then we can translate this system to another with different axis which will make easier the calculations, as it can be seen on figure 5.10.:

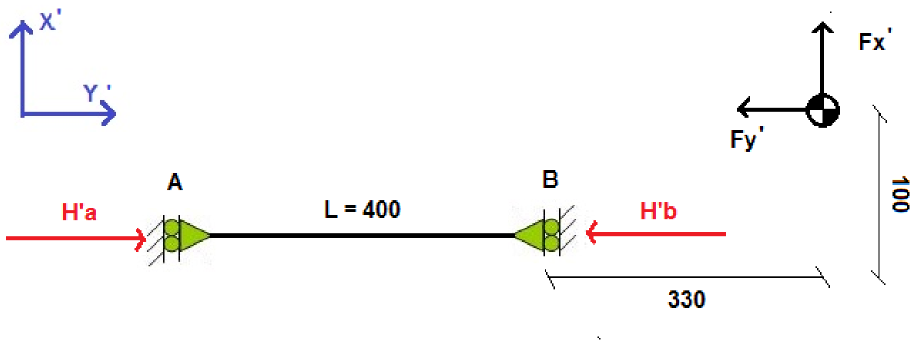


Figure 5.10. Free body diagram (4).

Then we will have:

$$F'_x = \cos(\alpha) \cdot F_x + \cos(\beta) \cdot F_y = (\cos(38.7) + \cos(51.3)) \cdot (-2450) = -3444\ [N]$$

$$F'_y = \sin(\alpha) \cdot F_x - \sin(\beta) \cdot F_y = (\sin(38.7) - \sin(51.3)) \cdot 2450 = -380\ [N]$$

There will be neither momentum nor vertical forces on the supports Because of the ball connections. Therefore, the reactions will be:

$$\sum F'_x = H'_a - F'_x = 0 \rightarrow\ H'_a = 3444\ [N] \qquad (5.3.c)$$

In this case we suppose that all the force made by Fx is absorbed by the first support due to it is the worst effort case which the bar can be submitted.

Diagram of axial forces:

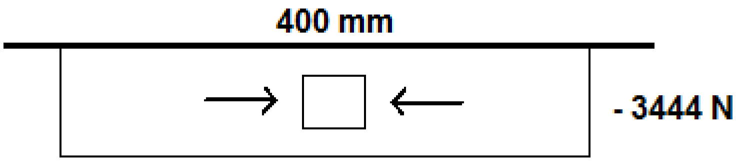


Figure 5.11. Axial force distribution.

Once we have figured out the reactions and the forces that there will be in our system we can proceed to dimension the bar. The resistance of the bar will be restricted by the maximum load that can be afforded, as in this case there is a pure axial effort:

$$N_{max} = A \cdot \sigma_{yd} \qquad (5.9)$$

Where:

$$N_c \leq\ N_{max} \qquad (5.10)$$

And applying both equations (5.13) and (5.14):

$$3444\ \leq \frac{\pi d^2}{4} \cdot \frac{258 \cdot 10^6}{1.5} \rightarrow d = \sqrt{\frac{3444 \cdot 1.5 \cdot 4}{258 \cdot 10^6 \cdot \pi}} \simeq 0.005\ [m] = 5\ [mm]$$

There are more calculations needed since the buckling risk exists because of the pure axial effort so it will be required to do another study subjected to new restrictions. Here it is the equation (5.11) that requires being satisfied.

$$N_{crit} = \chi \cdot A \cdot \sigma_{yd} \qquad (5.11)$$

Where χ is the buckling reduction coefficient and it is given by:

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 + \bar{\lambda}^2}} \leq 1 \qquad (5.12)$$

Being ϕ a shape factor and $\bar{\lambda}$ the reduced slenderness, both of them given by:

$$\phi = 0.5 \cdot \left[1 + \alpha\left(\bar{\lambda} - 0.2\right) + \bar{\lambda}^2\right] \qquad (5.13)$$

$$\bar{\lambda} = \frac{\lambda}{\lambda_E} \qquad (5.14)$$

α will be the elastic imperfection coefficient which in this case (circular section) will be 0,49. λ will be the mechanical slenderness of the section and λ_E the slenderness given by the young modulus and the yield stress, so both formulas will be:

$$\lambda = \frac{L_k}{i} \qquad (5.15)$$

$$\lambda_E = \pi\sqrt{\frac{E}{\sigma_y}} \qquad (5.16)$$

In this case L_k is the buckling length which due to our connections it will be $L_k = 1.0 \cdot L$. And i is the turning radius which for a circular section is r/2 or d/4. So doing all the calculations according equations from (5.11) to (5.16):

$$\lambda = \frac{L_k}{i} = \frac{1.0 \cdot 0.4}{\frac{0.005}{4}} = 320$$

$$\lambda_E = \pi\sqrt{\frac{E}{\sigma_y}} = \pi\sqrt{\frac{69 \cdot 10^9}{258 \cdot 10^6}} = 51.37$$

$$\bar{\lambda} = \frac{\lambda}{\lambda_E} = \frac{320}{51.37} = 6.23$$

$$\phi = 0.5 \cdot \left[1 + \alpha\left(\bar{\lambda} - 0.2\right) + \bar{\lambda}^2\right] = 0.5 \cdot [1 + 0.49(6.23 - 0.2) + 6.23^2] = 21{,}37$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 + \bar{\lambda}^2}} = \frac{1}{21.37 + \sqrt{21.37^2 + 6.23^2}} = 0.023 \leq 1$$

$$N_{crit} = \chi \cdot A \cdot \sigma_{yd} = 0.023 \cdot \frac{\pi \cdot 0.005^2}{4} \cdot \frac{258 \cdot 10^6}{1.5} = 77.67\ [N]$$

So the maximum load allowed for a 5 mm diameter circular bar is 77,67 N. So obviously the bar will not held the load because:

$$N_c > N_{crit}$$

It will be needed to recalculate the dimension for:

$$N_c \leq N_{crit} \leq \chi \cdot A \cdot \sigma_{yd}$$

And for taking into account that we want to use a telescopic bar so the section will be annulus then:

$$i = \frac{1}{4}\sqrt{d_e^2 - d_i^2}$$

The calculation has been done through iterations realized with Microsoft excel because the reduction coefficient will change when changing the turning radius. So finally we will get:

$$d_e = 0.025\, m = 25\, mm$$

$$d_i = 0.021 = 21\, mm$$

$$\chi = 0.025 \leq 1$$

$$N_{crit} = 10600[N] \rightarrow N_{crit} \geq N_c$$

The size of the section has been chosen according to the normal standard dimensions for telescopic bars that can be ordered to the suppliers.

Bar 3

Assumption: the bar is considered to be aligned with the ground floor in order to simplify the calculations and diagrams. This bar is assumed to have a rigid connection on the bicycle side (cantilever) and a ball joint on the wheelchair side. The acceleration of the system is assumed to be 2g to simulate an extreme case.

As it is said, it is considered to be on the plane XY instead of inclined. So it is necessary to calculate the angle φ, figure 5.9., to be able to translate the forces to relative axis an work with them on the beam.

