Design of a Lifting Platform for People with Locomotive Disabilities to be used on a Campus Bus
Design Studio/INEGI

Andreea Ştefan

Diploma Project
Orientador na FEUP: Prof. Fernando Gomes de Almeida

Faculdade de Engenharia da Universidade do Porto
Mestrado Integrado em Engenharia Mecânica

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Summary

The project's aim is to create a mechanism that will facilitate the transportation of people with disabilities (students and teachers) in a campus bus. This will encourage the integration of disabled people in the community and will also consist a technical challenge for the designers.

Practically the project has two main parts: researching the field to find all the necessary information and data related to such a mechanism, and the second part being the actual design of the mechanism.

For the first part my colleague Ioana Adina Neacsu and I talked to specialists, personnel responsible with the rehabilitation of people with disabilities and manufacturers of equipment needed for our project. We analyzed the strengths and weaknesses, the parts we should insist on, creating a hierarchy of the most important issues that are primary for the project. This analysis was made from two points of view, from the passenger's point of view and from potential customer's point of view, that may be interested in buying our product. The second part implies strength and dynamic calculations, 3D simulations, design and selection of proper technologies that would be used for the mechanism.

The results obtained are summarized in the last chapter, consisting of conclusions of the work that has been made.

Acknowledgment

We would like to express our thanks to a series of professors from both the host and home universities that offered us their support throughout the our work on this project:

- coordinators: prof. Fernando Gomes de Almeida, University of Porto and prof. Stefan Pastrama, Department of Mechanical Engineering, University POLITEHNICA of Bucharest.

- professors: Jorge Lino from INEGI, Carlos Aguiar and Xavier Carvalho from Departamento de Engenharia Mecânica e Gestão Industrial, FEUP and prof. Tiberiu Laurian and prof. dr. Traian Cicone, Department of Mechanical Engineering, University POLITEHNICA of Bucharest.

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We are grateful as well to Carla Monteiro, Assistant to EDAM and Transportation Systems MIT PT, and to our colleague Ricardo Almeida, IT & PM consultant, MIT Portugal, PhD student from the Design Studio in FEUP where we performed most of our work on the project.

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Detailed Content

Note: The content of this project is an integrated part of a team project I shared with my colleague Ioana Adina Neacsu. Her project, entitled *Concept generation and integration of a lifting mechanism on a campus bus* contains the complementary data in the design of the mechansim and therefore, several references were done to her work during my project.

The *Concept Development* chapter is a team work that we split in two parts, as it can be noticed in the detailed content below.

In the *Briefing on the Dynamic Analysis* chapter, I made reference to my colleague's work, as a consequence of the strong interrelationship that exists between the two projects.

The Part B of the *Actuation Technology and Detailed Operation Procedure* chapter briefly presents the complementary work done by my colleague, in order to emphasize the entire set of components and devices used for this mechanism.

1. Abstract

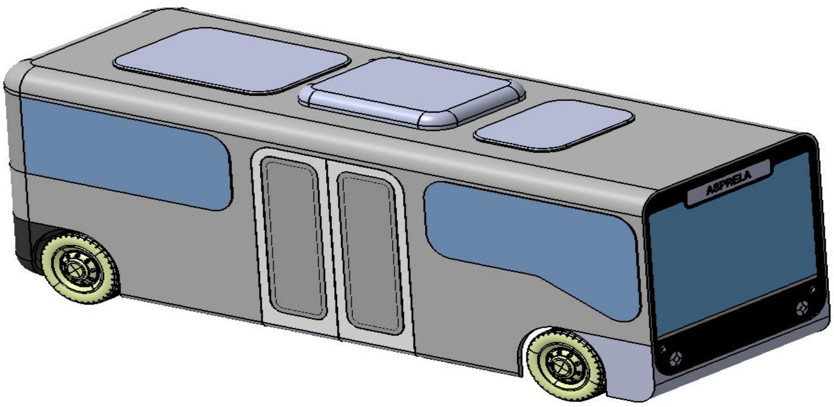
The objective of this thesis is to design a lifting device that facilitates getting in/out of an existing bus of the people with locomotive disabilities.

The present work makes part of the CIVITAS project that is going on at the Faculty of Engineering – University of Porto, Portugal. The CIVITAS project involves the design of a campus bus out of an existing one, that the Faculty has in its possession. Our target is to develop the best solution for the lifting device, taking into account the physical and material constraints as well as the passenger's safety and easy accessibility of the device.

Nowadays there exist a set of lifting devices that have been implemented on a limited number of public transport busses, on specialized or on personal vehicles. The device developed in this thesis reveals a relatively new concept that is fitting the space, safety and easy-access requirements of the project bus.

To achieve the goals of this project, we followed the product design methodology from specialized books that lead us to the final concept which was submitted to structural analyses and that will be furthermore optimized and animated using a computer aided design program.

Careful consideration of functional and physical domains guided us to an effective solution to this design problem. This solution is viable from the point of view of structural analysis and with continued work we hope that it may someday come to fruition as an effective and useful product.



CIVITAS Campus Bus

2. Purpose of the project

The project consists in the development of the product until the stage of an analytical prototype and its modeling, the next stages being continued by the time the material resources are available.

The first aspects of the project were identified in order to be able to start the process of design. Among them there are:

a) Operating Environment. The device will be mounted on a bus that will circulate inside a student campus, with wide roads, 5 days per week.

b) The product has to be able to lift all types of wheelchairs(standard wheelchairs) and the maximum possible weight for these cases, which is 350kg.

c) The product has to adapt to the constraints of the bus design:

- space inside the bus
- time of operation
- safety
- stability
- accessibility.

3. Concept development

3.1.1 Identifying the customer needs

Like any other product, our attention as producers is focused on the customer needs. The concept of customer in our case can be split into two categories:

- the effective users of the lift, and
- different companies that wish to implement our mechanism on various buses.

The possible buyers of the mechanism shall be referred to as *customers*, while the term *users* will be used for the real beneficiaries of the lift (people with locomotive disabilities).

In this paragraph we will be discussing in parallel about both types of needs (customers and user needs).

3.1.2 Gather raw data from customers and users

According to the statistics performed by the Bureau of Transportations Statistics - U.S. Department of Transportation, when having to use a lift mechanism, users think about safety and the ability to use the lift first. Other factors include the size of the user, wheelchair size, and how else the van will be used- weather is a normal bus, or a private bus designed especially for disabled people.

From the point of view of customers buying the idea, other issues might be of a greater importance: total cost, maintenance cost and difficulty, easy to be adapted to more types of buses or how much does the mechanism respect the rules and regulations referring to lifts of people with disabilities.

Observing the product in use helps producers notice important details about customer/user needs. During a visit in a rehabilitation center in Gaia (Centro de Reabilitacao Proffisional de Gaia), we took notice of two main solutions for getting disabled persons into the bus:

- side ramp, fulfills its main function and is cheap- advantage to the customer, but needs an additional person that helps the person in the wheelchair to get on the bus- disadvantage for the user;

- folding platform that consists of a metal plate that goes outside the bus, and through an hydraulic actuation, it transports the wheelchair inside the bus. The main drawbacks are that the controller for this system is not available directly to the user (so again another person is needed to hold the controller), and that the security fixing inside the bus cannot be performed by the user himself.

3.1.3 Interpret raw data in terms of customer needs

From the point of view of users the following needs have been identified:

- To lift the desired weight
- Simple actuation
- Safety outside
- Safety inside
- Easy access
- Relatively short time of operation
- Back-up system
- Stability

From the point of view of customers the following needs have been identified:

- Low Cost
- Easy Adaptable
- Long life
- To lift the maximum weight
- Suitable for a wide range (from standards) of wheelchairs
- Is lightweight
- Short time of operation- when used
- Can be accessed for maintenance
- Utility cost
- Allows easy replacement of worn parts
- Not to interfere the well functioning of the other parts of the bus
- Low noise level
- Small overall dimensions
- Adaptable to different levels of ground
- Light for night operation
- Operational Environment

3.1.4 Organize the needs into a hierarchy

The goal of this step is to organize the above needs into a hierarchical list so that the result is avoiding work with a large number of detailed needs which are difficult to summarize for use in subsequent development activities.

The list will consist of a set of primary needs, each one of which will be further characterized by a set of secondary needs. The triple-star symbol signifies the highest importance.

***To lift the desired weight

***Safety outside

The mechanism is stable

The mechanism is perfectly horizontal

The mechanism has anti-slip surface

The mechanism has a threshold warning signal

The mechanism has handrails

The mechanism has edge guards

***Safety inside

The mechanism provides security belts inside the bus

***Long life

The mechanism survives heavy use
The mechanism can be easily maintained
The parts can be easily changed

**Simple actuation

The mechanism can be actuated by simple button pushes.

**The mechanism is stable and vibration free
**Low Cost

The device should not exceed the average price of similar products on the market, but opposite, being economically reliable.
**Easy Adaptable
    The mechanism is designed to work on more types of buses
**Suitable for a wide range (from standards) of wheelchairs
    The mechanism works with electric wheelchairs
    The mechanism works with manual wheelchairs
*Is lightweight
    The mechanism's parts are made, where possible, from aluminum and lightweight materials
**Short time of operation- when used
    The mechanism performs the least number of movements
**Utility cost

The mechanism consumes little energy and fuel.

*Low noise level

The parts in motion permit lubrication to reduce noise

The mechanism is phonic isolated

*Small overall dimensions

The mechanism fits easily in the structure of the bus

The mechanism occupies little space inside the bus

**Adaptable to different levels of ground

The mechanism detects the level of ground

*Light for night operation

The mechanism has intermittent lights delimitating the operating space

* Easy access
* Relatively short time of operation
* The mechanism has a manual back-up system

3.2. Product Specifications

3.2.1. Establishing target specifications

Customer needs are generally expressed in the ´language of the customer´ being helpful in developing a clear sense of the issues of interest to clients. Even so, they provide little specific guidance about how to design and engineer a product, therefore, at this level our aim (the development team) is to establish a set of specifications which spell out in precise, measurable detail what the product has to do. A specification consists of a *metric* and a *value*. For example, ´average time to get the wheelchair inside the bus´ is a metric, while ´less than 15 seconds´ is the value of a metric. Thus, in the early stage of development, the product specifications have been identified and only after this we can proceed to design the product that will meet those specifications.

For establishing the specifications of the product we followed the steps below:

a) Prepare the list of metrics

The most useful metrics are those that reflect as directly as possible the degree to which the product satisfies the customer needs. The importance of a metric is derived from the importance ratings of the needs it reflects.

<u>THE NEEDS-METRICS MATRIX</u>

The rows of the matrix correspond to the customer needs, and the columns of the matrix correspond to the metrics. A mark in a cell of the matrix means that the need and the metric associated with the cell are related. Performance relative to the metric will influence the degree to which the product satisfies the customer need.

NEEDS / METRICS	Integrated led /light to lighten the platform area	s exactly two operations made by the passanger	Perfect horizontal	Minimum edge shield	Smooth operation (acceleration, vibration..	Blocking system (belts)	Anti-slip surface	Aid handle bar	Max. weight	Effort done by the passenger	Time for the passanger to get in the bus	Time for a complete operation (in and out of the bus)	Manual actuation in case of device breakdown	Vibration free	Stiff (deformation)
Lifts the desired weight									x						
Simple actuation		x													
Safety outside			x	x	x		x	x							
Safety inside						x									
Easy access										x	x				
Relatively short time of operation												x			
Back-up system													x		
Stablility														x	x
Low Cost															
Easy Adaptable															
Long life															
To lift the maximum weight									x						
Suitable for a wide range(from standards) of															
Is lightweight															
Short time of operation- when used															
Can be accessed for maintenance															
Utility cost															
Allows easy replacement of worn parts															
Not to interfere the well functioning of the other parts of															
Low noise level															
Small overall dimensions															
Adaptable to different levels of ground															
Light for night operation	x														
Operational Environment															

Table 3.1 Needs-Metrics Matrix

METRICS / NEEDS	Competitive price?	done by the mechanic to install inside the bus vs the time	Durability(osa punem in number of cycles, depinde de mecanism)	Total mass	Time to disassemble /assemble for maintenance	Energy and fuel consumption	Special tools required for maintenance	Noise atenuation	Small volume of the device inside the bus	Platform's range of descent	Dimensions of the platform	Time for a complete operation of the device (in and out of the bus)	Dimensions of the platform or the surface that holds the wheelchair	Frequency of usage
Lifts the desired weight														
Simple actuation														
Safety outside														
Safety inside														
Easy access														
Relatively short time of operation														
Back-up system														
Stablility														
Low Cost	x													
Easy Adaptable		x												
Long life			x											
To lift the maximum weight														
Suitable for a wide range(from standards) of											x			
Is lightweight				x										
Short time of operation- when used												x		
Can be accessed for maintenance					x									
Utility cost						x								
Allows easy replacement of worn parts							x							
Not to interfere the well functioning of the other parts of														
Low noise level								x						
Small overall dimensions									x		x			
Adaptable to different levels of ground										x				
Light for night operation														
Operational Environment														x

Table 3.1 Needs-Metrics Matrix-Continuation

b) Development of a cost model of the product

The purpose of this process is to make sure that the product can be produced at the target cost. The target cost refers to the manufacturing cost at which the company can make adequate profits while still offering the product to the end customer at a competitive price. It is also a kind of performance model, but instead of predicting the value of a technical performance model, it predicts cost performance.

In order to estimate the first manufacturing costs, a bill of materials is drafted, which contains a list of all parts and the estimation of the fabrication or purchasing price for each component. The bill of materials is useful throughout the development process and is updated regularly to reflect the current status of the estimated manufacturing cost.
At this point of concept development, in the above mentioned list cannot yet be included all the components because of the complexity of the product itself. Table 3.1shows the major components and the subsystems with their corresponding cost boundaries.

Table 3.2 Bill of materials with cost estimates

Component	Quantity	High[€]	Low[€]	High total[€]	Low total [€]
Platform structure	1	120	75	120	75
Platform	1	100	90	100	90
Aid-Handle bar	1	20	10	20	10
Principal arm	1	90	75	90	75
Secondary arm	4	30	15	120	60
Middle bearing	2	50	40	100	80
Side bearing	8	25	15	200	120
Hollow square profile	2	50	35	100	70
Bushing	6	10	8	60	48
Translation system	2	2000	1500	4000	3000
Backup system	1	50	40	50	40
Hydraulic Cylinder	1	750	500	750	500
Hand pump	1	400	200	400	200
Belt system	1	50	40	50	40
Movable floor	1	50	30	50	30
Electric motor with gearbox	1	110	80	110	80
Ramp	1	15	10	15	10
Bolts and screws	20	5	2	100	40
Total				6435 €	4568€

3.3 Concept Generation

The concept generation began with a set of customer needs and target specifications and it continued with a sequence of steps that imply the use of some classical tools in the concept development process. In the end it has resulted in a set of product concepts from which the final one was selected on the basis of a continuous refinement. The Concept Generation process is also developed using the tools from the *Product design and development* book.(no. 1 in the Bibliography section).

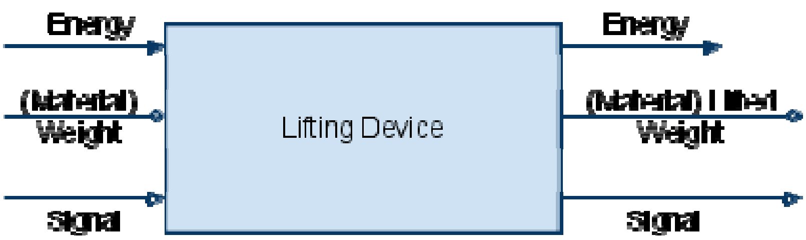
3.3.1. Clarify the Problem

After reflecting upon the general understanding of the purpose of the project we decomposed the overall problem into smaller problems as it follows:

Electrical Energy --»Convert Electrical Energy into Mechanical Energy --»Store Energy---»Apply Mechanical Energy to the Device

The starting point is sketching our product as a black box with main inputs and outputs, also known as Overall Functional Decomposition, as it can be seen bellow:

Overall Functional Decomposition



The main functions of the product are the inputs of the black box (see sketch above).

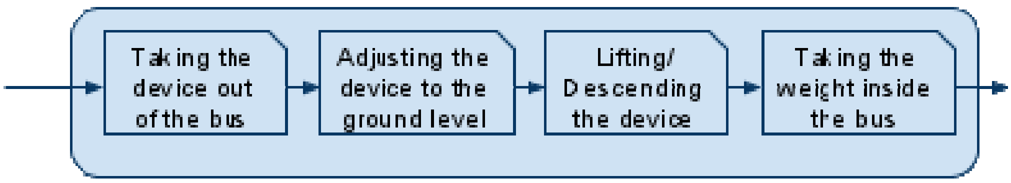


Figure 3.1 Applying Mechanical Energy to the Weight Function

Refinement of the Functions

A more specific description of the problem is obtained by refining the functions into sub-functions. Each sub-function describes a specific operation or category of operations in order to sum up for the overall function of the product. This process is repeated until we establish that each sub-function can be analyzed separately without implying a specific technological working principle for the product concept.

For example, the *Applying Mechanical Energy to the weight* sub-function will be further split including sub-functions such as *Taking the device out of the bus* sub-function that will involve the sequence all actions that will lead to the fulfillment of that specific sub-function. Of course, it is here where the designer has the freedom to develop many ideas and limit the concepts to a reasonable number that will be analyzed further.

Once the problem decomposition has been completed, we have decided to focus on the analysis of the critical sub-functions. Each of the sub-functions will end by being analyzed taking into account their importance.
The primary sub-function that consists the major interest of the project and that will be analyzed in the next paragraphs is the application of the mechanical energy to the lifting device, the set of movements that will ensure the entire operation of lifting and getting in/out of the bus (see *Figure 3.1*).

3.3.2 Search externally

During the concept generation stage external search helps to find existing solution to both the overall problem and to the sub-functions previously identified. There are more ways of gathering this kind information, among of them we have used: consulting experts, search patents and search published literature.

Consulting experts is an efficient way of gaining knowledge from experienced professionals that have encountered one or more of the sub-functions that the project is facing. Also, experts can redirect the search in a more specific area which usually returns useful information.

The experts we interacted with during our project work and the information we gathered from there are briefly described bellow:

1) **CRPG** (Centro de Reabilitacao Profissional de Gaia, near Porto city, Portugal) is a platform of specialized resources, to support people whose career was affected by illness or accident, rehabilitating or converting them professionally at the contexts of work, promoting their adaptation and adjustment, thus enabling the continuation or resumption of employment.

The purpose of our visit was to observe closely the functioning mechanism of a lifting platform for people with disabilities mounted on a special van, and thus to notice which are the drawbacks of such a system, what can be improved and which is the opinion of the end-user.
Also, we have gained information about the restrictions imposed by law when designing such a device as follows:

- the minimum available space provided inside the bus (and also on the lifting platform) should be 0.75x1.0 [m]
- the precision stop until the level of the ground should be higher than +/-0.02 [m]
- if the level difference between the floor and the platform is greater 0.75 [m] protection bars or doors at the access of the platform must be available
- all the edges of the platform (except the ones that allow access) must have protection shields of at least 0.1 [m]
- the control of the platform must be visible.