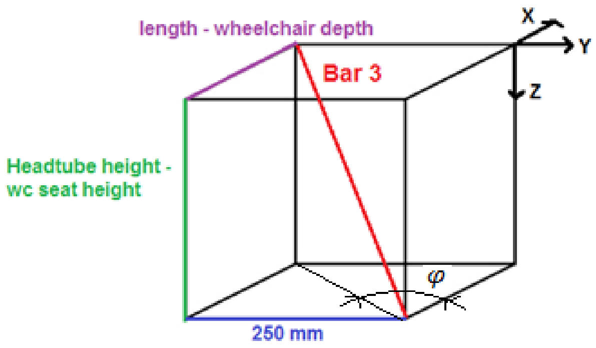


Figure 5.12. 3D view for bar 3.

According to the measurements for the longest bar, size XXL, which could suffer larger bending moments, the angle is simply calculated thanks to geometry as equation (5.21). Measurements can be checked on Appendix 4, bars dimensioning.

$$\varphi = arctg\left(\frac{d_{X,XXL}}{250}\right) = 28.8º \qquad (5.17)$$

According to that, the representation of the assumption on the plane XY is shown in the figure 5.13. with a supposed acceleration of the system of 2g and a total bar length of 642mm, and also it is shown the relative coordinates system which is used to calculate the responses on the bar (system X'Y').

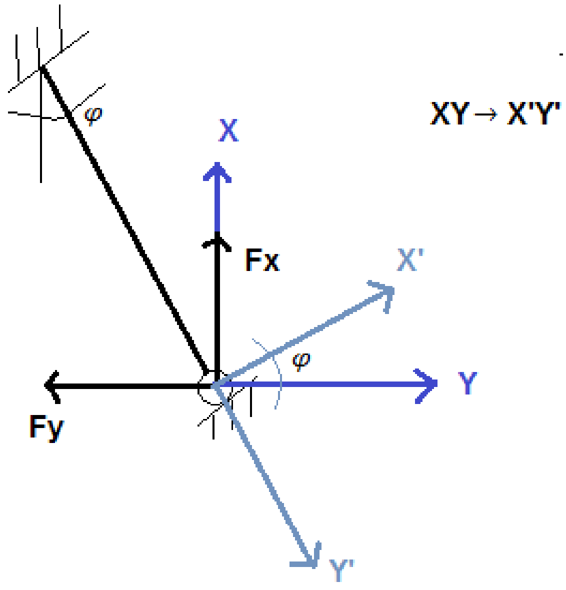


Figure 5.13. Free body force diagram (5).

The translations of the forces on the new relative coordinates system are easily calculated according geometric relations.

$$F_{X,X'} = F_X sen\varphi = 1176{,}8[N]$$

$$F_{X,Y'} = F_X(-cos\varphi) = -2140{,}6[N]$$

$$F_{Y,X'} = F_Y(-cos\varphi) = -2140{,}6[N]$$

$$F_{Y,Y'} = F_Y(-s\varphi) = -1176{,}8[N]$$

The resultant forces on the new axis are $F_{X'}$ = -963.8[N] and $F_{Y'}$ = -3317.4[N].

The resultant body diagram is shown below on figure 5.14.

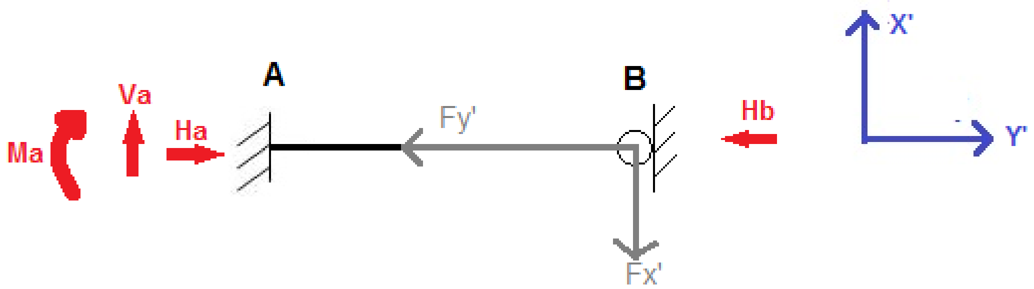


Figure 5.14. Resultant force diagram (6).

Global Equilibrium

Axial forces

$$\sum F_{X'} = 0 \rightarrow V_A - F_{X'} = 0 \rightarrow V_A = F_{X'} = 963{,}8[N] \quad (5.3.d.)$$

Shear forces

$$\sum F_{y'} = 0 \rightarrow H_A - H_B - F_{Y'} = 0 \rightarrow H_A - H_B = F_{Y'} \quad (5.4.d)$$

As it can be seen on the sum according Y'-axis, there is not possible to calculate the values of the axial responses directly (hyper static problem). It is assumed, due to the bar is subjected to compression, that the compression reaction will be considerably larger that the traction one. According to that it is assumed, approximately, that:

$$H_A = F_{Y'} = 3317{,}4[N]$$

And due to ball joint boundary condition, the bending moment is:

$$\sum M_B = 0 \rightarrow -M_A - V_A \cdot l = 0 \rightarrow M_A = -V_A \cdot l = -963{,}8 \cdot l[N \cdot m] \quad (5.5.d)$$

If the length of the bar is taken into account, the bending moment on A point is:

$$M_A = -963{,}8 \cdot 0{,}642 = -618{,}8[N \cdot m]$$

To get a certain knowledge about the distributions inside the bar, it is also studied an equilibrium with a cut on the bar, as follows in 5.15.

Cuts Equilibrium

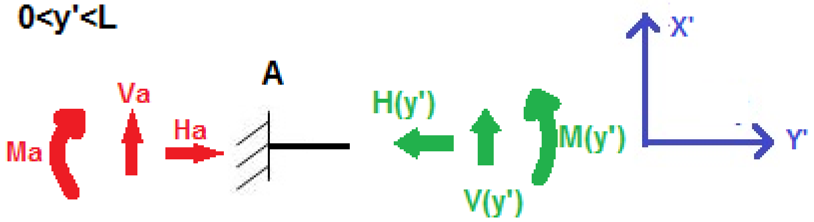


Figure 5.15. Cuts equilibrium.

Axial force

$$\sum F_{Y'} = 0 \rightarrow H_A - H(y') = 0 \rightarrow H(y') = H_A = 3317{,}4[N] \quad (5.3.e)$$

Shear forces

$$\sum F_{X'} = 0 \rightarrow V_A + V(y') = 0 \rightarrow V(y') = -V_A = -963{,}8[N] \quad (5.4.e)$$

Bending moment

$$\sum M_A = -618{,}8[N \cdot m] \rightarrow M(y') + V(y') \cdot y' = -618{,}8[N \cdot m] \rightarrow M(y') = -618{,}8 + 963{,}8 \cdot (y')[N \cdot m]$$

(5.5.e)

To sum up, the resultant forces and bending moment are:

- $V_A = 963{,}8[N]$.
- $H_A = 3317{,}4[N]$.
- $M_{A(Z)} = -618{,}8[N \cdot m]$.

As it is seen, the major bending moment is reached on A point, so that it will be the one that will be taken into account when dimensioning.