2) **ABER** is a manufacturer of hydraulic equipments and specialized on elevation systems for both heavy industry and home applications. As featured products we can mention gear pumps, oil bent hydraulic motors, hydraulic tipping valves and various models of flow dividers. The discussion with one of their specialists lead us to consider hydraulic actuation as a feasible solution for our lifting problem. Hydraulics offer a good power/weight ratio, are highly reliable with minimum maintenance, can withstand over-loads without damage, are simple to control and have a high rigidity.

The visit to ABER also provided us an insight on the elevation systems, especially on the manufacturing and principle of functioning of the scissors linkage as well as on the hydraulic network, the overall dimensions a hydraulic equipment can have and the way you can purchase it.

Search patents

We have found on United States Patent website several manufacturers that represent a rich source of technical information, containing detailed drawings and explanations of how similar already existing products work. The information we found helped us in our concept development and will be stored in the Bibliography part of the project.

Published Literature

Published literature includes journals, conference proceedings, trade magazines, government reports, market, consumer and product information. Thus we have conceived a list of sources of information of existing solutions, mainly using engineering references such as Mark's Standard Handbook of Mechanical Engineering and Mechanisms and Mechanical Devices Sourcebook. This part will be included as well to the project's annexes.

3.3.3 Search internally

Following both individual and group working sessions regarding the sub-problem of conversion of energy and set of movements needed for the entire operation of the device, we have made a table with possible solutions for each of the sub-functions involved(*see Table 3.2*).

Table 3.3 Possible Solutions for the implementation of the Actuation Sub-function

Solutions to the sub-function of Taking the device out of the bus	**Solutions to the sub-function of Adjusting the device to the ground level**	**Solutions to the sub-function of Lifting/Descending the device**	**Solutions to the sub-function of Taking the device inside the bus**
Hydraulic equipment	Proximity Sensors	Arm Actuation	Linkages
Pneumatic equipment	Springs	Cam Actuation	Pneumatic equipment
Linkages	Hydraulic Cylinder	Rack Actuation	Worm drive gearing
Ballscrews	Pneumatic Cylinder	Pneumatic cylinder	Ballscrews
Worm drive gearing	Cam	Rotary hydraylic cylinder	Hydraulic equipment
Leadscrew driver			Leadscrew driver

3.3.4. Explore systematically

Using a systematic exploration we have analyzed the space of possibilities by organizing and synthesize the solutions we concluded in previous paragraph(*see Table 3.3*).

There exists two specific tools that we have used in our work for managing the complexity of the problem and organizing the thinking, and these are the concept *Classification Tree* and the *Concept Combination Table*.

The *Concept Classification Tree* is used to divide the entire space of possible solutions into several distinct classes which will facilitate comparison and pruning. We have used the classification tree to show the alternative solutions to the energy source sub-function.

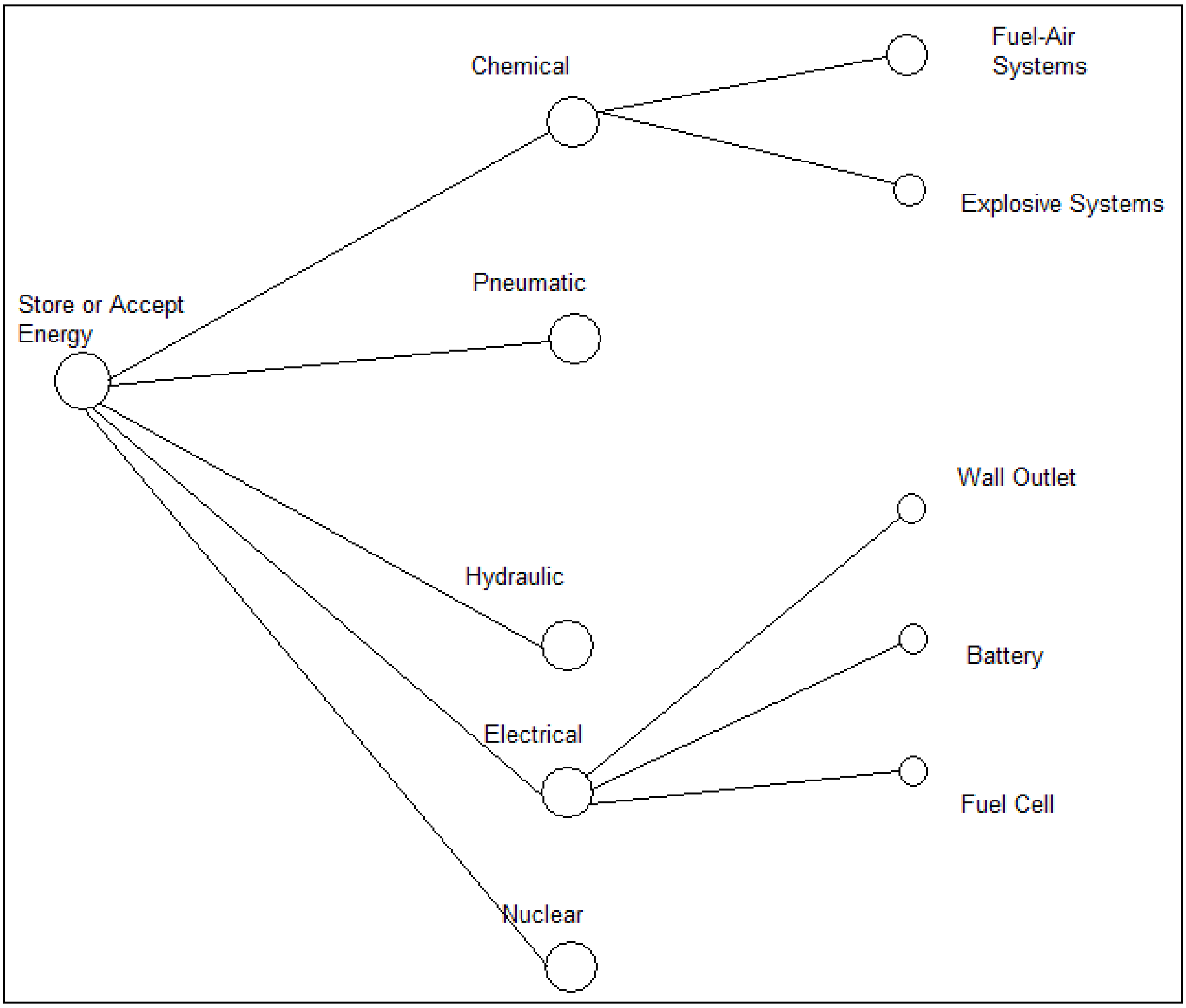


Figure 3.2 Concept Combination Tree

The *Concept Combination Table* provides a way to consider combinations of solution fragments systematically. The columns in the table correspond to the sub-functions identified in an earlier stage. For example the sub-function of Applying Mechanical Energy to the Weight and its sub-functions are headed in the columns bellow. The entries in the column of the Taking the Device out of the Bus function are a hydraulic equipment, a lead screw driver, a solenoid or a worm drive gearing.

Partial solutions to the overall problem are formed by combining one fragment of each column. The combination of fragments are refined before an integrated solution emerges(*Table 3.4*).

Table 3.4 Concept Combination Table for the Actuation Function

Taking the device out of the bus	Adjusting the device to the ground level	Lifting/Descending the device	Taking the device inside the bus
Hydraulic equipment	Springs	Hydraulic Arm Actuation	Linkages
Leadscrew driver	Proximity Sensors	Cam Actuation	Leadscrews
Solenoids	Hydraulic Cylinder	Rack Actuation	Worm drive gearing
Worm drive gearing			Ballscrews

3.4 Concept Selection

3.4.1 Refine Concepts

The technical analysis made previously indicated us some potentially viable designs that will be presented in this paragraph. The selection process usually indicates a comparative analysis of the available design solutions. A decision matrix (*Table 3.5*) helps to identify the best solution by forcing one to consider a variety of factors in a systematic way.

<u>The decision matrix.</u>

The rows are dedicated to designs and the columns are assigned categories in which the designs are to be judged, such as cost, ease of use, efficiency, performance, reliability and any others that are appropriate to the problem.

Each category is then assigned a weight factor, which measures its relative importance.

Table 3.5. The decision matrix

	Cost	**Safety**	**Performance**	**Reliability**	**RANK**
Weight Factor	**0.25**	**0.35**	**0.15**	**0.25**	**1.0**
Design 1	**5**	**8**	**7**	**7**	**6.85**
	1.25	**2.8**	**1.05**	**1.75**	
Design 2	**4**	**7**	**6**	**5**	**5.6**
	1.00	**2.45**	**0.90**	**1.25**	
Design 3	**7**	**8**	**7**	**7**	**7.35**
	1.75	**2.8**	**1.05**	**1.75**	

The body of the table(*Table 3.4*) is filled with numbers which rank each design on a convenient scale, such as 1 to 10, in part. We have examined the designs and have scored each of them.

The scores are then multiplied by the weight factors(which are usually chosen so as to sum up to a convenient number such as 1) and the products summed for each design. The weighted scores then give a ranking of designs.

The Decision Matrix, in the way it is constructed in *Table 3.4* reveals the 3 most suitable concepts we concluded and that were analyzed at a more detailed level in the next paragraphs.

3.4.2 Expose final designs

After the entire analysis of the concept generation we have concluded 3 potential mechanisms that will be presented briefly in this paragraph. All three of them include the same type of element that stores the weight, more exactly a platform. The difference consists in the way of implementing the movements and the space the device needs for storing.

Design no. 1 Device and Platform Stored under the Bus

The **platform** is connected to two lateral supports with the help of two sets of actuating arms. The two lateral supports, are sliding on a shell casing that is mounted under the bus floor.

The actuating arms form a scissors linkage that ensures the vertical movement upwards and downwards.

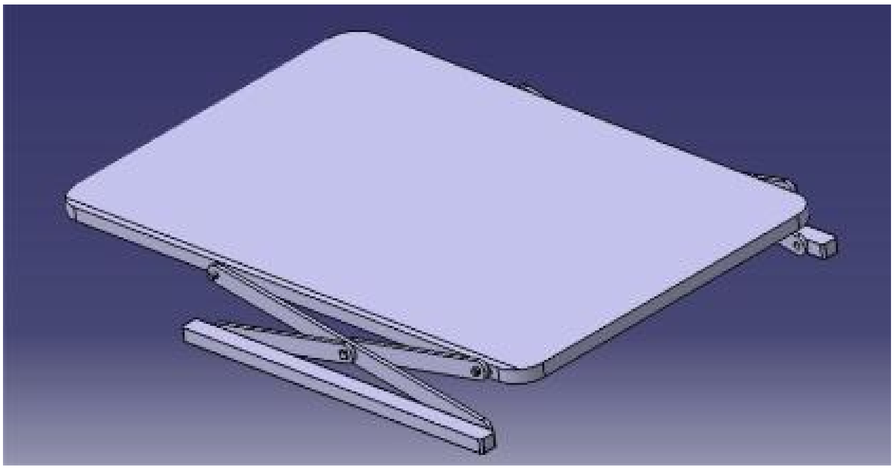


Figure 3.3 Scissors Linkage for the Concept no 1.

The movements that the platform is operating are:

- horizontal translation for the exit of the platform outside the bus,
- descending: from the mounting level to the ground – to take the passenger in wheelchair;
- lifting: from the ground to the level of the bus - effective lift.
- descending: to the storage level of the device;
- horizontal translation – takes the device inside the storage casing, under the bus level.

The scissors linkage is composed of 3 arms: one main arm and 2 complementary arms placed in parallel on both sides of the main arm, acting synchronously. The mechanism is actuated by the rotation of the main arm that implies the set of movements necessary to lift and to descend the platform in a smooth, safe and efficient way (*Figure 3.3*).

When the platform is outside the bus, it remains rigid due to the scissors linkages that exists between the supports and the actual platform. In order to achieve a perfect connection between the platform and the bus floor, it is required an additional mini-platform or a complementary movement of the main mechanism towards the interior level of the bus to ensure the smooth passing of the weight inside the bus. The second solution for leveling at the bus floor could be implemented by calculating exactly the lateral sliding of the scissors linkage while lifting, such that the platform itself could ensure the safe passing of the weight in/outside the bus.

Advantages:

- implies no space occupied inside the bus
- prevents lateral sway and misalignment
- storage compartment in order to prevent from weather conditions
- small overall dimensions and efficient storage

Disadvantages

- the mounting of the platform under the bus implies a lifting/descending of the scissors linkage above the sliding arms that reflects in a stronger and more complex actuation device for the linkage.
- the safety handle can not be mounted directly on the platform.
- it determines a relatively big height of the device that may affect the access of other passengers inside the bus on a simple basis – no stairs or the implications that the presence of stairs may add.

Design no. 2 – Device Stored Inside the Bus

This device also uses a platform for the lifting function, but in this case the platform is stored vertically, inside the bus, along with the other main components – arms linkage.

In this case the mechanism consists in two sets of arms, mounted directly on the lateral sides of the platform. Each set of arms has the shape of a parallelogram that will be actuated hydraulically in order to take the platform out of the bus but it also ensures all the movements necessary for an efficient process (*Figure 3.4*).

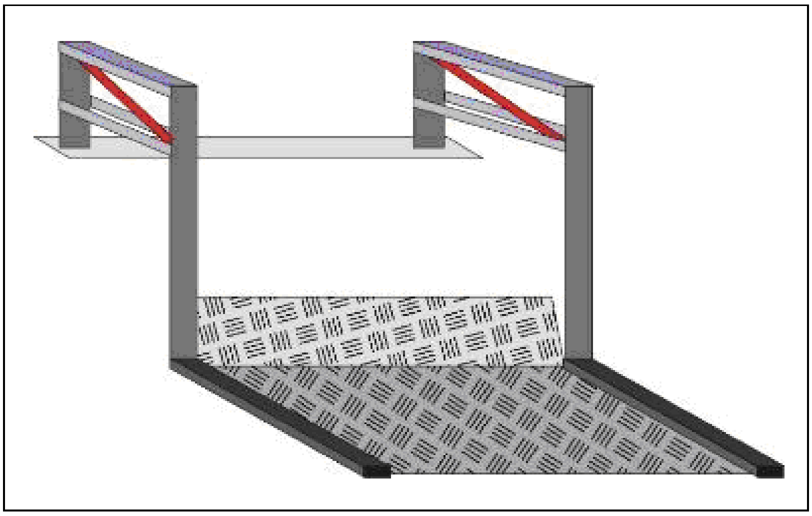


Figure 3.4 Lifting mechanism for the Concept no. 2
(mechanism in the interior of the bus).

The movements developed by this mechanism are the following:

- rotation of the platform from vertical to horizontal position while also performing a part of the process of descending towards the ground level.

- descending the platform to the ground level and the reverse process which has the exact characteristics.

The whole mechanism is sustained by the parallelogram structure of the arm, actuated by a hydraulic cylinder placed diagonally inside the structure (see *Figure 3.4*.)

Advantages:

- With dual hydraulic lifting arms, it provides a strong reliability and safety by its lift strength and dependability for a long usage period.

- The hydraulic actuation of the arm structure is compact and ensures alone the majority of necessary movements, implicitly the reversed ones.

- Quiet and very stable mechanism

Disadvantages:

- As we are dealing with a small campus bus, both the dimensions of the platform, linkages and the actuating system for such a mechanism are very large. This makes this concept, though quiet, reliable and stable, unsuitable for our design case.

- The bus is provided with only one door and it is projected for the use of all students in the campus. Therefore, the storage of such a design would either block the entrance for other passengers or an eventual solution of splitting the platform inside the bus, would still occupy considerable space.

- More expensive than the previous one.

Design no. 3 – Device under the bus, platform at the bus level.

This concept places the main part of the mechanism bellow the interior level of the bus, having the platform stored as an integrated part of the bus floor.

The device is composed of two main mechanisms:

- a sliding mechanism – that takes the platform out of the bus and brings it back in;

- a lifting and descending mechanism – lifts the platform from the ground level to the bus floor level on the exterior part; this mechanism fully ensures the reversed operation.

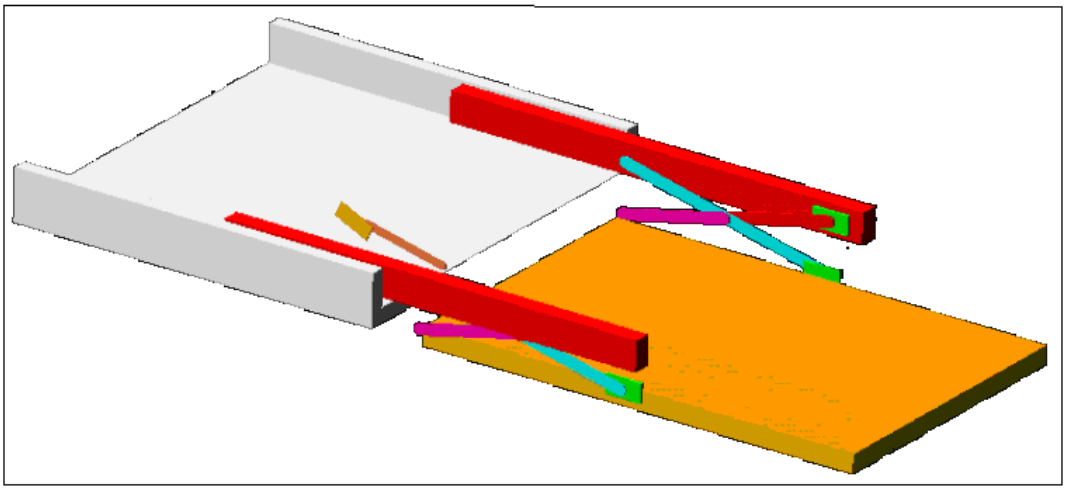


Figure 3.5. Scissors Linkage – ADAMS model.

The scissors linkage mechanism used in this concept is similar to the one used for the first concept. This time tough, the movements are limited only between the sliding arms(supports) level and the ground level. More exactly, the scissors linkage has the role of lifting and descending the platform only between two levels(*Figure 3.5*).

Advantages:

- takes less space inside the bus
- prevents lateral sway and misalignment
- implies a smaller lifting distance as compare to the first concept
- fewer movements which performed by a less complicated mechanism.
- storage compartment in order to prevent from weather conditions
- the safety handle can be mounted directly on the platform.
- the storage of the platform at the bus floor level ensures the passing of other passengers as well.

Disadvantages:

- the sliding mechanism of taking the platform in and out of the bus would have to ensure the sliding of the weight.(which in the first case was not necessary).
- It requires a precise calculation of the space in which it can be mounted and optimal arrangement of the components.

3.5 Final Concept

3.5.1 Analyzing the mechanism

After performing a systematic and overall comparison between the 3 concepts we concluded that concept that will define our product is the concept no.3 that will consist the subject of the further analyses in our project.

Bus Floor Integrated-platform lifting device – final concept

The concept no.3 (*Figure 3.6.*) has proven to be our final decision and therefore, from now on the project will be focused on the design of this mechanism.

A detailed description of the chosen concept will be given bellow and, together with the input data of the project, they will consist the basis of further analyses.

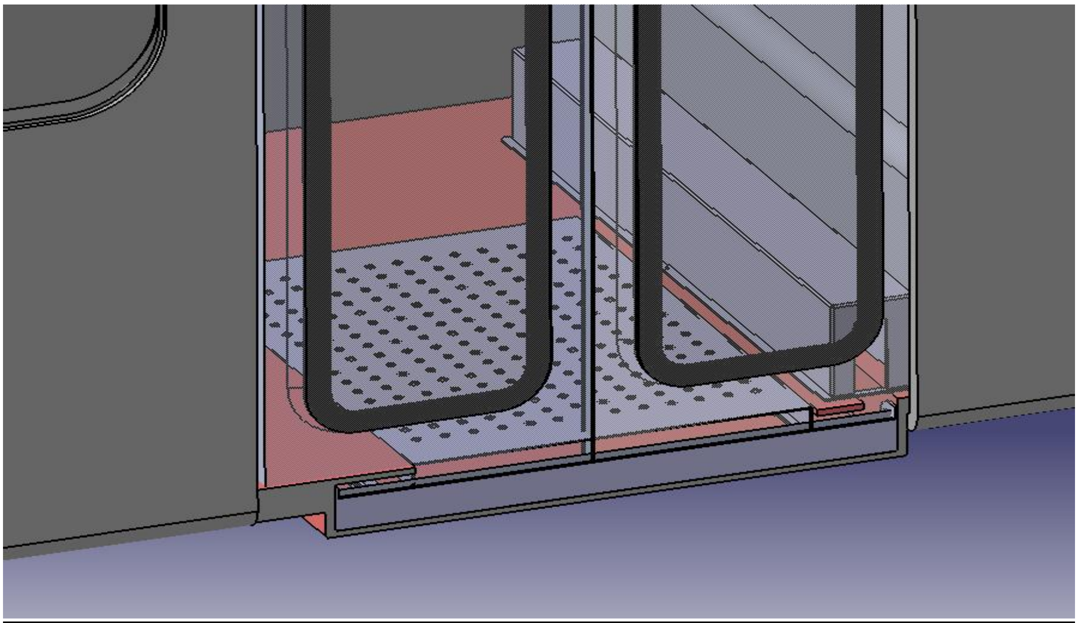


Figure 3.6. Final Concept, CATIA model – Design no.3

This concept involves the following main mechanisms:

- *the main mechanism*: - a scissors linkage, that enables the lifting and descending of the platform.

- *the translation mechanism* : - a sliding assembly will pull and push the linkages, supports and platform, in and out the storage place.

- *Ramp-movement mechanism* : - that actuates the ramp attached to the front side of platform.

All these mechanisms come together with a set of *sensors* that are placed in the key points of the device, in order to ensure the smooth and efficient succession/superposition between all movements involved(*Figure 3.7*).

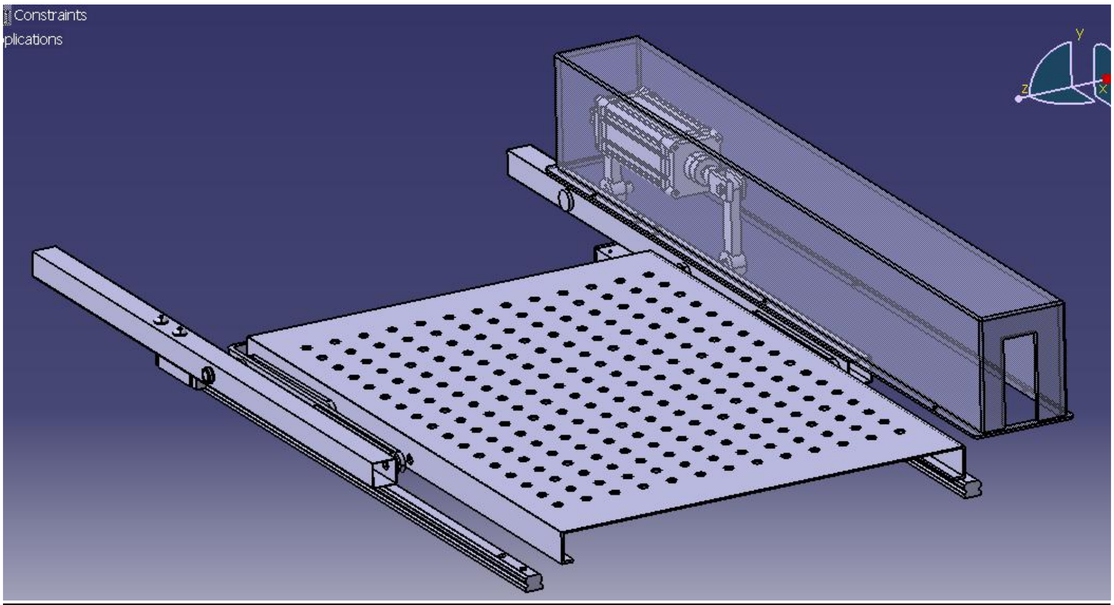


Figure 3.7 3D CATIA model of the final concept – Initial position, in the bus.

Choosing the type of actuation of the scissors linkage

One of the main concerns of the project was to choose the right type of actuation for the lifting and the lowering of the platform. We decided to keep the idea of using a cylinder, for reliability, controllability and functionality reasons. But making the choice between using a hydraulic or a pneumatic cylinder was based upon the following factors:

- hydraulic systems can develop much higher pressures, thereby producing much higher forces in actuated components.
- the hydraulic fluids are incompressible
- hydraulics give very smooth motion of actuated components, since there is no "bounce" due to the fluid compressing and expanding as in pneumatics.
- hydraulics can easily stop motion in the middle of actuator movement, where pneumatics (without a lot of additional effort) only accurately position at the end stops of actuator movement.
- the speed of actuator movement can be more accurately controlled in hydraulics because of the smooth motion as described above.
- pneumatic systems are often used instead because pneumatic pressure is usually cheaper to obtain, especially since most industrial facilities already have compressed air available.

Besides the characteristics of hydraulic equipment stated above, we can also mention the ability to hold loads rigidly, which is quite essential for our project.

Based on these facts, we can now confirm that the best solution for the lifting and lowering of the platform is using a hydraulic cylinder.

3.5.2 Design details of the final concept’s mechanisms

3.5.2.a Scissors Linkage mechanism.

As previously stated, this linkage will ensure big part of the purpose of the device, more exactly, to lift and descend a maximum weight at the desired level.

The linkage consists in a set of three arms connected in the following way: the main arm(the blue arm in *Figure 3.8*) is connected at its middle to the other two secondary arms (green and red arms in *Figure 3.8*). The two secondary arms are mounted one in the continuation of the other, each on one side of the main arm having a synchronous movement.

As stated previously, there will be two sets of scissors linkages, on both lateral sides of the platform. The main arms are linked together by a transmission rod at the back side of the platform, thus forming an U-shaped arm.

Each scissors linkage will be linked on one side to the platform and on the other side to the sliding arms. When the arms are in horizontal position, aligned with the platform, they will all translate along the sliding arms inside the bus.

The necessity of using three arms is due to the geometry and limitation of high stresses in the joints. The usage of only two arms would not make possible the lifting or descending movement due to the fact that the load to be lifted will be place between the arms and also due to the fact that the linkage implies a complete folding state(completely unachievable with a two arms design).

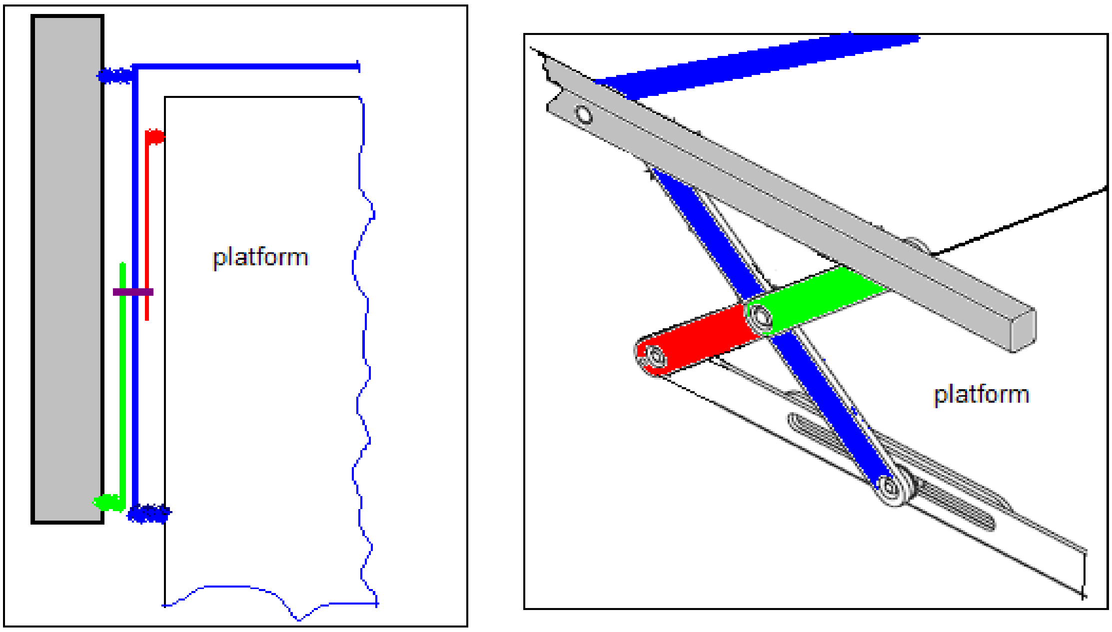


Figure 3.8 Sketch of Scissors Linkage mechanism

The lifting and descending movements of the arms involves small translation of the whole linkage, either to the left or to the right depending on the direction of actuation. This can be an important characteristic and it can also be useful if is integrated in the mechanism's purposes.

This translation is ensured by the existence of different types of joints according to the point of connection. There are joints that ensure only rotation, rotation and sliding or multiple joint(that links three arms).

The evolution of each joint's position in the arm linkage mechanism described above is shown in the *Figure 3.9*. More exactly, the possible positions are the following:

1) **ABC_1D_1 –** the maximum height position – the arms are completely streched;
2) **ABC_2D_2** – intermediary height and position
3) **ABC_3D_3** – the 0 position – the arms are fully folded in horizontal position aligned with the sliding arms and the platform.

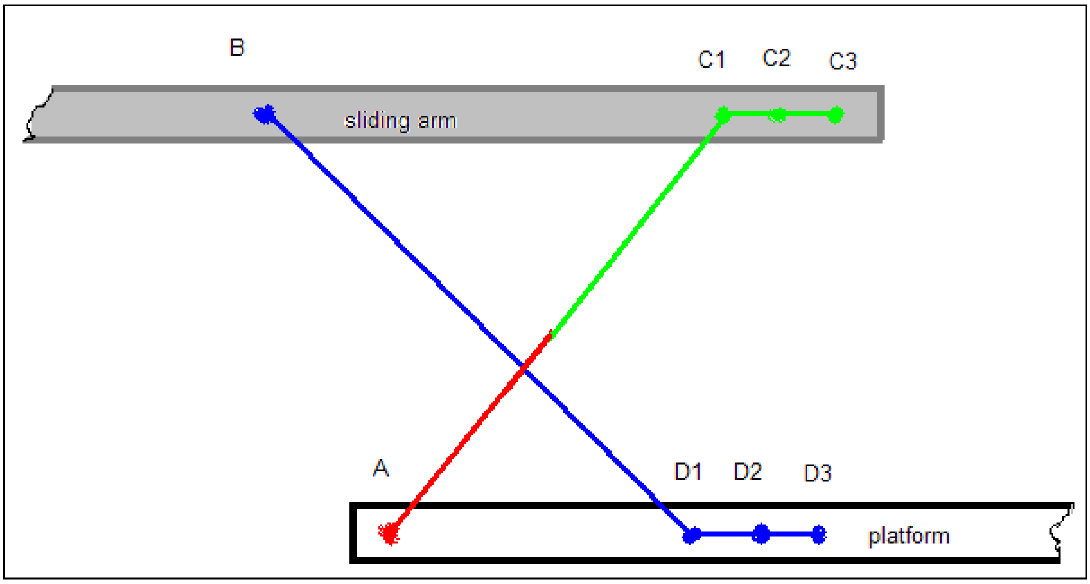


Figure 3.9 Evolution of the sliding joints relative to their support.

The support is thus sustaining one secondary arm(sliding joint) and the main arm(rotating one) which is connected to the actuation device that will be defined in a separate chapter.

3.5.2.b The translation mechanism.

The translation mechanism refers to the sliding of the platform from/towards the storage space, in our case, the bus floor. As we mentioned before, the supports of the platform are sliding on a shell casing from the storage level, that also contributes to the stability of the device.

The sliding device will be mounted on the shell casing as an intermediary between the latter and the platform.

The mechanism that will ensure this translation will be a sliding mechanism, connected to an electric motor, with a proper design that will fit the space(*Figure 3.10*). It will follow the principle of supporting the sliding arms and translate them along the maximum stroke until outside of the bus.

Once the supports are completely outside the bus, the main mechanism is ready to be actuated. A draft of the mechanism it modeled in the *Figure 3.10*.

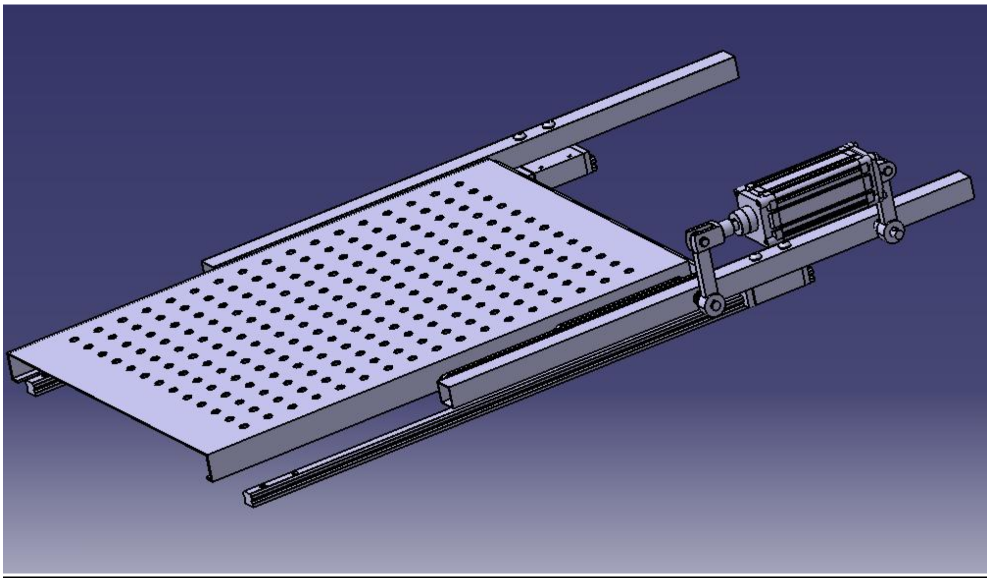


Figure 3.10 3D CATIA model of the assembly - Translation motion

3.5.2.c Ramp-movement mechanism.

Another important aspect is the ramp that will be mounted on the front side of the platform for the following reasons:

- connection of levels: it connects the platform with the ground floor when the passenger gets on or out of the platform(*Figure 3.11*).

- safety: except the moments when it connects the levels, it is stored in vertical position to ensure the safety of the person in the wheelchair during the lifting and descending operations.

The ramp will go down when the platform reaches the ground level at the signal of a sensor of proximity and will be lifted in vertical position after the person in the wheelchair gets on the platform/gets out of the platform.

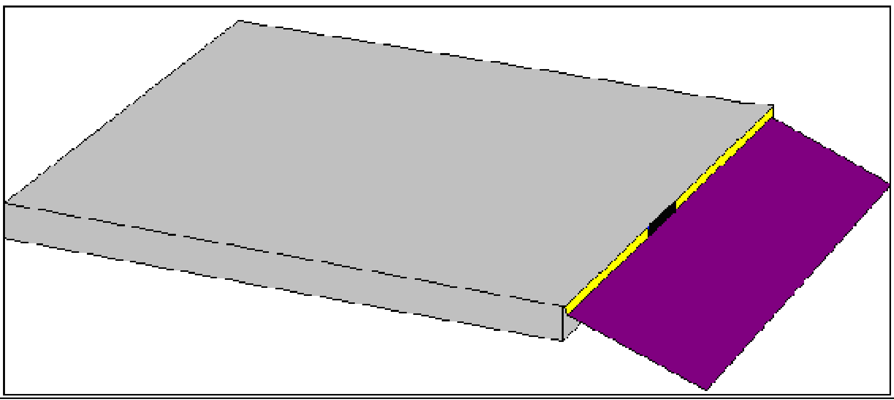


Figure 3.11 Front Ramp

The way in which this actuation will be done will be discussed in the actuation technology chapter.

The platform will have to be as light as possible, resistant and eliminate slippery effects.

4 Briefing on Dynamic Analysis

In this chapter, I will make a short summary of the work my colleague Ioana Adina Neacşu did in her project, *Concept generation and integration of a lifting mechanism on a campus bus,* focusing on the data I needed for the Strength Analysis chapter in my project.

Thus in the Dynamic Analysis chapter of the project mentioned above one there was performed a pre-dimensioning of the system, calculating the basic dimensions of the mechanism that will be the basis of the strength calculation. Thus, a value of 580 mm of the principal arm was obtained, 290 mm the length of one secondary arm, the distance between the edge of the platform and the main joint of the principal of 50 mm, the height at which the hydraulic cylinder is positioned to be of 150 mm.

An analysis was performed using the software ADAMS, Automatic Dynamic Analysis of Mechanical Systems, in order to test the virtual prototype and optimize design for performance, safety, and comfort. The conclusions of this analysis are outlined below.

Repartition in time of each motion

0…5 seconds : Horizontal movement to take the platform outside the bus

5…8 seconds : Vertical movement to lower the platform reaching the ground level

8…13 seconds:The platform remains on the ground, waiting for the passenger to go on it

13…16 seconds : Vertical movement to lift the platform and the passenger at the level of the bus

16…21 seconds : Horizontal movement to take the platform along with the passenger inside the bus.

- When the platform starts to descend, the secondary arms tend to travel backwards from the direction of the platform. When the platform ascends, the process is reversed
- The rod travels a distance of 50 mm from when the platform starts to move on the vertical direction
- The highest velocity in the system is of 0.4 m/s, which may appear quite high for such an application, but nevertheless this value is normal to be high at the beginning of the motion, due to the inertial forces.

- All graphics that plot the evolution of the forces in different joints show a sudden increase at time=10 seconds. That is the moment when the maximum force of 4200 N is applied in order to simulate the effect the passenger in wheelchair has on the platform. The most loaded joints are A (because the piston force is directed transmitted through the principal arm extension) and C.
- The maximum torque in the system is in joint A, but close to this value is, as expected, joint B
- The piston results in a power consumption of 430 Watt at most, while the sliding system has a maximum power consumption of 170 Watt.