Since the plane XY is finished, it is being analyzed the plane YZ, which means the gravity force. It is taken an acceleration of 2g (as previous bars, equation (5.2)). As the now both rear wheels remains on the assembly, this third bar will no subjected to an excessive moment. We consider the half of the wheelchair and user's weights.

$$Fg = m \cdot 2g = 1221{,}3[N]$$

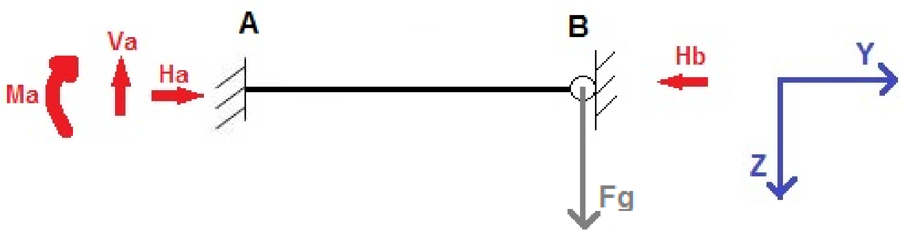


Figure 5.16. Free body diagram (7).

Global Equilibrium

Axial forces

$\sum F_y = 0 \rightarrow$There are not axial forces in this case. (5.3.f)

Shear forces

$\sum F_x = 0 \ \rightarrow V_A - F_g = 0 \rightarrow V_A = F_g = 1221{,}3[N]$ (5.4.f)

Bending moment

$\sum M_B = 0 \rightarrow -M_A - V_A \cdot l = 0 \rightarrow M_A = -V_A \cdot l = -784{,}1[N \cdot m]$ (5.5.f)

To sum up the results are:

- $V_A = 1221{,}3[N]$.
- $M_{A(X)} = -784{,}1[N \cdot m]$.

At this point, in which all the efforts on the bar are already calculated, it is possible to calculate the minimum diameters to stand them. As in the bar 1, it is necessary to follow equation (5.6).

$$\frac{\sigma_y}{\gamma_s} \geq \frac{N}{A} + \frac{M_z \cdot y}{I_z} + \frac{M_x \cdot z}{I_x} \tag{5.6}$$

And taking the similar consideration about axial forces, because it is a similar case, the equation is reduced to:

$$\frac{258 \cdot 10^9}{1.5} \geq \frac{618{,}8 \cdot \frac{d_e}{2}}{\frac{\pi}{64} \cdot ({d_e}^4 \_ {d_i}^4)} + \frac{784{,}1 \cdot \frac{d_e}{2}}{\frac{\pi}{64} \cdot ({d_e}^4 \_ {d_i}^4)}$$

Resolving the inequation (5.6), the minimum diameters required for standing the moments are:

- $d_e = 44\ [mm]$
- $d_i = 17\ [mm]$

That is the calculation for a rigid bar to hold the stresses and moments. Anyway, the bar is going to be manufactured by an external company. According their provided data sheet, the telescopic bar will be made by:

- Inner tube: De = 75 [mm] and Di = 71 [mm].
- Outer tube: De = 80 [mm] and Di = 76 [mm].

*All formulas that are used are provided by [33] *Apéndice B. Dimensionamiento y comprobación de secciones*. October 15, 2014. http://ocw.bib.upct.es/pluginfile.php/5495/mod_resource/content/1/B-dimensionado-comprobacion_v1.pdf

5. MATERIALS

Aluminum 6061-T6; 6061-T651

Subcategory: 6000 Series Aluminum Alloy; Aluminum Alloy; Metal; Nonferrous Metal
Close Analogs:
Composition Notes:
Aluminum content reported is calculated as remainder.
Composition information provided by the Aluminum Association and is not for design.
Key Words: al6061, UNS A96061; ISO AlMg1SiCu; Aluminium 6061-T6, AD-33 (Russia); AA6061-T6; 6061T6, UNS A96061; ISO AlMg1SiCu; Aluminium 6061-T651, AD-33 (Russia); AA6061-T651

Component	Wt. %	Component	Wt. %	Component	Wt. %
Al	95.8 - 98.6	Mg	0.8 - 1.2	Si	0.4 - 0.8
Cr	0.04 - 0.35	Mn	Max 0.15	Ti	Max 0.15
Cu	0.15 - 0.4	Other, each	Max 0.05	Zn	Max 0.25
Fe	Max 0.7	Other, total	Max 0.15		

Physical Properties	Metric	English	Comments
Density	2.7 g/cc	0.0975 lb/in³	AA; Typical

Mechanical Properties

Hardness, Brinell	95	95	AA; Typical; 500 g load; 10 mm ball
Hardness, Knoop	120	120	Converted from Brinell Hardness Value
Hardness, Rockwell A	40	40	Converted from Brinell Hardness Value
Hardness, Rockwell B	60	60	Converted from Brinell Hardness Value
Hardness, Vickers	107	107	Converted from Brinell Hardness Value
Ultimate Tensile Strength	310 MPa	45000 psi	AA; Typical
Tensile Yield Strength	276 MPa	40000 psi	AA; Typical
Elongation at Break	12 %	12 %	AA; Typical; 1/16 in. (1.6 mm) Thickness
Elongation at Break	17 %	17 %	AA; Typical; 1/2 in. (12.7 mm) Diameter
Modulus of Elasticity	68.9 GPa	10000 ksi	AA; Typical; Average of tension and compression. Compression modulus is about 2% greater than tensile modulus.
Notched Tensile Strength	324 MPa	47000 psi	2.5 cm width x 0.16 cm thick side-notched specimen, K_t = 17.
Ultimate Bearing Strength	607 MPa	88000 psi	Edge distance/pin diameter = 2.0
Bearing Yield Strength	386 MPa	56000 psi	Edge distance/pin diameter = 2.0
Poisson's Ratio	0.33	0.33	Estimated from trends in similar Al alloys.

Fatigue Strength	96.5 MPa	14000 psi	AA; 500,000,000 cycles completely reversed stress; RR Moore machine/specimen
Fracture Toughness	29 MPa-m½	26.4 ksi-in½	K_{IC}; TL orientation.
Machinability	50 %	50 %	0-100 Scale of Aluminum Alloys
Shear Modulus	26 GPa	3770 ksi	Estimated from similar Al alloys.
Shear Strength	207 MPa	30000 psi	AA; Typical

Electrical Properties

Electrical Resistivity	3.99e-006 ohm-cm	3.99e-006 ohm-cm	AA; Typical at 68°F

Thermal Properties

CTE, linear 68°F	23.6 µm/m-°C	13.1 µin/in-°F	AA; Typical; Average over 68-212°F range.
CTE, linear 250°C	25.2 µm/m-°C	14 µin/in-°F	Estimated from trends in similar Al alloys. 20-300°C.
Specific Heat Capacity	0.896 J/g-°C	0.214 BTU/lb-°F	
Thermal Conductivity	167 W/m-K	1160 BTU-in/hr-ft²-°F	AA; Typical at 77°F
Melting Point	582 - 652 °C	1080 - 1205 °F	AA; Typical range based on typical composition for wrought products 1/4 inch thickness or greater; Eutectic melting can be completely eliminated by homogenization.
Solidus	582 °C	1080 °F	AA; Typical

Liquidus	652 °C	1205 °F	AA; Typical

Processing Properties

Solution Temperature	529 °C	985 °F	
Aging Temperature	160 °C	320 °F	Rolled or drawn products; hold at temperature for 18 hr
Aging Temperature	177 °C	350 °F	Extrusions or forgings; hold at temperature for 8 hr

REFERENCES

[1] Information provided by The Aluminum Association, Inc. from Aluminum Standards and Data 2000and/or International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys (Revised 2001).