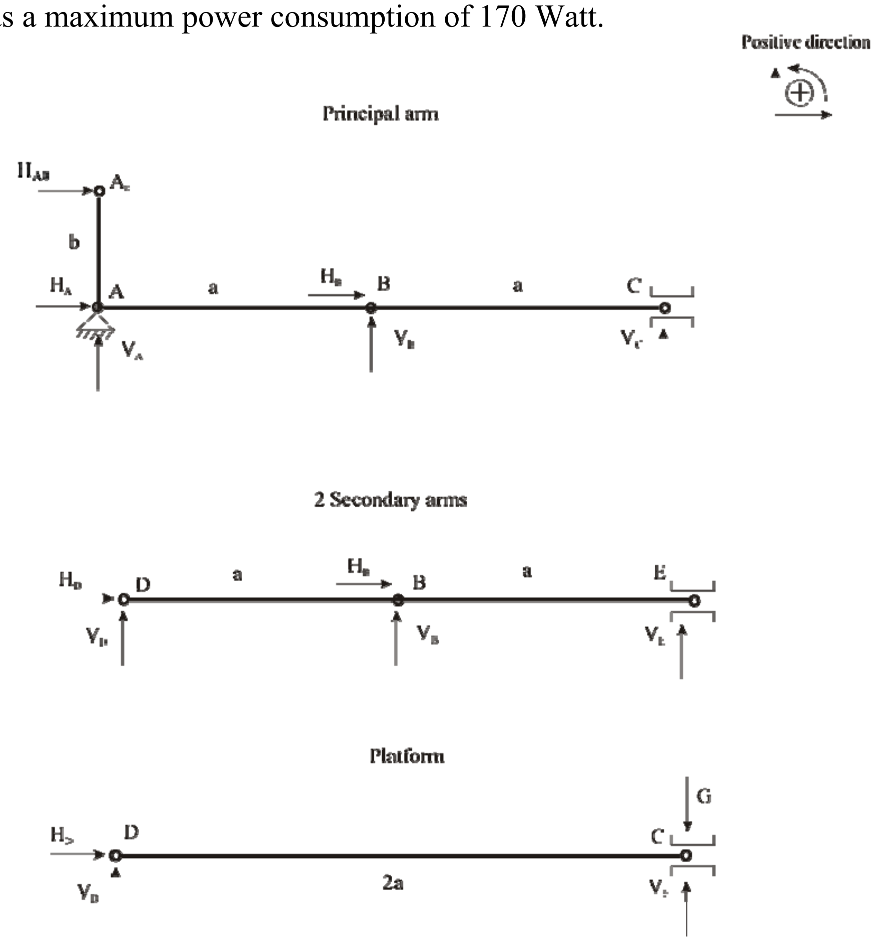


Figure 4.1 Forces acting upon our mechanism

a=290 mm [length of the secondary arm]

b=150 mm [height at which the piston is mounted]

c=20 mm [distance from the edge of the platform to the joint]

G=4200 N [maximum force on the platform]

$H_{A0}=-16240\ N;$	$H_B=0\ N;$	$V_D=144.828\ N;$
$H_A=16240\ N;$	$V_B=289.655\ N;$	$H_D=0\ N$
$V_A=4055.172\ N;$	$V_C=-4344.828\ N;$	$V_E=144.828\ N$

5. Strength Analysis

Once our mechanism was submitted to the static analysis in ADAMS software, the successful resulting model will be analyzed from the strength point of view in ANSYS software.

ANSYS structural mechanics solutions offer best-in-class simulation tools for product design and optimization that increase productivity, minimize physical prototyping and help deliver better and innovative products in less time.

Using this analysis we wish to recheck the model (verify the reactions resulted in ADAMS – see the project *Concept generation and integration of a lifting mechanism on a campus bus,* Ioana Adina Neacsu - Dynamic Analysis chapter), to define all the dimensions of the main components (platform, the set of 3 arms and the sliding arm), the materials and other characteristics of the mechanism.

5.1 Platform

As presented in a previous chapter, the platform consists of an Aluminium housing with Steel inner structure. The purpose of the shell is to reduce the weight of the platform and to ensure a non-slippery surface with the help of small holes that are manufactured on the housing.

Input Data of the Analysis:

a) Dimensions: - taken into account the standard dimensions for such lifting devices, we have chosen to work with a 850mm wide and 1200mm long platform.

b) Forces: - the force considered in the platform analysis is the maximum weight that can act on it: 350kg.

c) Constraints: - the 4 linking points have been fully constrained in order to perform the static analysis (see *Figure 5.1*)

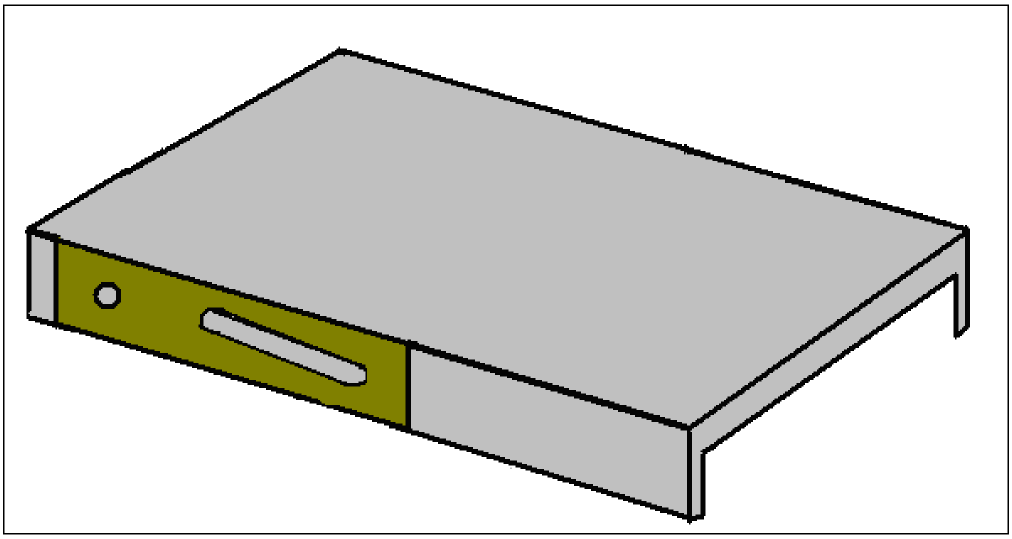


Figure 5.1 The two linking points with the arms on one side of platform

Processing

Starting from the input data, the other dimensions of the platform have been continuously improved by redesigning the rigid structure and the aluminium shell so as to reach a satisfying geometry, resistance and weight.

The rigid structure was meshed using BEAM188 3-D Linear Finite Strain Beam elements and the aluminum cover with SHELL63 Elastic Shell that has both bending and membrane capabilities(see *Figure 5.2* and *Figure 5.3*).

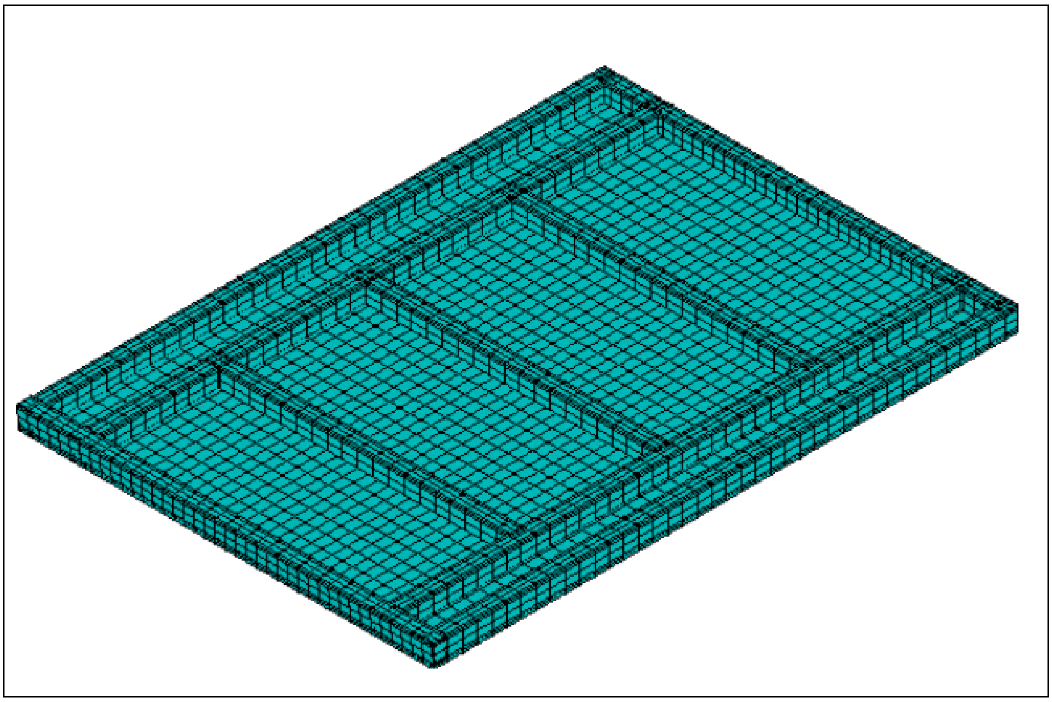


Figure 5.2 Platform Meshed Model – Rigid Structure Face

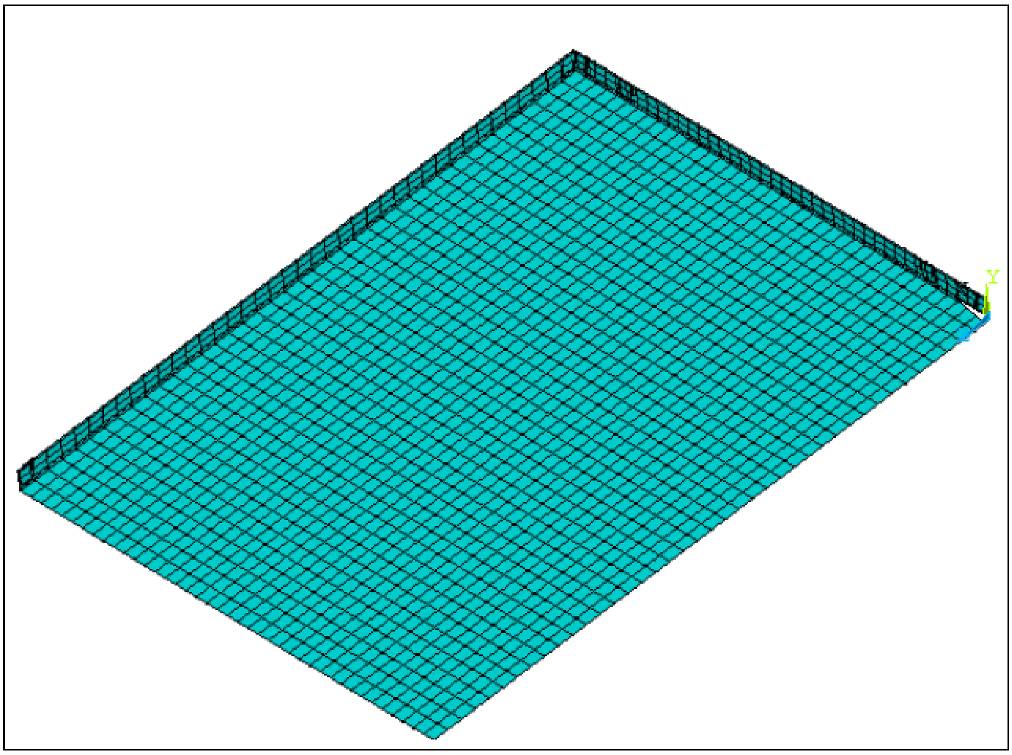


Figure 5.3 Platform. Meshed Model – Al Housing Face

The sections of the beam and of the shell are shown in the figure below: The shell has a 10mm thickness and the final beam dimensions are:

Height: 30mm

Width :40mm

Thickness(in all directions):5mm

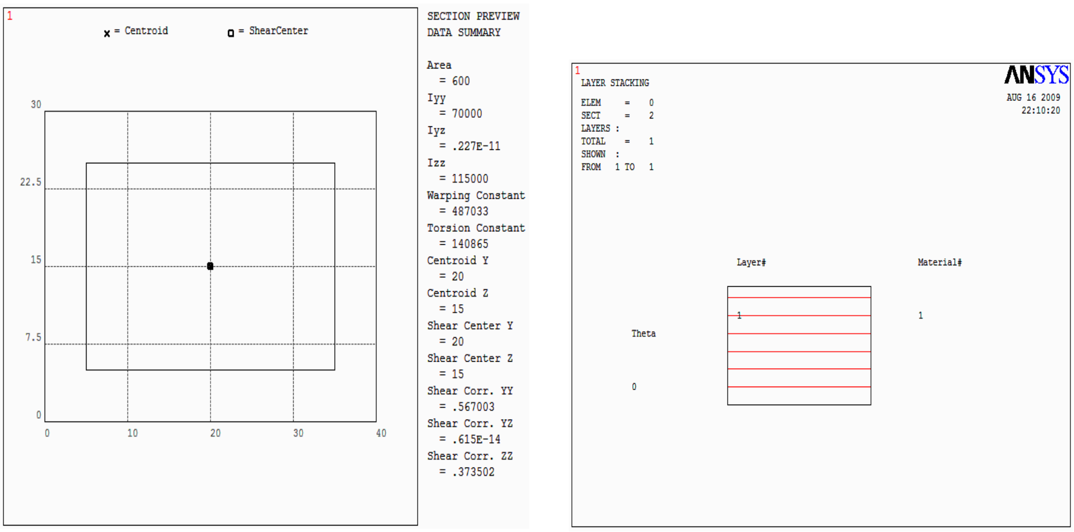


Figure 5.4 Beam and Shell Elements' Section

The model was done using a shell with no holes for reasons of faster analysis. Nevertheless, considering the number of holes and their distribution(see *Figure 5.5*, Right), the stresses determined by each hole were taken into consideration in the final results.

Several models of the platform with holes were done to interpret their influence before sketching the simpler model. The types of elements varied as well as the meshed model.

Post-processing

The static analysis of the platform includes the blocking of the four joints on the platform and distribution of the force on the platform to check its strength in the critical cases.

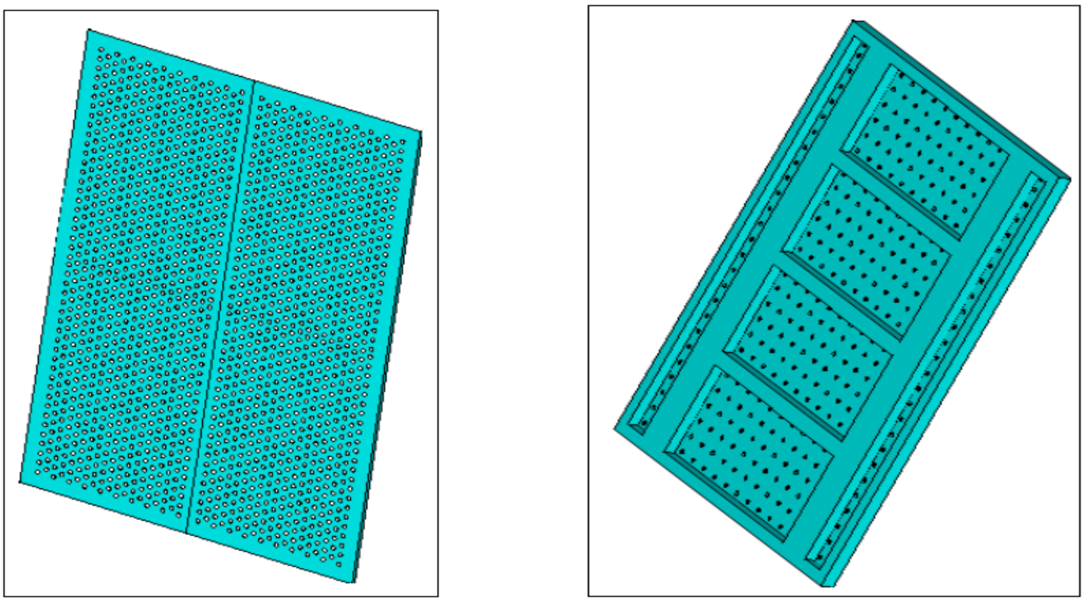
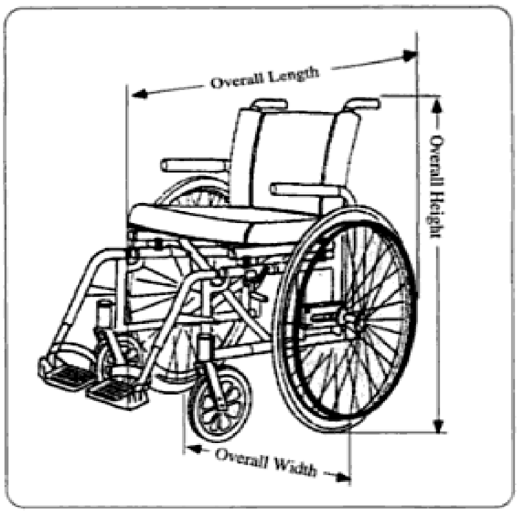


Figure 5.5 Two different models of the platform with holes

Taking into consideration the standard dimensions of the wheelchairs from specialized institutions we determined the spots or surfaces on the platform where the weight is concentrated. The worst case scenario was analyzed by supposing the passenger in the wheelchair is positioning himself as close to the front side of the platform as possible facing the bus.



Overall length: 780mm,
Overall Height: 940mm,
Overall Width: 610mm

Figure 5.6 Definitions of overall length, width and height of a wheelchair

Thus, using the standard dimensions and the average tread width of the wheels, that is max 30mm, the loads were defined on specific surfaces on the platform(see *Figure 5.7*).

The material used in the final model for the rigid structure is AISI Steel 1020 (see *Table 5.1*) and 6061 Al alloy for the shell.