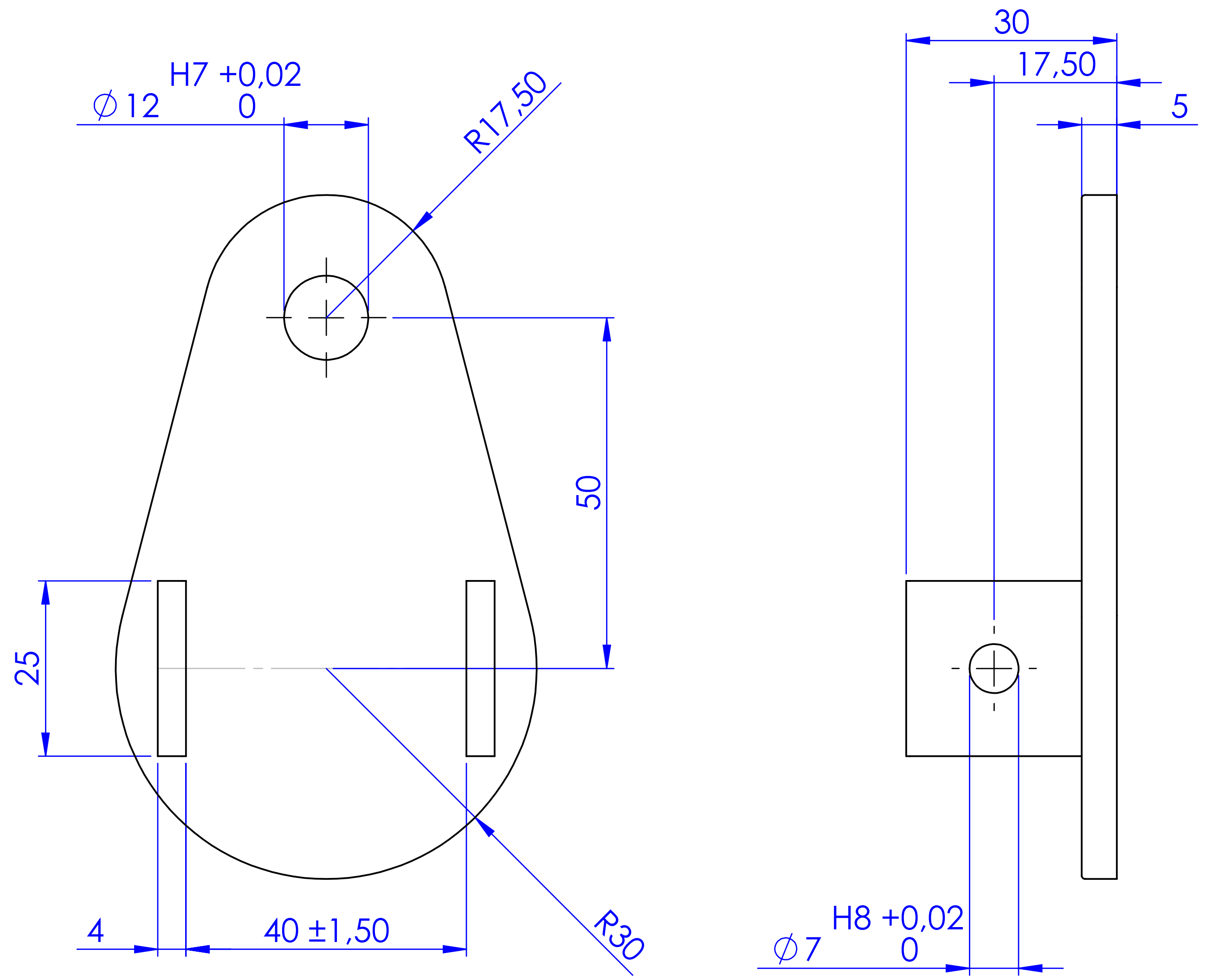
[2] Metals Handbook, Vol.2 - Properties and Selection: Nonferrous Alloys and Special-Purpose Materials, ASM International 10th Ed. 1990.

[3] Structural Alloys Handbook, 1996 edition, John M. (Tim) Holt, Technical Ed; C. Y. Ho, Ed., CINDAS/Purdue University, West Lafayette, IN, 1996.

[4] BOYER H. E. & GALL T. L. Metals Handbook, Eds., American Society for Metals, Materials Park, OH, 1985.

All edges R0.5 but ∅12 whole ones

∅12 mm hole could be ∅12,7 as well due to american dimensions Quick - Releases



DRAWN BY:

BLANCA ADIEGO CALVO

ALVARO SARRIA RICO

AARHUS UNIVERSITY

SCHOOL OF ENGINEERING

MATERIAL:

Al 6061-T6

TITLE:

WHEELCHAIR -BICYCLE ATTACHMENT

WEIGHT (g):

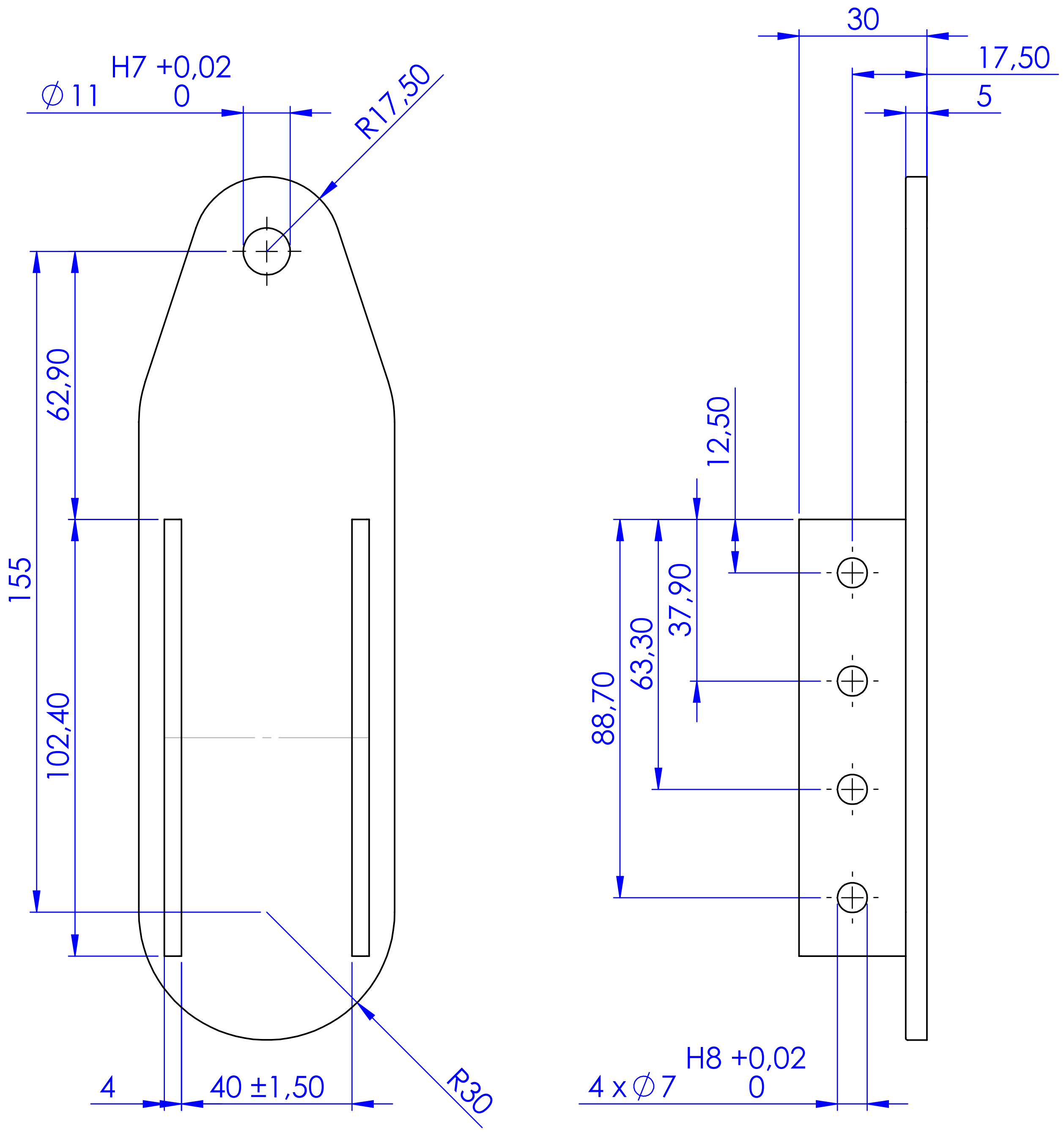
PART NAME: Join_Bar1

A4

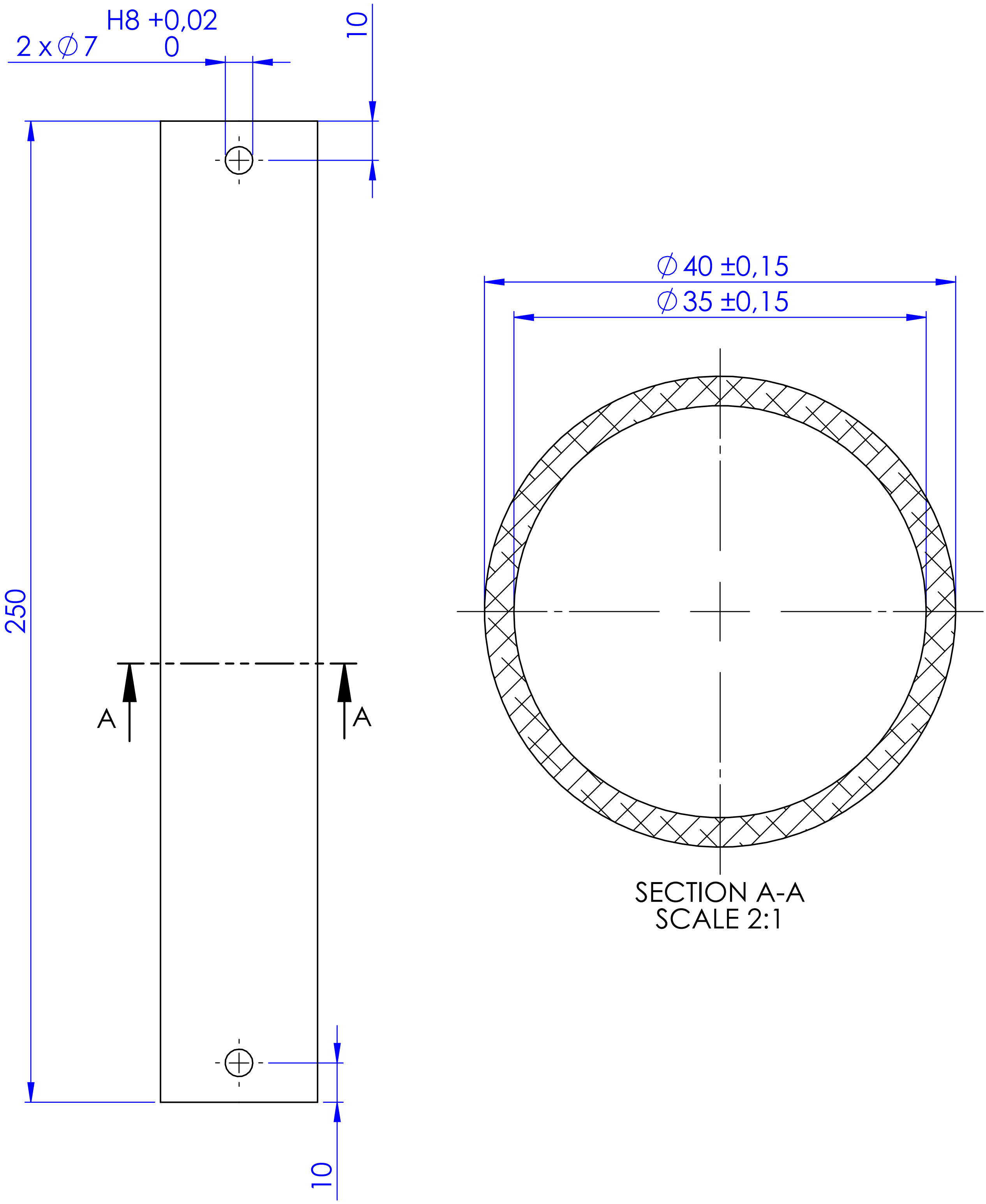
SCALE 1:1

SHEET 1 OF 1

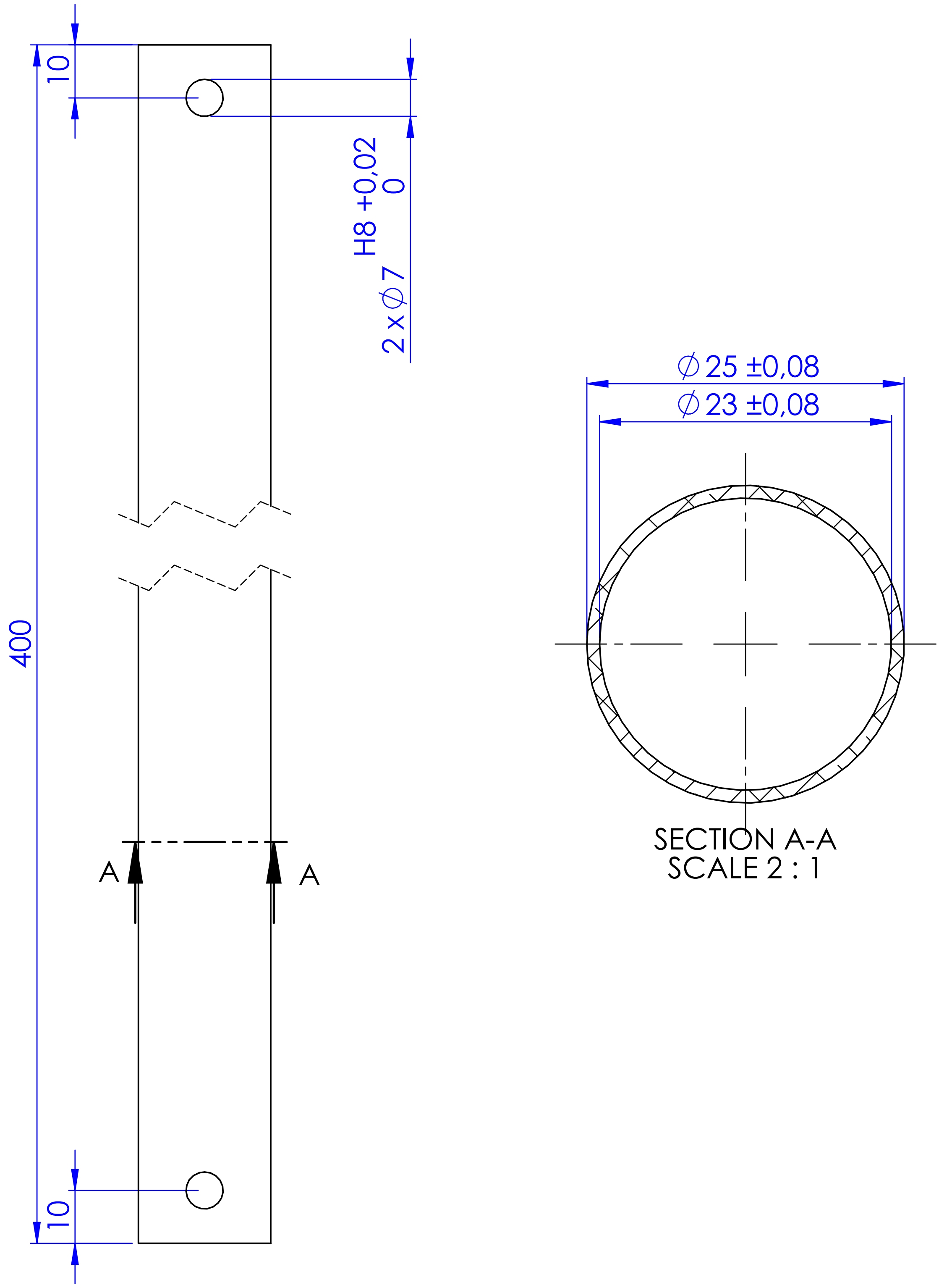
All edges R0.5 but whole edges



DRAWN BY: BLANCA ADIEGO CALVO, ALVARO SARRIA RICO	AARHUS UNIVERSITY SCHOOL OF ENGINEERING	
MATERIAL: 6061-T6 (SS)	TITLE: WHEELCHAIR -BICYCLE ATTACHMENT	
WEIGHT (g):		
	PART NAME: Join_Bar1 (2)	A4
	SCALE 1:1	SHEET 1 OF 1