Table 5.1 Mechanical Properties of AISI 1020 Steel

Mechanical Properties	Metric
Hardness, Brinell	137
Hardness, Knoop	156
Hardness, Rockwell B	75
Hardness, Vickers	143
Tensile Strength, Ultimate	472 MPa
Tensile Strength, Yield	384 MPa
Elongation at Break	32.0 %
Reduction of Area	66.5 %
Modulus of Elasticity	200 GPa
Bulk Modulus	140 GPa
Poissons Ratio	0.290
Charpy Impact	16.9 J @Temperature -30.0 °C

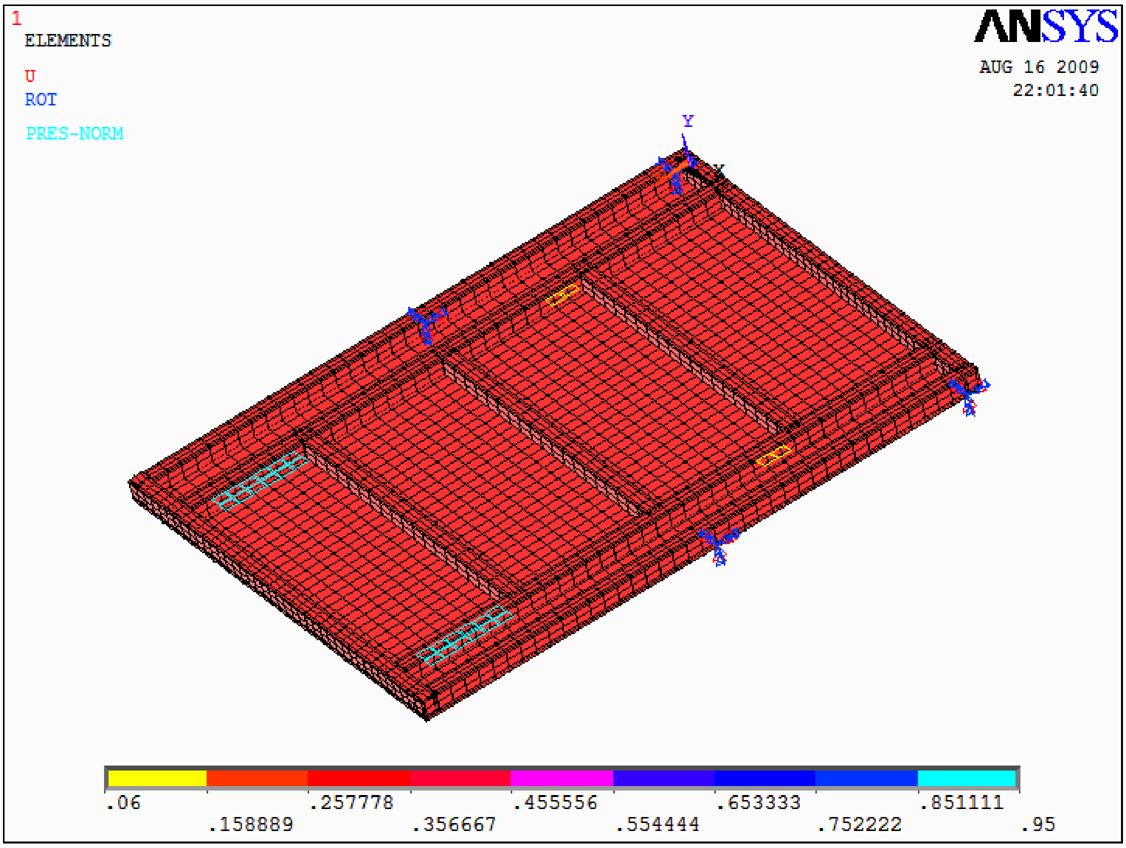


Figure 5.7 Platform. Boundary Conditions and Distributed Forces

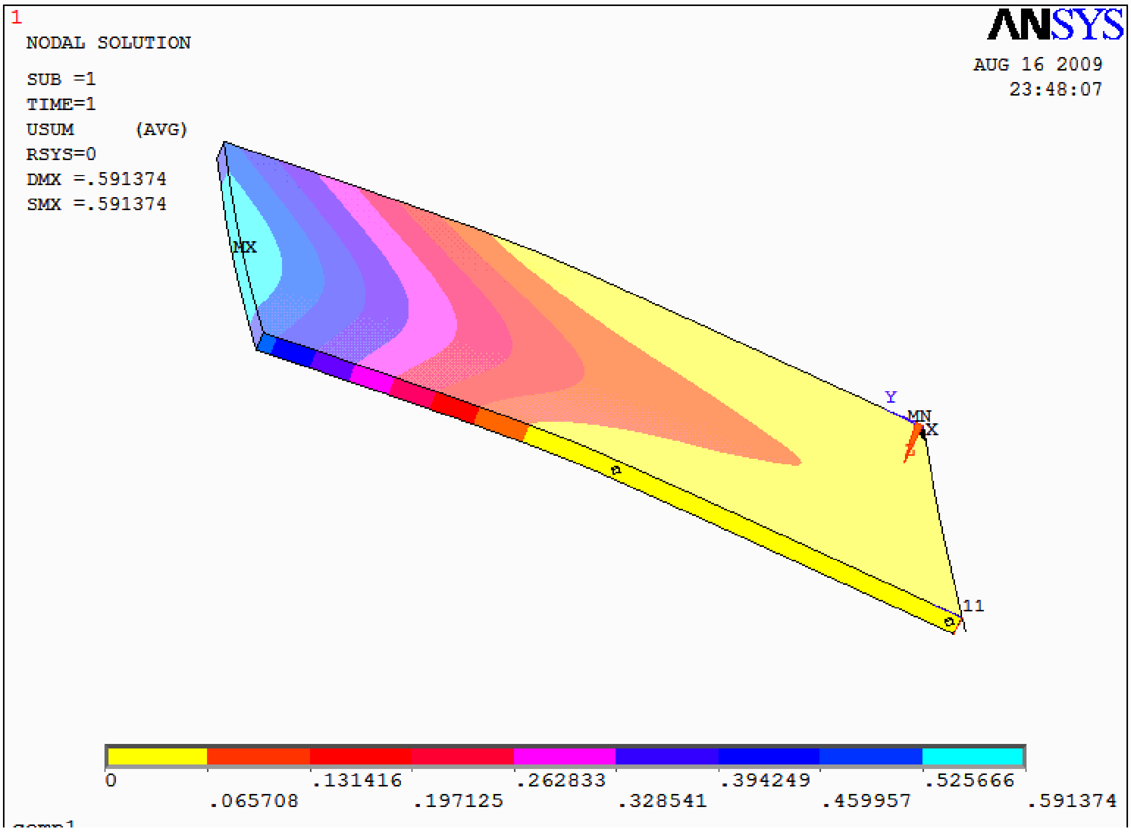


Figure 5.8 Displacement Vector Sum

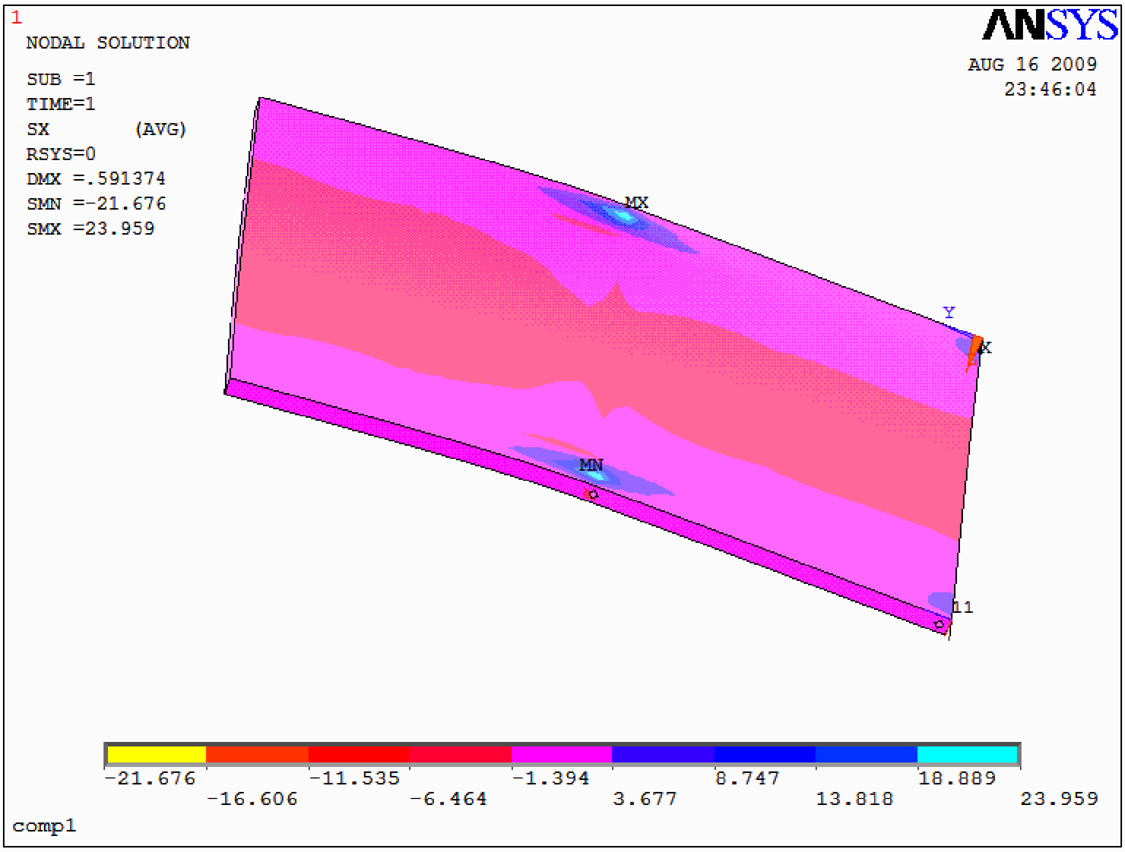


Figure 5.9 X component of stress

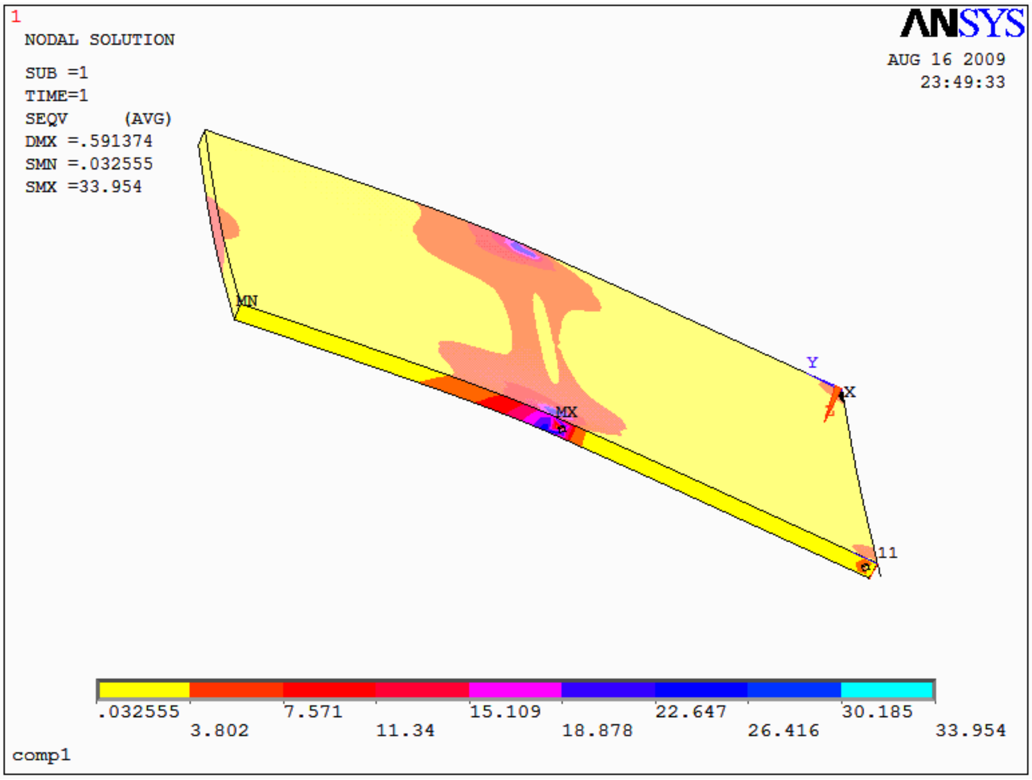


Figure 5.10 Platform: Von Mises Stress

Conclusions.

- The deformation of less than 10mm reveals a stable platform, mainly due to the steel rigid structure.

- The von Mises stresses found on the final model vary in the allowable range(*Figure 5.10*).

- The weight of the platform, m=38 kg is comparable to that of similar products on the market where they vary from 25 to 45 kg, depending on the material, structure of the platform and the rest of linking components of the mechanism.

- The final dimensions of the platform can be noticed in the figure 7.9.

5.2 Principal Arm

The principal arm of the scissors linkage has a U-shape with a vertical bar on the right side. This shape is due to the fact that the two corresponding arms on the lateral sides of the platform are linked through a bar of similar cross-section and characteristics.

The vertical bar is connected directly to the actuation source of the arms, that is the hydraulic cylinder.

The connecting bar has the role to transmit the rotation movement induced by the vertical arm and thus synchronizing the motion to both sets of scissors linkage.

The principal arm has 4 support points: 2 rotation joints at the connection with the cantilever and 2 hinges at the connection to the platform. (see *Figure 5.11*).

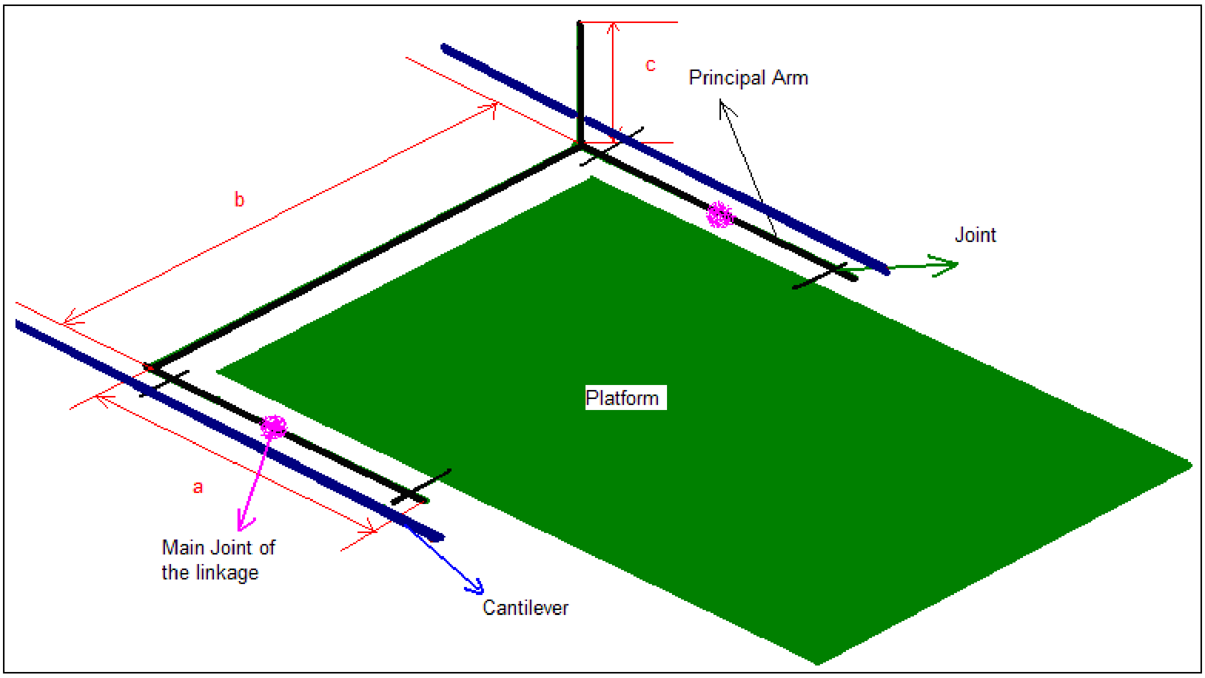


Figure 5.11 The sketch of the Principal Arm

Taken as input data the product specifications of the device, the forces and the dimensions resulted from ADAMS we have performed the static analysis in ANSYS.

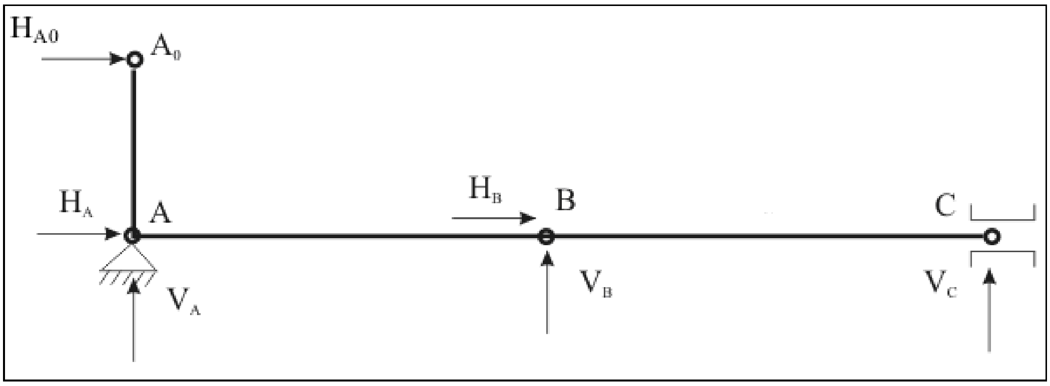


Figure 5.12 Principal Arm: Reaction and Forces resulted from ADAMS

Strength Analysis

Input Data:

a) Dimensions: - the length of the lateral bars: a= 580mm

- the length of the transmitting bar: b= 850mm
- the length of the vertical bar: c= 150mm
- position of the main joint of the linkage (point B in *Figure 5.12*)

b) Forces: - force acted by the hydraulic cylinder: H_{A0}= 16240N

- constraints of the principal arm, valid for both lateral pieces(*Figure 5.12*):
- point A: connection with the cantilever;
- point C: connection with the platform;
- point B: main joint of the linkage;

Processing.

Using the above the input data, it was created the model in ANSYS. In the view of meshing, BEAM188 3-D Linear Finite Strain Beam elements were used. (see *Figure 5.13*) Specifications: 112 nodes and 59 nodes. This type of element allows the user to work with sections in the analysis. The chosen section for the principal arm and the data summary of the section profile can be seen in *Figure 5.13,* right side.