DRAWN BY: BLANCA ADIEGO CALVO, ALVARO SARRIA RICO	AARHUS UNIVERSITY SCHOOL OF ENGINEERING
MATERIAL: AISI 1045 Steel	TITLE: WHEELCHAIR -BICYCLE ATTACHMENT
WEIGHT (g): [illegible]	PART NAME: Bar1 — A4
	SCALE 1:2 — SHEET 1 OF 1



DRAWN BY:
BLANCA ADIEGO CALVO
ALVARO SARRIA RICO

AARHUS UNIVERSITY
SCHOOL OF ENGINEERING

MATERIAL: 6061-T6 (SS)

TITLE: WHEELCHAIR -BICYCLE ATTACHMENT

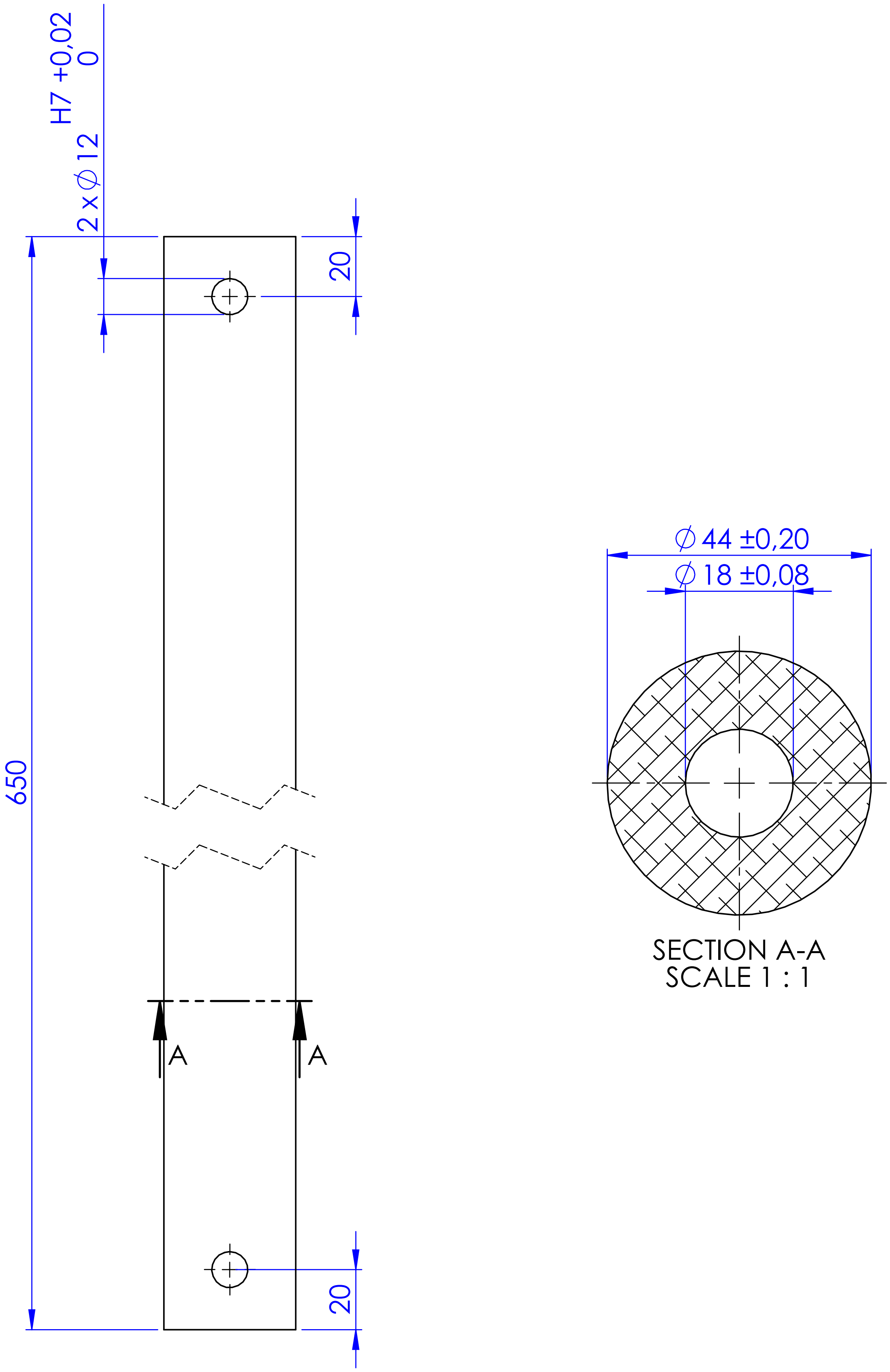
WEIGHT (g):