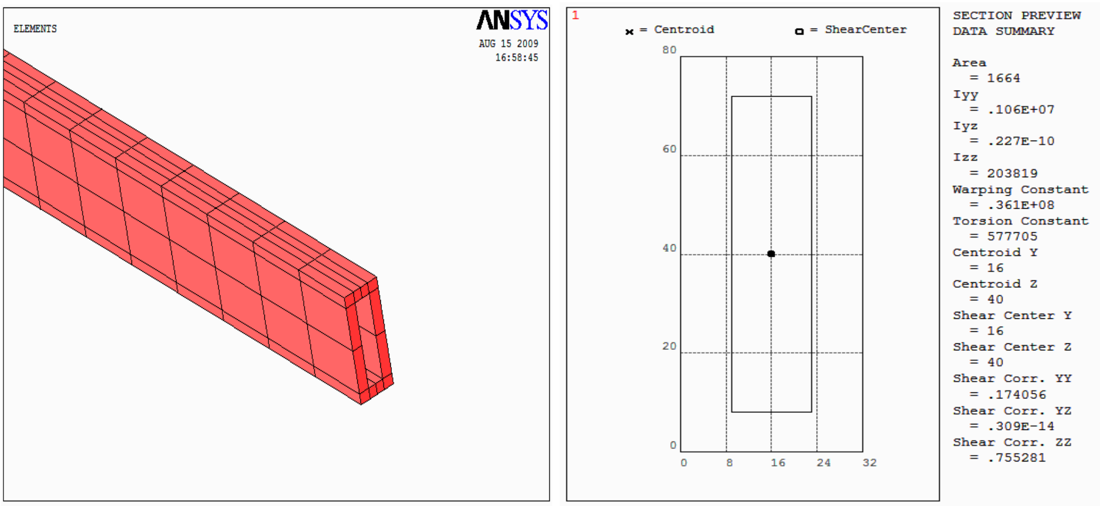


Figure 5.13 Profile of the Section:

Left: 3D view of the section; Right: Section view and Data

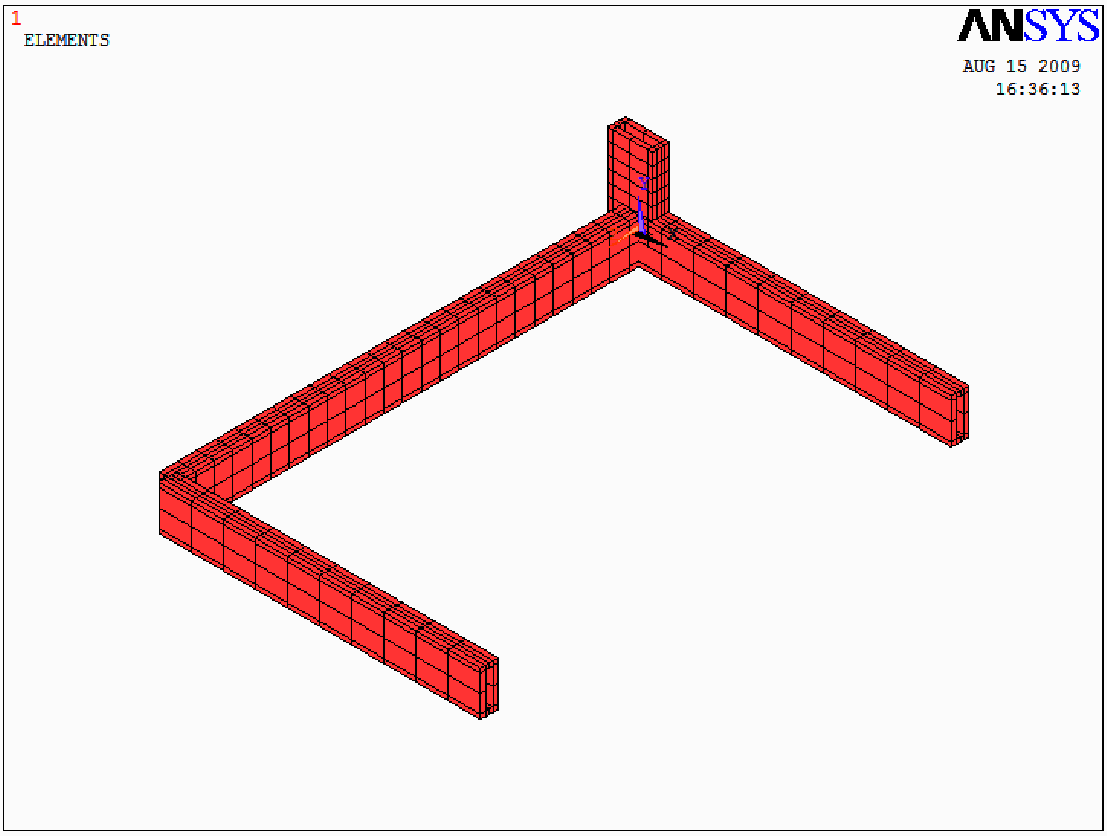


Figure 5.14 Principal Arm Model in ANSYS. Plot with Elements.

After setting the constraints and forces on the model(see *Figure 5.12*), the last step before the analysis is to establish the material characteristics.

A set of materials were used from the material library until a suitable one was found to fulfill the conditions of a successful analysis and to provide suitable characteristics of the arm. The material used in the final model is the same as for the rigid structure of the platform, that is AISI Steel 1020 having the properties listed in the *Table 5.1*.

<u>Solving.</u>

The static analysis of the model has revealed the stresses, the deformations and the mass of the principal arm. After several iterations involving different materials and section profiles, the final model was reached.
The main considerations when analyzing the model were:
- the dimensions of the arm, taking into account standards and space restrictions
- maximum weight of the arm, in order not to exceed a limit.
- the allowable stresses and deformations correlated to the mechanism the arm belongs to.

<u>Post-processing.</u>

a) Displacement. The maximum deformation of the final model is of 14mm. Taken into consideration the overall dimensions of the lifting device and the safety of the passenger using the platform, this value is allowable and does not represent a factor of concern.

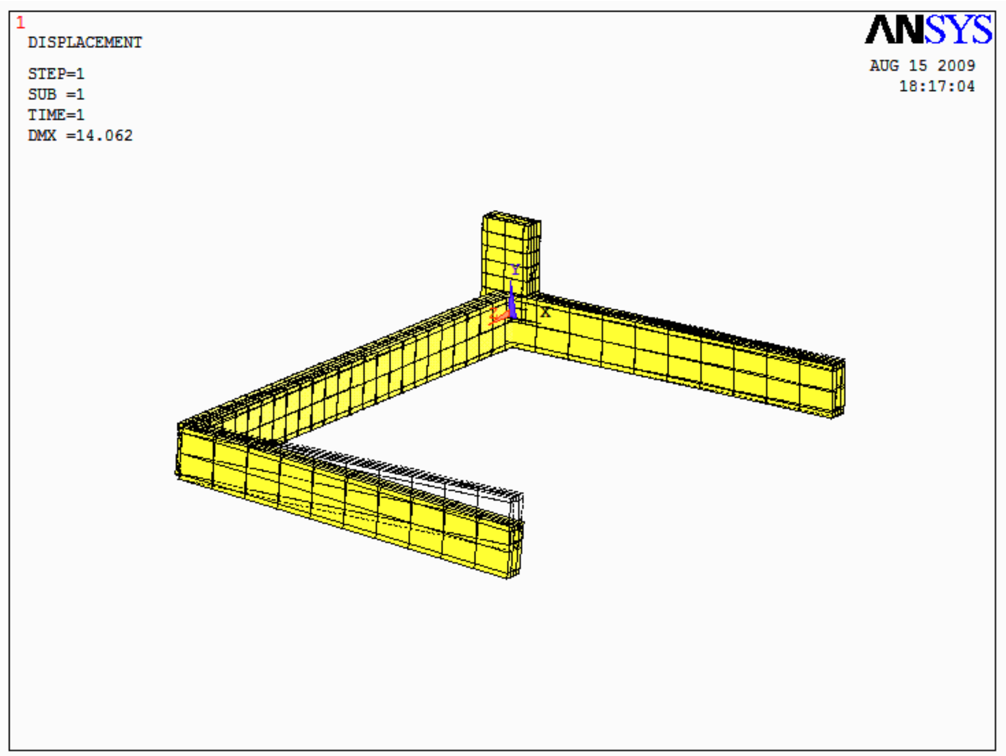


Figure 5.15 Deformed and un-deformed shape of the model

under the hydraulic actuation.

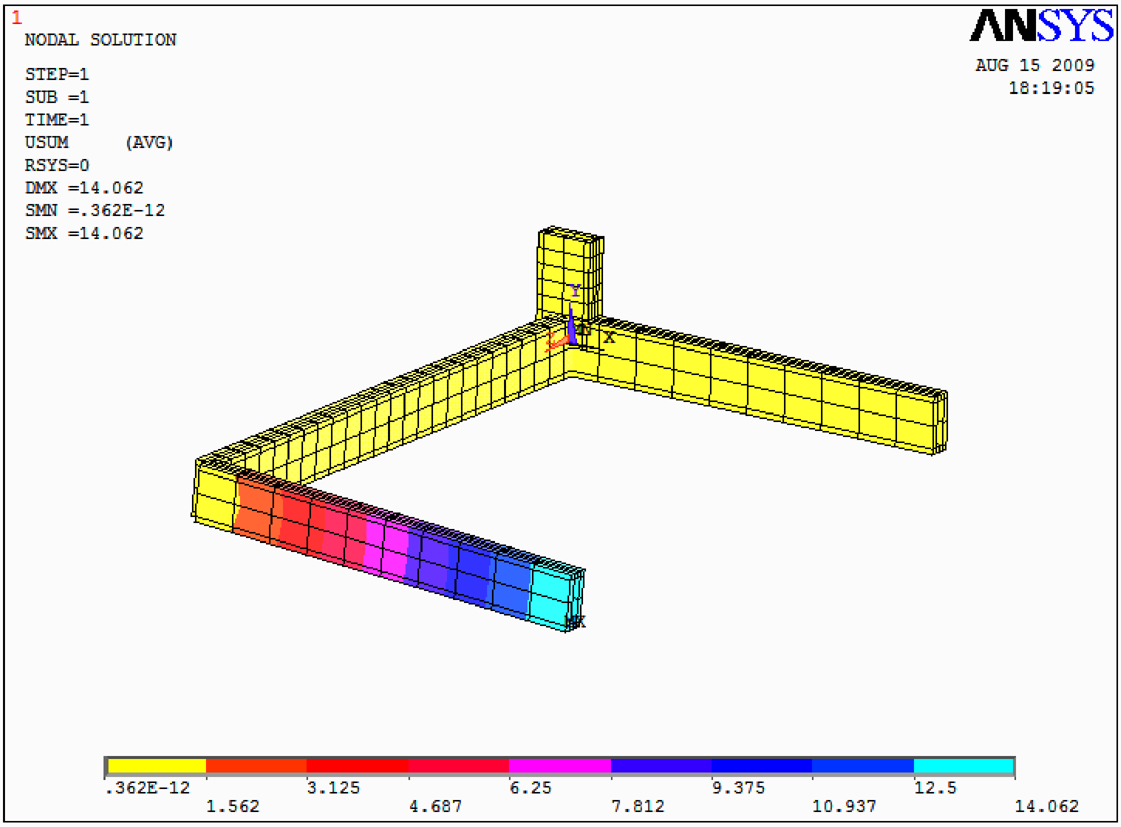


Figure 5.16 Nodal solution – Displacement vector sum

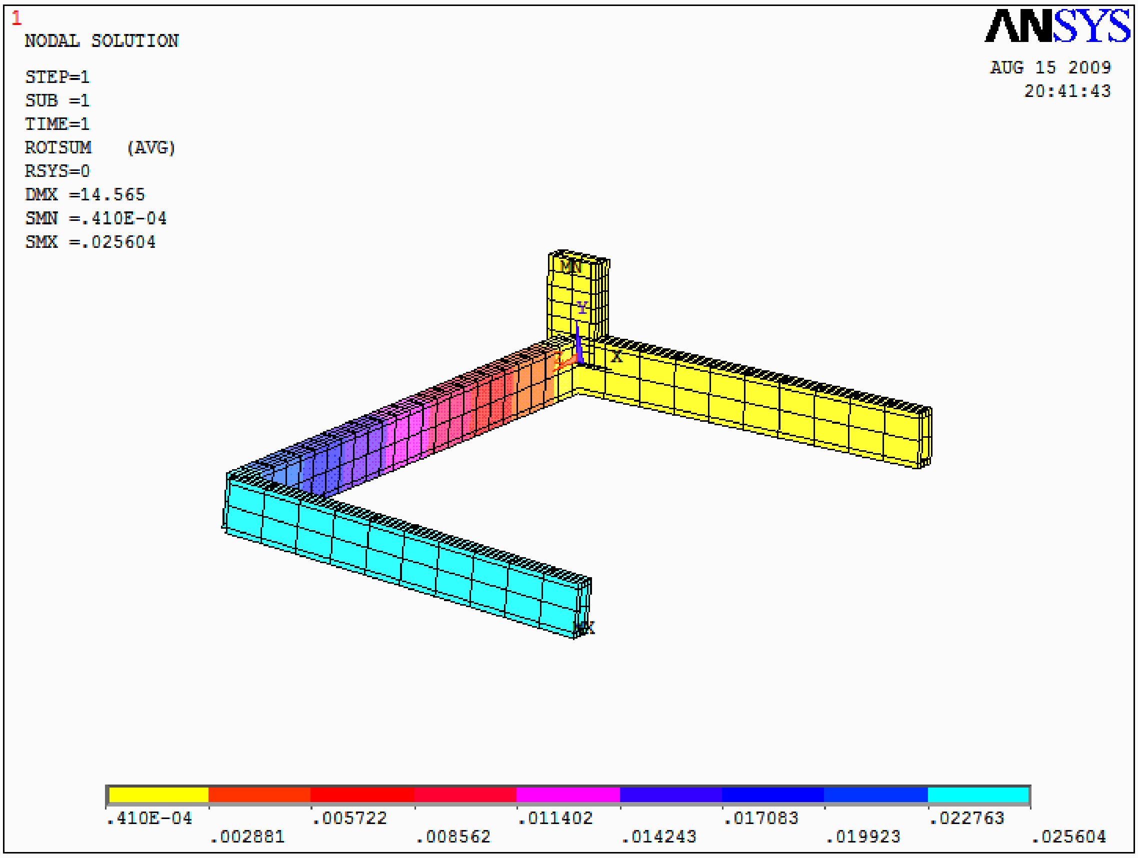


Figure 5.17 Rotation vector sum.

b) Stresses. The values in the drawings are expressed in MPa.

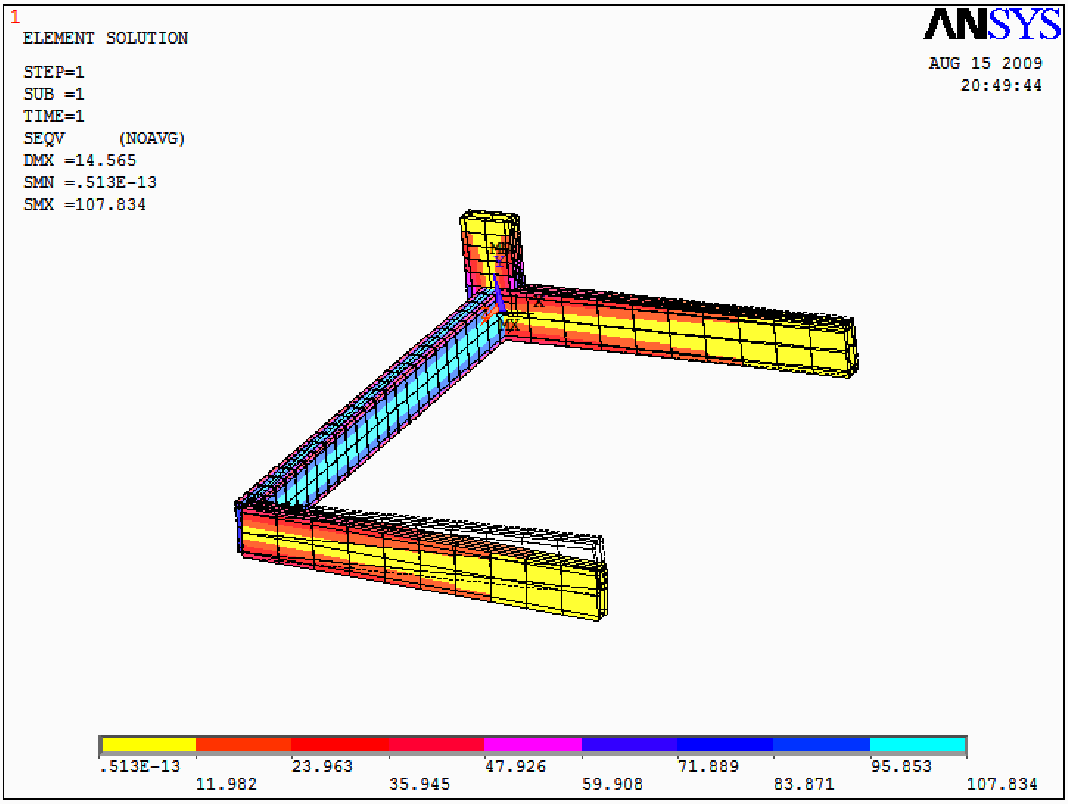


Figure 5.18 Von Mises Stresses. Element Solution

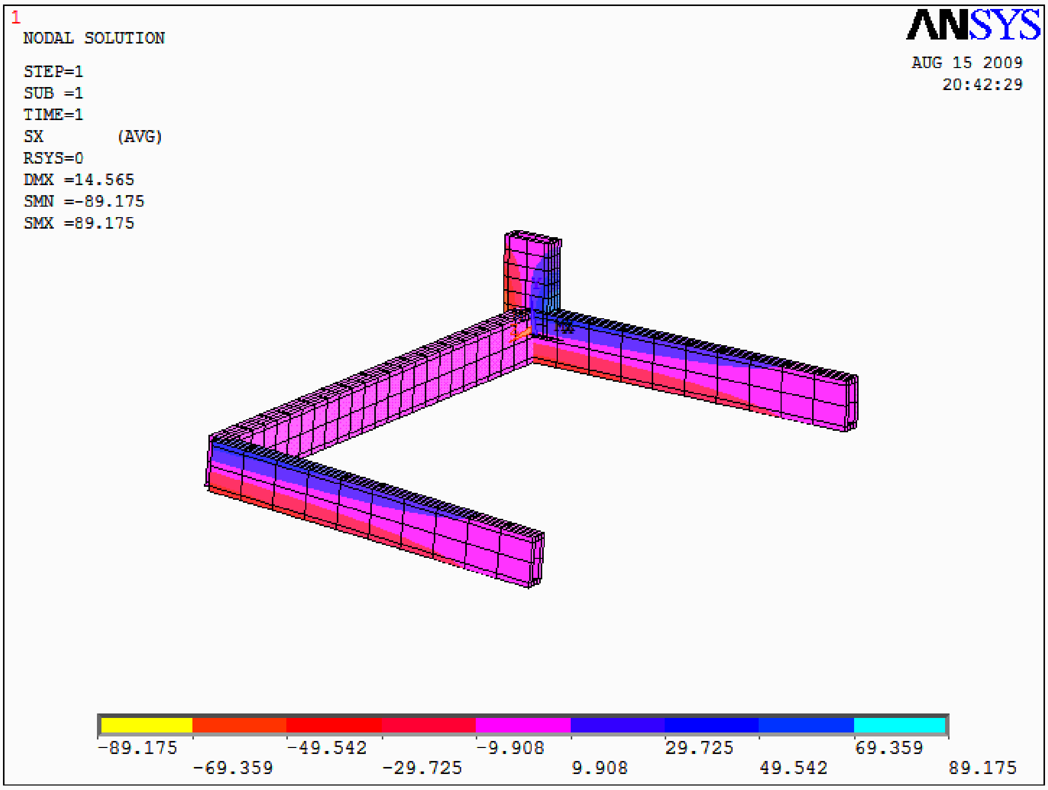


Figure 5.19 Component of Stress of X-direction.

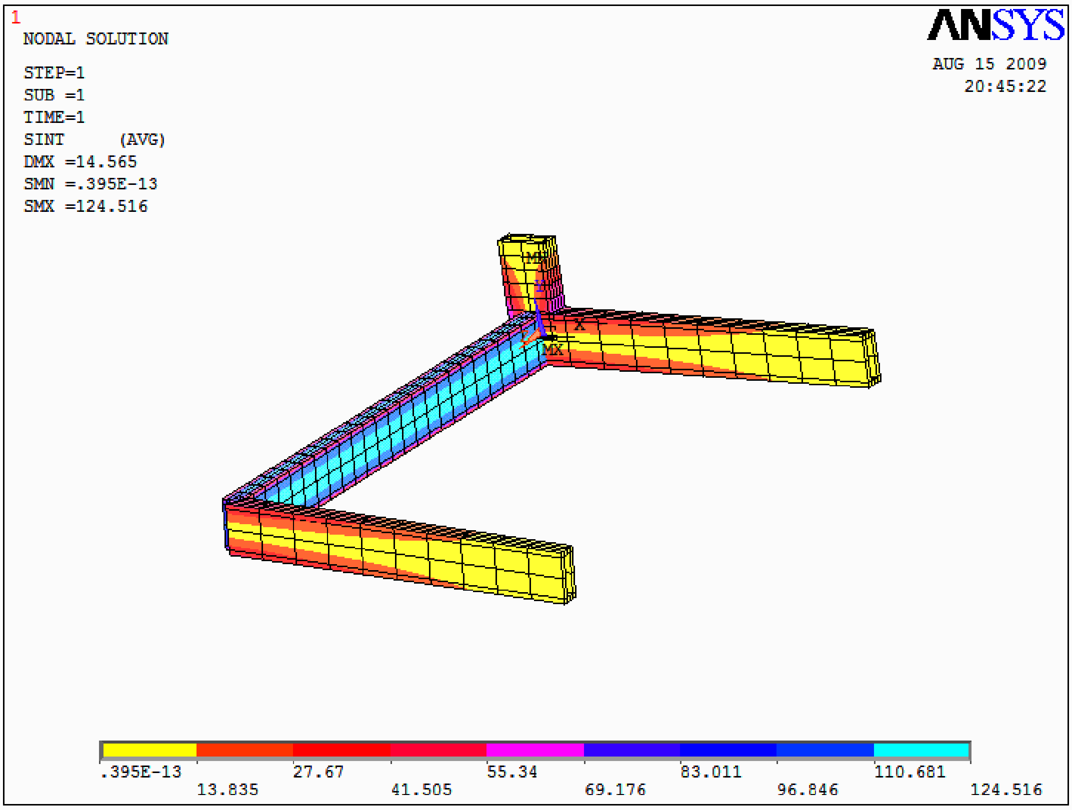


Figure 5.20 Stress Intensity.

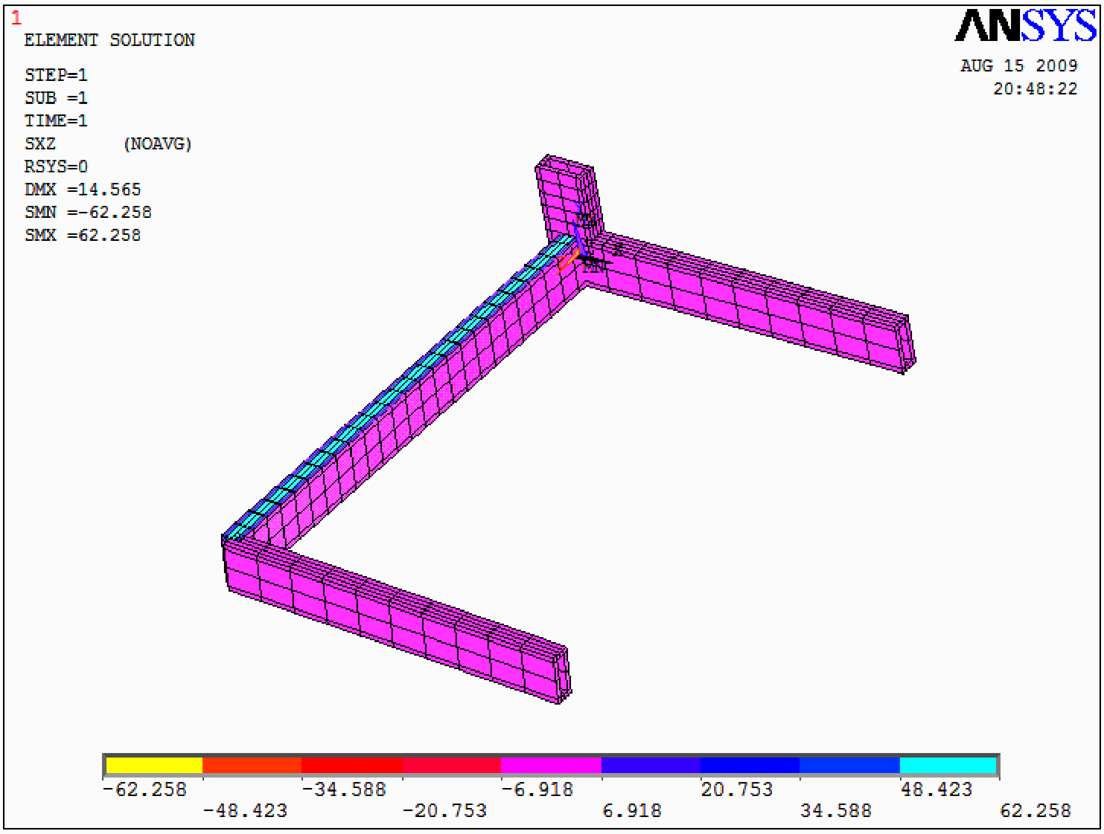


Figure 5.21 XZ Shear Stress

The resulting model has the cross-section as described in *Figure 5.22*.

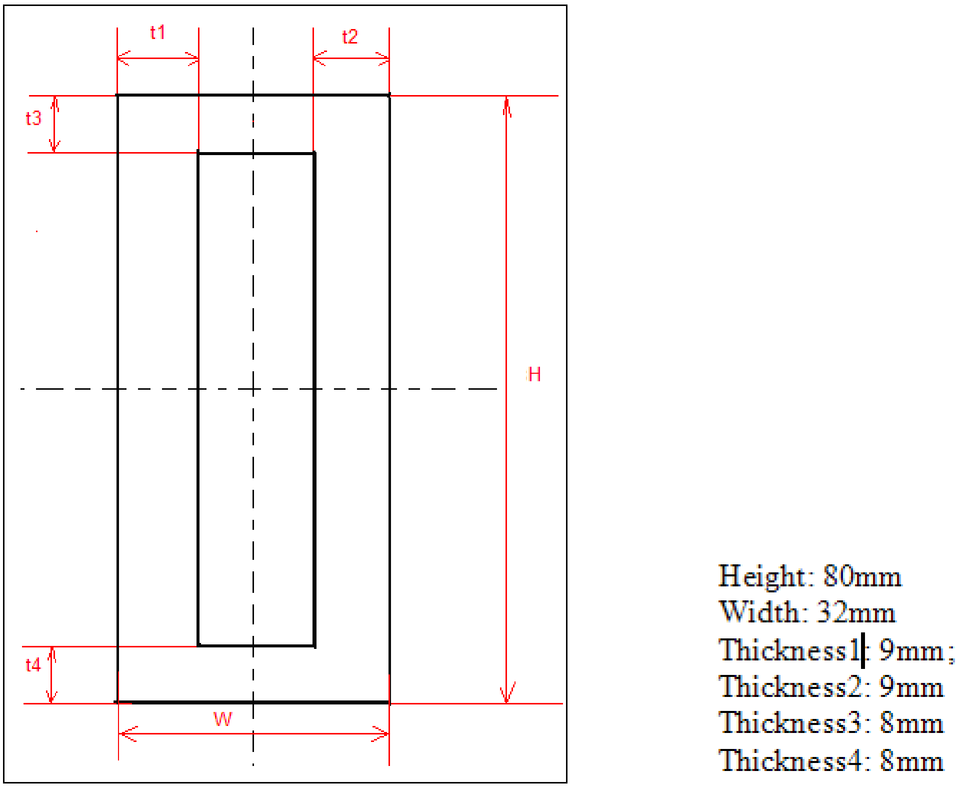


Figure 5.22 Final Cross-section of the arm.

```
***** POST1 TOTAL REACTION SOLUTION LISTING *****

LOAD STEP=     1  SUBSTEP=     1
 TIME=    1.0000      LOAD CASE=   0

THE FOLLOWING X,Y,Z SOLUTIONS ARE IN THE GLOBAL COORDINATE SYSTEM

  NODE      FX          FY          FZ          MX          MY          MZ
     1   16259.      2030.0     0.24673E-19
     2  0.26686E-07  2030.0     0.17718E-18
    99  -16259.

TOTAL VALUES
VALUE   0.40322E-07  4060.0     0.20185E-18  0.0000      0.0000      0.0000

LIST NODAL FORCES FOR SELECTED NODES       1 TO     112 BY       1
CURRENTLY SELECTED NODAL LOAD SET= FX    FY    FZ    MX    MY    MZ

   NODE  LABEL     REAL           IMAG
     59  FY     -2175.00000    0.00000000
     64  FY      145.000000    0.00000000
     79  FY     -2175.00000    0.00000000
     84  FY      145.000000    0.00000000
```

<u>Conclusions.</u>

1) The reactions and forces acting on the principal arm were checked with the values obtained from ADAMS.

2) The model behaves well under the given constraints and has a mass of 25kg.

3) The maximum displacement of 14mm is in the allowable interval(see *Figure 5.16*).

4) The final model of the arm consists in a valid solution from the point of view of dimensions(see *Figure 5.22*), stresses and weight.

5.3 Secondary Arms

The two sets of secondary arms are having the same characteristics on each of the lateral sides of the platform. The strength analysis was done for one set, considering the two secondary arms as a continuous arm to enable the model.

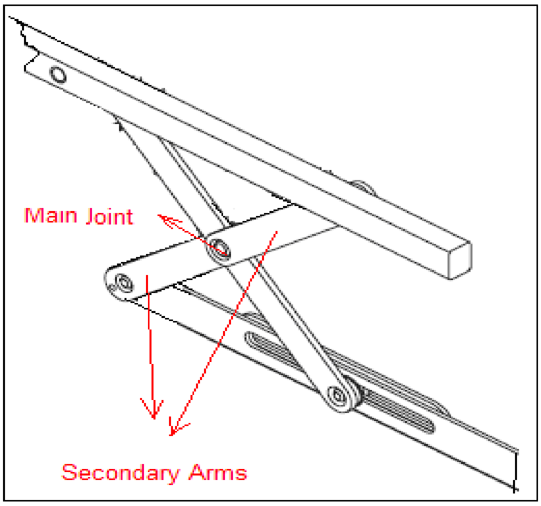


Figure 5.23 Secondary Arms.

<u>Input Data:</u>

a) Dimensions: - the length of one secondary arm: 290mm

- the length of the entire bar to be modelled:580mm
- position of the main joint of the linkage–the point where all three arms meet(*see Figure 5.23*).

b) Reactions: - constraints of the secondary arms, valid for both sets of linkages(see *Figure 5.23*).

- point D: connection with the platform;
- point E: connection with the cantilever;
- point B: main joint of the linkage;

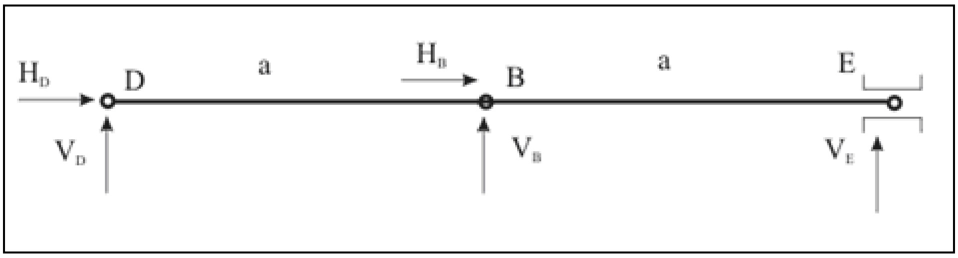


Figure 5.23 Secondary Arms: Reactions resulted from ADAMS

<u>Processing</u>

The model was meshed using also BEAM188 elements with the final cross-section as shown in the *Figure 5.25*. Models with other elements were also checked(see *Figure 5.24*). The cross-section was refined to meet the strength, geometry and mass constraints. Therefore the final total mass is of 4kg.

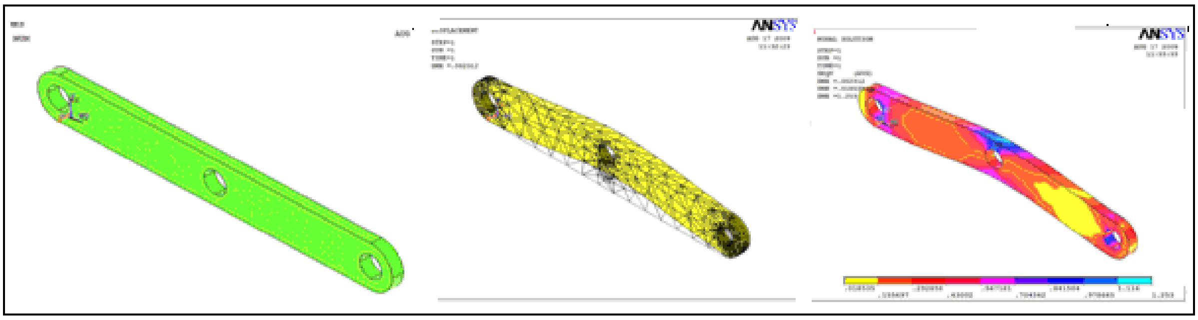
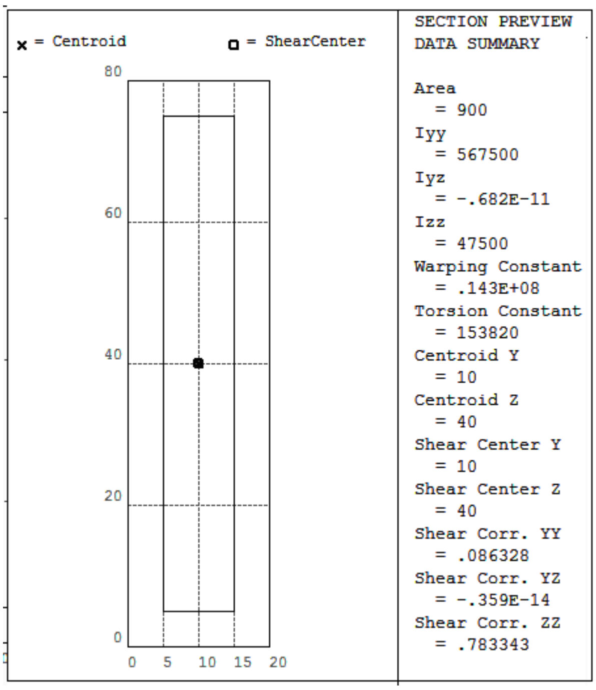


Figure 5.24 Secondary Arms Simulation with Brick Elements.



Height: 80mm
Width: 20mm
Thickness(in all directions): 5mm

Figure 5.25 Cross-section of the Secondary Arms.

Post-Processing

1)Displacement. The deflection of the secondary arms appear at the main joint level and it is negligible.

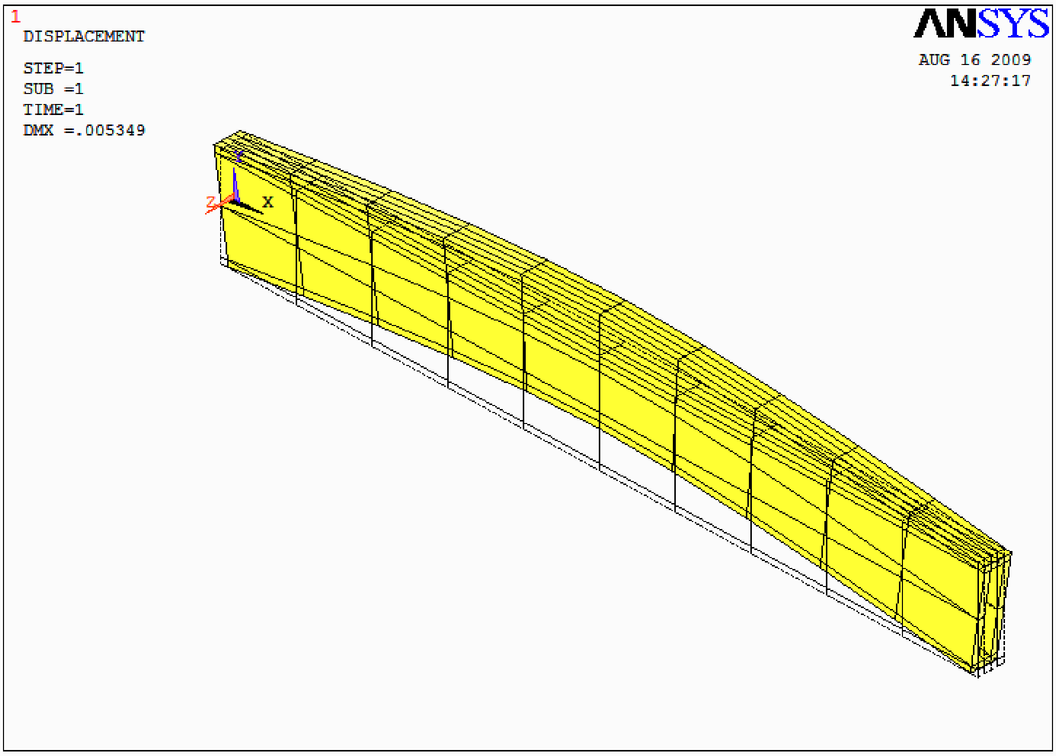


Figure 5.26 Deformation of the Secondary Arms.