PART NAME: Bar2

A4

SCALE 1:1

SHEET 1 OF 1



DRAWN BY: BLANCA ADIEGO CALVO, ALVARO SARRIA RICO	AARHUS UNIVERSITY SCHOOL OF ENGINEERING
MATERIAL: 6061-T6 (SS)	TITLE: WHEELCHAIR -BICYCLE ATTACHMENT
WEIGHT (g):	
	PART NAME: Bar3 — A4
	SCALE 1:2 — SHEET 1 OF 1

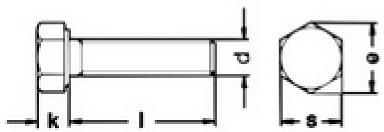
8. STANDARD ELEMENTS

Hex Cap Screws

A2 / A4 Stainless

Fully Threaded

H005 - 933-A2
H006 - 933-A4



Diameter	M3				M4				M5				M6			
k	2				2.8				3.5				4			
s max.	5.5				7				8				10			
e min.	6.01				7.66				8.79				11.05			
b up to 125	–				14				16				18			
b up to 200	–				–				–				24			
Length (mm)	Full Thread		Part Thread		Full Thread		Part Thread		Full Thread		Part Thread		Full Thread		Part Thread	
	A2	A4	A2	A4	A2	A4	A2	A4	A2	A4	A2	A4	A2	A4	A2	A4
	H005	H006	H025	H026	H005	H006	H025	H026	H005	H006	H025	H026	H005	H006	H025	H026
5	100															
6	100				100				100							
8	100					100			100	100			100	100		
10	100				100	100			100	100			100	100		
12	100				100	100			100	100			100	100		
14													100			
16	100				100	100			100	100			100	100		
20	100				100	100			100	100			100	100		
25	100				100	100			100	100			100	100		
30					100	100			100	100			100	100		
35					100	100			100	100			100	100		
40					100	100			100	100	100		100	100		
45											100	100	100	100	100	100
50									100		100	100	100	100	100	100
55															100	100
60											100	100	100	100	100	100
65															100	100
70													100	100	100	100
80															100	100
90															100	100
100															100	100
110															100	
120															100	
140															100	
Order Number -> 933-A2 M3x20 = H005-003-0020 | 931-A4 M6x100 = H026-006-0100																

Diameter	M8				M10				M12				M14			
k	5.3				6.4				7.5				8.8			
s max.	13				17				19				22			
e min.	14.38				18.90				21.1				24.49			
b up to 125	22				26				30				34			
b up to 200	28				32				36				40			
Length (mm)	Full Thread		Part Thread		Full Thread		Part Thread		Full Thread		Part Thread		Full Thread		Part Thread	
	A2	A4	A2	A4	A2	A4	A2	A4	A2	A4	A2	A4	A2	A4	A2	A4
	H005	H006	H025	H026	H005	H006	H025	H026	H005	H006	H025	H026	H005	H006	H025	H026
10	100	100														
12	100	100														
16	100	100			100	100										
20	100	100			100	100			50	50						
25	100	100			100	100			50	50			50	50		
30	100	100			100	100			50	50			50	50		
35	100	100			100	100			50	50			50	50		
40	100	100			100	100			50	50			50	50		
45	100	100	100		100	100			50	50			50	50		
50	100	100	100	100	100	100	100	100	50	50	50	50	50	50	50	
55	100		100		100		100	100	50		50	50				
60	100	100	100	100		100	100	100	25	25	25	25		25	25	
65			100	100		100	100	100			25	25	25	25		
70	100		100	100	100		100	100	25		25	25	25	25	25	
75								100				25				
80	100		100	100	50		50	50	25		25	25		25	25	25
90			100	100			50	50			25	25			25	25
100	100		100	100	50		50	50	25		25	25			25	25
110			50				50	50			25	25				
120			50	50			50	50			25	25				25
130											25					
140							50	50			25	25				25
150			50				50				25					
160											25					
180											25					
Order Number -> 933-A2 M10x20 = H005-010-0020 | 931-A4 M14x120 = H026-014-0120																

Diameter	M16				M18				M20				M22			
k	10				11.5				12.5				14			
s max.	24				27				30				32			
e min.	26.75				30.14				33.53				35.72			
b up to 125	38				42				46				50			
b up to 200	44				48				52				56			
b over 200	57				61				65				69			
Length (mm)	Full Thread		Part Thread		Full Thread		Part Thread		Full Thread		Part Thread		Full Thread		Part Thread	
	A2	A4	A2	A4	A2	A4	A2	A4	A2	A4	A2	A4	A2	A4	A2	A4
	H005	H006	H025	H026	H005	H006	H025	H026	H005	H006	H025	H026	H005	H006	H025	H026
20	25	25														
25	25	25														
30	25	25							25	25						
35	25	25							25							
40	25	25				25			25	25						
45	25	25							25	25						
50	25	25				25			25	25						
55	25	25	25	25					25	25						
60	25	25	25	25		25			25	25						
65		25	25	25							25	25				
70	25	25	25	25		25			25	25	25	25				
75			25	25							25	25				
80	25	25	25	25		25			25	25	25	25				
90	25	25	25	25		25				25	25	25				
100	25	25	25	25		25			25		25	25				10
110			25								10					
120			25	25							10	10			10	
140			25	25							10	10				
150			25								10	10				
160			10	10							10					
180			10								10					
200			10								10					

Order Number -> 933-A2 M16x50 = H005-016-0050 | 931-A4 M20x150 = H026-020-0150

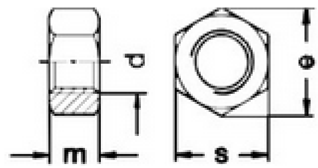
Diameter	M24				M30				M36			
k	15				18.7				22.5			
s max.	36				46				55			
e min.	39.98				50.85				60.79			
b up to 125	54				66				78			
b up to 200	60				72				84			
b over 200	73				85				97			
Length (mm)	Full Thread		Part Thread		Full Thread		Part Thread		Full Thread		Part Thread	
	A2	A4	A2	A4	A2	A4	A2	A4	A2	A4	A2	A4
	H005	H006	H025	H026	H005	H006	H025	H026	H005	H006	H025	H026
40		10										
50	10	10										
60	10	10				1						
70	10	10				1						
80	10	10	10	10		1						
90			10	10		1						
100		10	10	10	1	1						1
110			10									
120			10	10								1
140			10	10								
150				10				1				
160			10									
180			10									
200			10	10								

Order Number -> 933-A2 M24x50 = H005-024-0050 | 931-A4 M24x200 = H026-024-0200

DIN 934
ANSI B18.2.4.1M

Hex Nuts

Class 6/8
Class 10



Coarse Thread													
d	s max.	e min.	m max.	Class 6/8						Class 10		Class 12	
				Bare		Zinc		Hot Dip Galvanized					
				Pkg.	Order #	Pkg.	Order #	Pkg.	Order #	Pkg.	Order #	Pkg.	Order #
M2	4	4.32	1.6			100	N012-002-0000						
M2.5	5	5.45	2			100	N012-2.5-0000						
M2.6	5	5.45	2			100	N012-2.6-0000						
M3	5.5	6.01	2.4	100	N010-003-0000	100	N012-003-0000						
M3.5	6	6.58	2.8			100	N012-3.5-0000						
M4	7	7.66	3.2	100	N010-004-0000	100	N012-004-0000			100	N016-004-0000		
M5	8	8.79	4	100	N010-005-0000	100	N012-005-0000			100	N016-005-0000		
M6	10	11.05	5	100	N010-006-0000	100	N012-006-0000	100	N008-006-0000	100	N016-006-0000	100	N057-006-0000
M7	11	12.12	5.5	100	N010-007-0000	100	N012-007-0000						
M8	13	14.38	6.5	100	N010-008-0000	100	N012-008-0000	100	N008-008-0000	100	N016-008-0000	100	N057-008-0000
M10	17	18.9	8	100	N010-010-0000	100	N012-010-0000	100	N008-010-0000	100	N016-010-0000	100	N057-010-0000
M12	19	21.1	10	100	N010-012-0000	100	N012-012-0000	100	N008-012-0000	100	N016-012-0000	100	N057-012-0000
M14	22	24.49	11	100	N010-014-0000	100	N012-014-0000	100	N008-014-0000	100	N016-014-0000	100	N057-014-0000
M16	24	26.75	13	100	N010-016-0000	100	N012-016-0000	100	N008-016-0000	100	N016-016-0000	100	N057-016-0000
M18	27	29.56	15	50	N010-018-0000	50	N012-018-0000			50	N016-018-0000	50	N057-018-0000
M20	30	32.95	16	50	N010-020-0000	50	N012-020-0000	50	N008-020-0000	50	N016-020-0000	50	N057-020-0000
M22	32	35.03	18	50	N010-022-0000	50	N012-022-0000			50	N016-022-0000	50	N057-022-0000
M24	36	39.55	19	50	N010-024-0000	50	N012-024-0000	50	N008-024-0000	50	N016-024-0000	50	N057-024-0000
M27	41	45.2	22	25	N010-027-0000	25	N012-027-0000			25	N016-027-0000		
M30	46	50.85	24	25	N010-030-0000	25	N012-030-0000	25	N008-030-0000	25	N016-030-0000		
M33	50	55.37	26	10	N010-033-0000					10	N016-033-0000		
M36	55	60.79	29	10	N010-036-0000	10	N012-036-0000			10	N016-036-0000		
M39	60	66.44	31	1	N010-039-0000					1	N016-039-0000		
M42	65	71.3	34	1	N010-042-0000					1	N016-042-0000		
M45	70	76.95	36	1	N010-045-0000					1	N016-045-0000		
M48	75	82.6	38	1	N010-048-0000					1	N016-048-0000		
M52	80	88.25	42	1	N010-052-0000								
M56	85	93.56	45	1	N010-056-0000								
M60	90	99.21	48	1	N010-060-0000								
M64	95	104.86	51	1	N010-064-0000								
M68	100	110.51	54	1	N010-068-0000								
M72	105	116.16	58	1	N010-072-0000					1	N016-072-0000		
M76	110	121.81	61	1	N010-076-0000								
M80	115	127.46	64	1	N010-080-0000								
M90	130	144.08	72	1	N010-090-0000								
M100	145	161.02	80	1	N010-100-0000								

Fine Thread									
d	s max.	e min.	m max.	Class 8				Class 10	
				Bare		Zinc			
				Pkg.	Order #	Pkg.	Order #	Pkg.	Order #
M6 x 0.75	10	11.05	5	100	N010-006-0.75	100	N012-006-0.75		
M8 x 1	13	14.38	6.5	100	N010-008-0001	100	N012-008-0001	100	N016-008-0001
M10 x 1	17	18.9	8	100	N010-010-0001	100	N012-010-0001	100	N016-010-0001
M10 x 1.25	17	18.9	8	100	N010-010-1.25	100	N012-010-1.25	100	N016-010-1.25
M12 x 1	19	21.1	10	100	N010-012-0001	100	N012-012-0001		
M12 x 1.25	19	21.1	10	100	N010-012-1.25	100	N012-012-1.25	100	N016-012-1.25
M12 x 1.5	19	21.10	10	100	N010-012-01.5	100	N012-012-01.5	100	N016-012-01.5
M14 x 1.5	22	24.49	11	100	N010-014-01.5	100	N012-014-01.5	100	N016-014-01.5
M16 x 1.5	24	26.75	13	100	N010-016-01.5	100	N012-016-01.5	100	N016-016-01.5
M18 x 1.5	27	29.56	15	50	N010-018-01.5	50	N012-018-01.5	50	N016-018-01.5
M18 x 2	27	29.56	15	50	N010-018-0002				
M20 x 1.5	30	32.95	16	50	N010-020-01.5	50	N012-020-01.5	50	N016-020-01.5
M20 x 2	30	32.95	16	50	N010-020-0002				
M22 x 1.5	32	35.03	18	50	N010-022-01.5	50	N012-022-01.5	50	N016-022-01.5
M22 x 2	32	35.03	18	50	N010-022-0002				
M24 x 1.5	36	39.55	19	50	N010-024-01.5				
M24 x 2	36	39.55	19	50	N010-024-0002			50	N016-024-0002
M27 x 1.5	41	45.2	22	25	N010-027-01.5				
M27 x 2	41	45.2	22	25	N010-027-0002				
M30 x 1.5	46	50.85	24	25	N010-030-01.5				
M30 x 2	46	50.85	24	25	N010-030-0002			25	N016-030-0002
M30 x 3	46	50.85	24	25				25	N016-030-0003
M33 x 1.5	50	55.37	26	10	N010-033-01.5				
M33 x 2	50	55.37	26	10	N010-033-0002				
M36 x 1.5	55	60.79	29	10	N010-036-01.5				
M36 x 2	55	60.79	29	10	N010-036-0002				
M36 x 3	55	60.79	29	10	N010-036-0003				
M39 x 3	60	66.44	31	1	N010-039-0003				
M42 x 3	65	71.3	34	1	N010-042-0003				
M45 x 3	70	76.95	36	1	N010-045-0003				
M48 x 3	75	82.60	38	1	N010-048-0003				

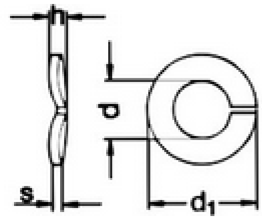
DIN 128A

Lock Washers

Spring Steel

Spring Form "A" (Curved)

W043 - 128A Zinc Plated



For Screw	d	d_1	s	h		Pkg.	Order #
				min.	max.		
M4	4.1	7.6	0.8	1.2	1.4	100	W043-004-0000
M5	5.1	9.2	1	1.5	1.7	100	W043-005-0000
M6	6.1	11.8	1.3	2	2.2	100	W043-006-0000
M8	8.1	14.8	1.6	2.45	2.75	100	W043-008-0000
M10	10.2	18.1	1.8	2.85	3.15	100	W043-010-0000
M12	12.2	21.1	2.1	3.35	3.65	100	W043-012-0000
M14	14.2	24.1	2.4	3.9	4.3	100	W043-014-0000
M16	16.2	27.4	2.8	4.5	5.1	100	W043-016-0000
M18	18.2	29.4	2.8	4.5	5.1	100	W043-018-0000
M20	20.2	33.6	3.2	5.1	5.9	100	W043-020-0000