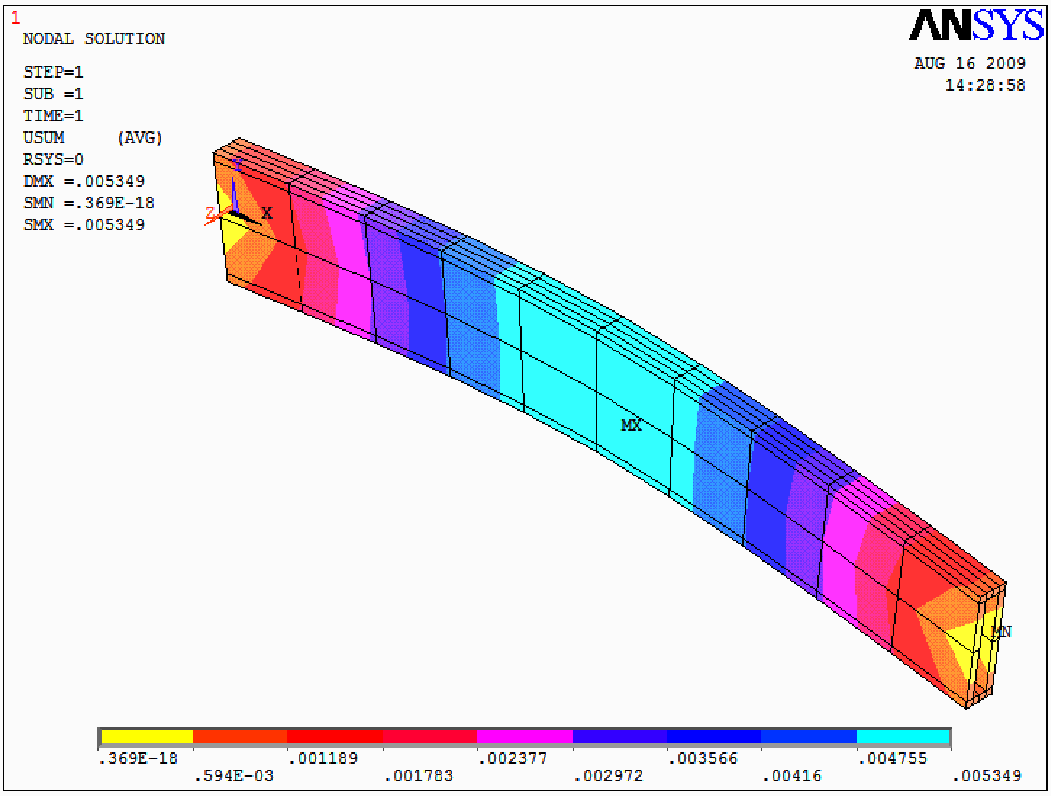


Figure 5.27 Displacement Vector Sum

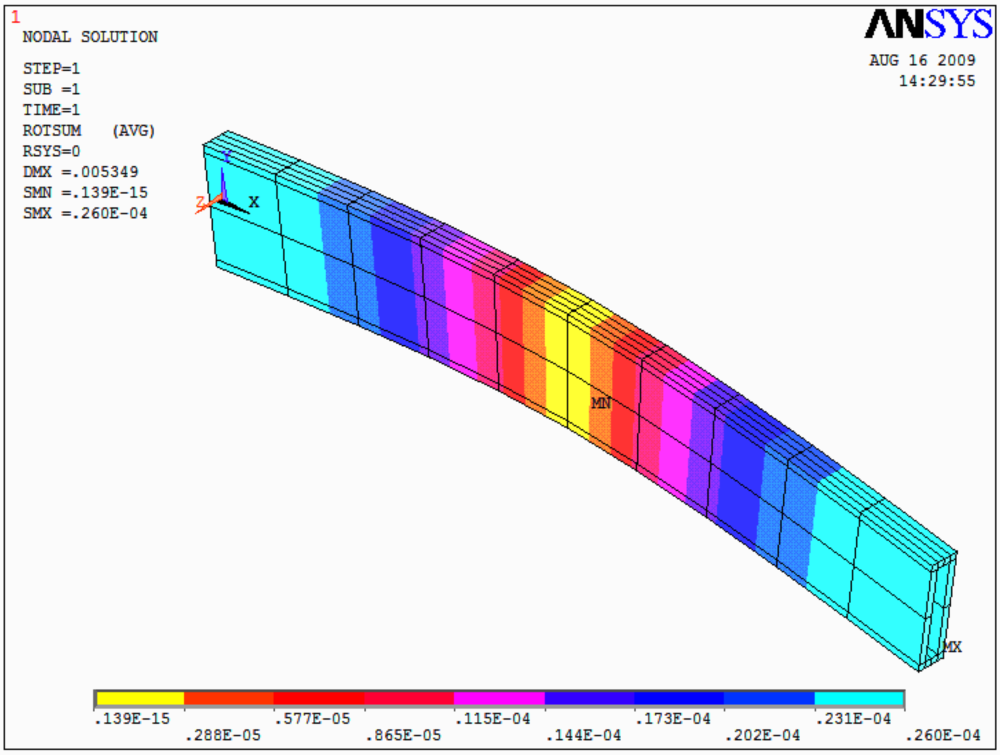


Figure 5.27 Rotation Vector Sum

2)Stresses.

The material used for the Secondary Arms is also AISI Steel 1020 having the properties listed in the *Table 5.1*.

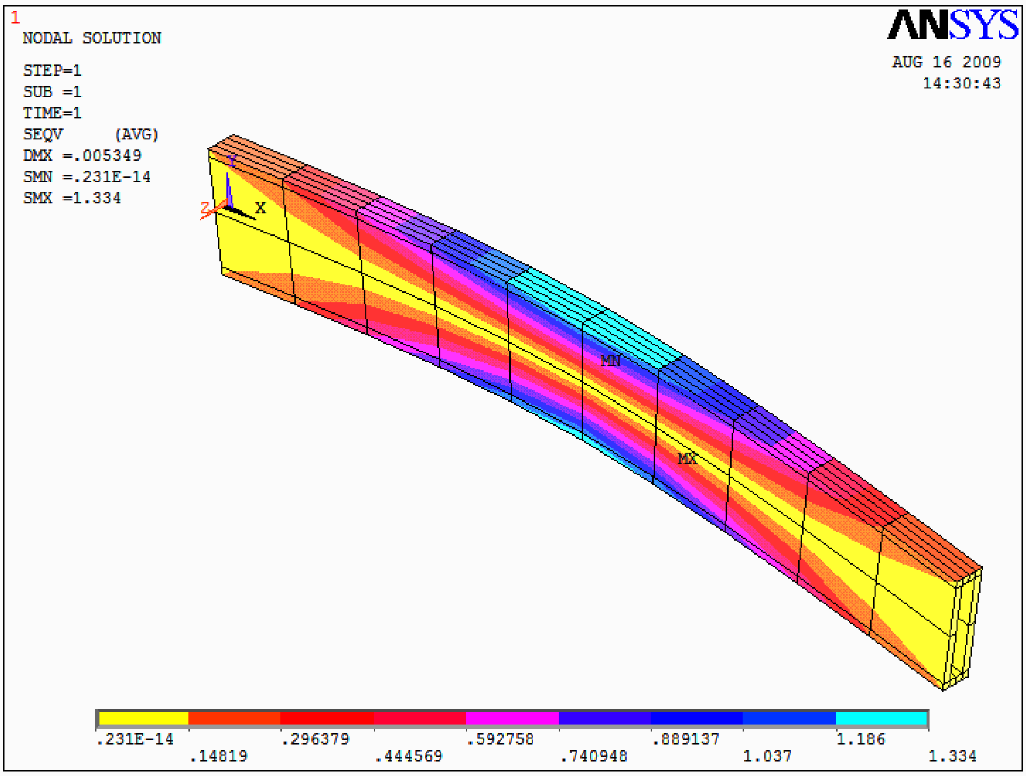


Figure 5.28 Von Mises Stresses. Nodal Solution

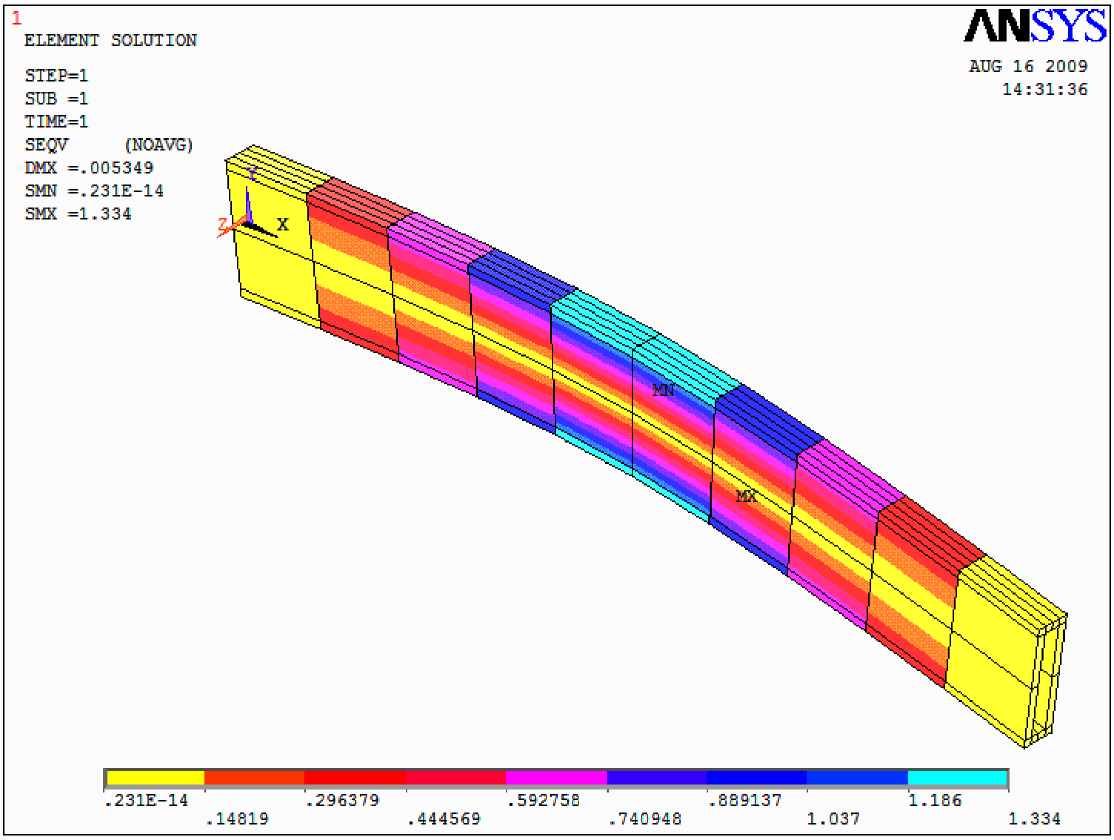


Figure 5.29 Von Mises Stresses. Element Solution

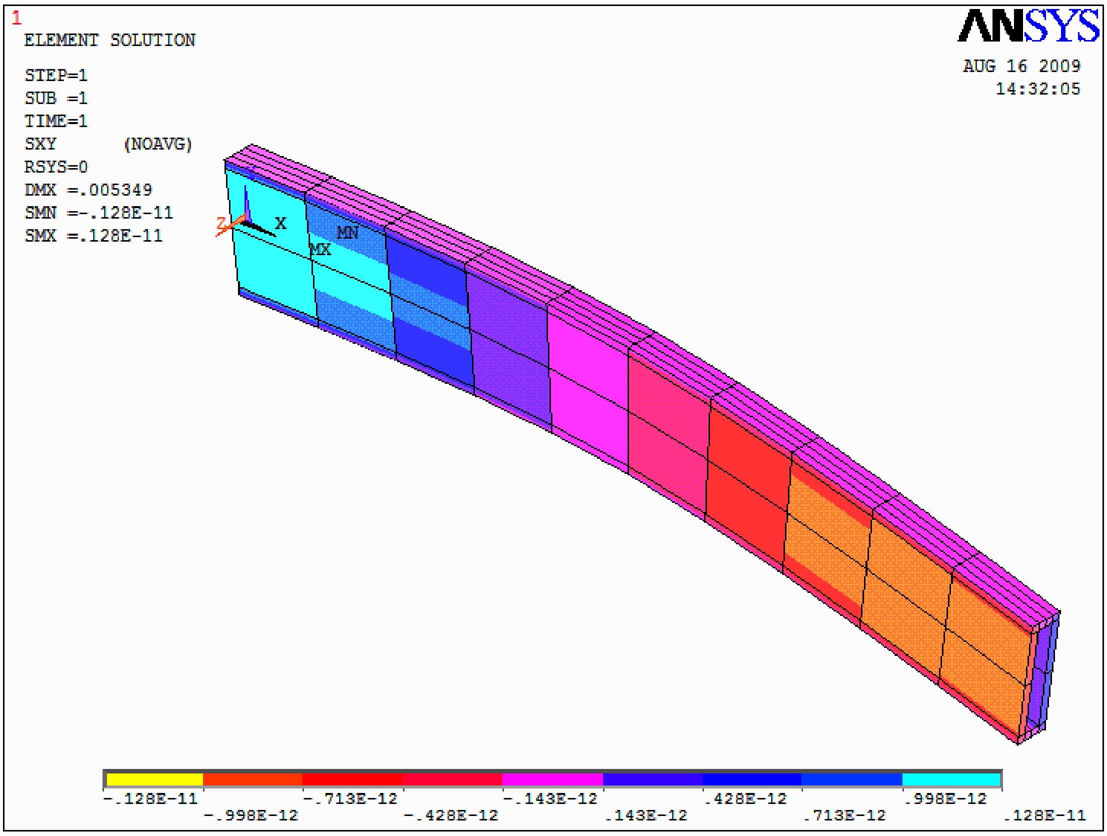


Figure 5.30 XY Shear Stress

Conclusions.

- The model behaves well under the given conditions and correlates with a suitable geometry and a reasonable mass.

5.4 Sliding Arm

The sliding arm is the component that slides the platform inside and outside the bus and it is connected to the platform through a secondary arm at a point and the main arm at another point(see *Figure 5.31*). The arm will be analyzed in the case when the platform is outside the bus in horizontal position(before descending) with maximum weight(see *Figure 5.32*)

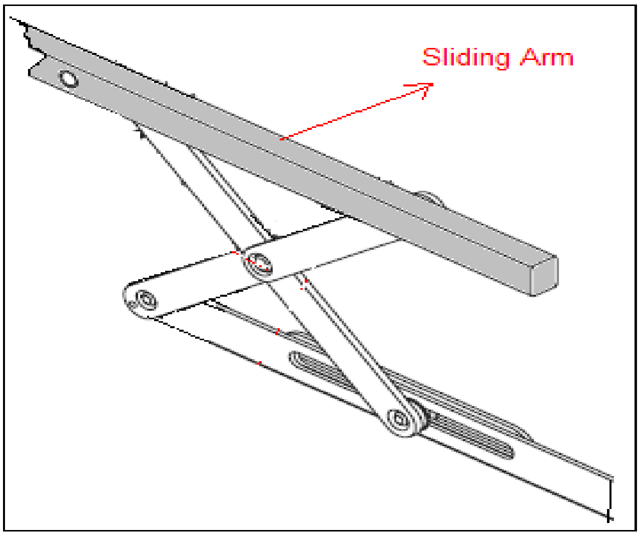


Figure 5.31 Sliding Arm

<u>Input Data</u>

a)Dimensions: - length of the sliding arm: 1200mm

- distance between carriages of the sliding mechanism: 520mm

b) Force: - maximum force applied on the platform and transmitted to the sliding arm: $G_{max}/2 = 2100N$;

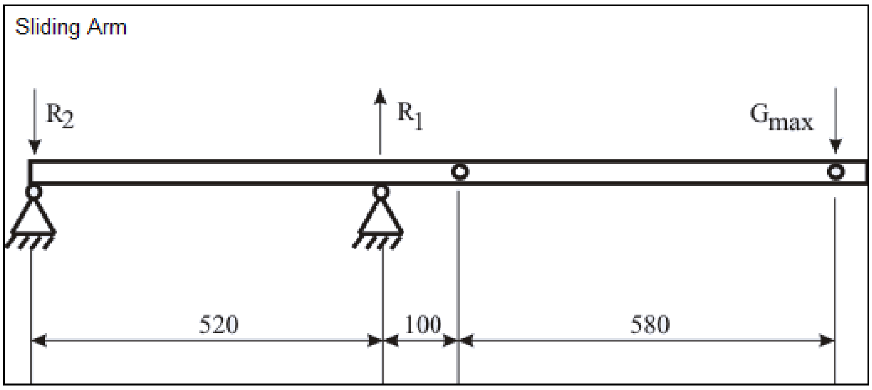


Figure 5.32 Reaction and Forces in the sliding arm.

G_{max} = 4200N; R_1= 9692N; R2= 5492N

Processing

The model was created using BEAM188 3-D Linear Finite Strain Beam elements and cross-sections. The material used is Steel 1020 with material properties shown in the *Table 5.1*.

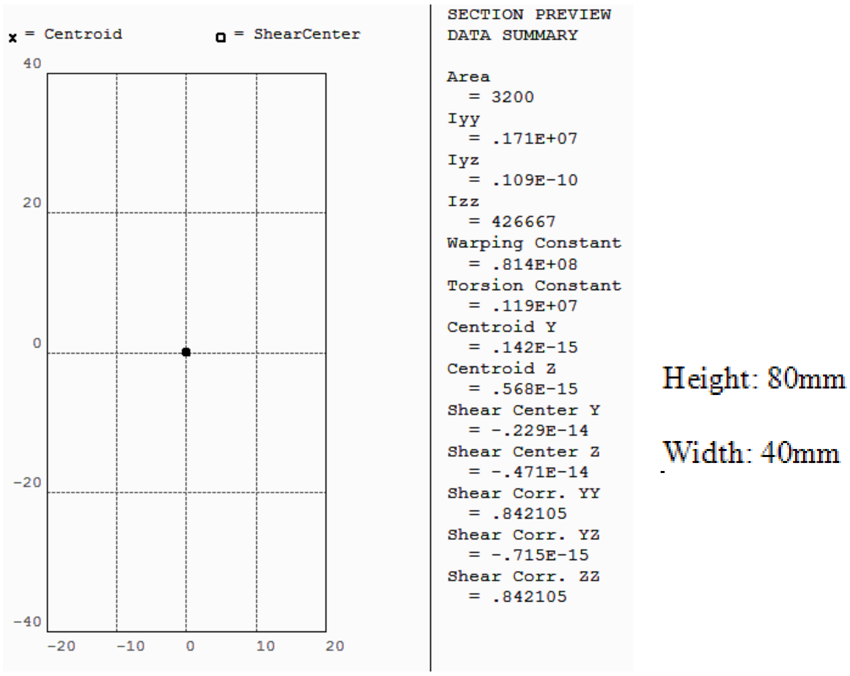


Figure 5.33 Cross-Section of the Sliding Arm

Post-processing

a) Displacement

The displacement of the sliding arm is of maximum 5mm(see *Figure 5.34*).

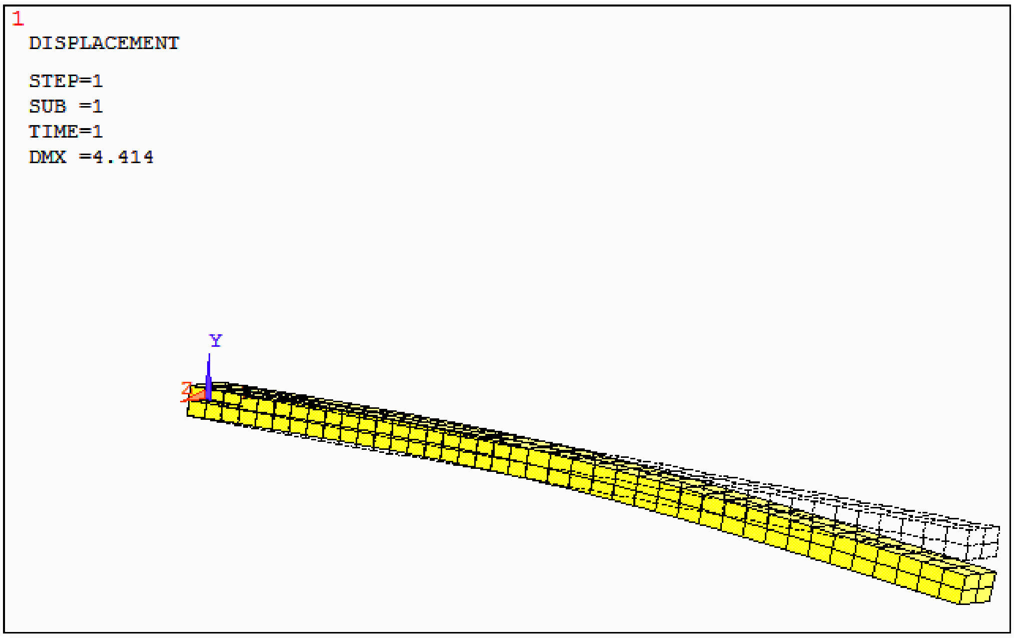


Figure 5.34 Displacement of the sliding arm. Deformed and un-deformed shape.

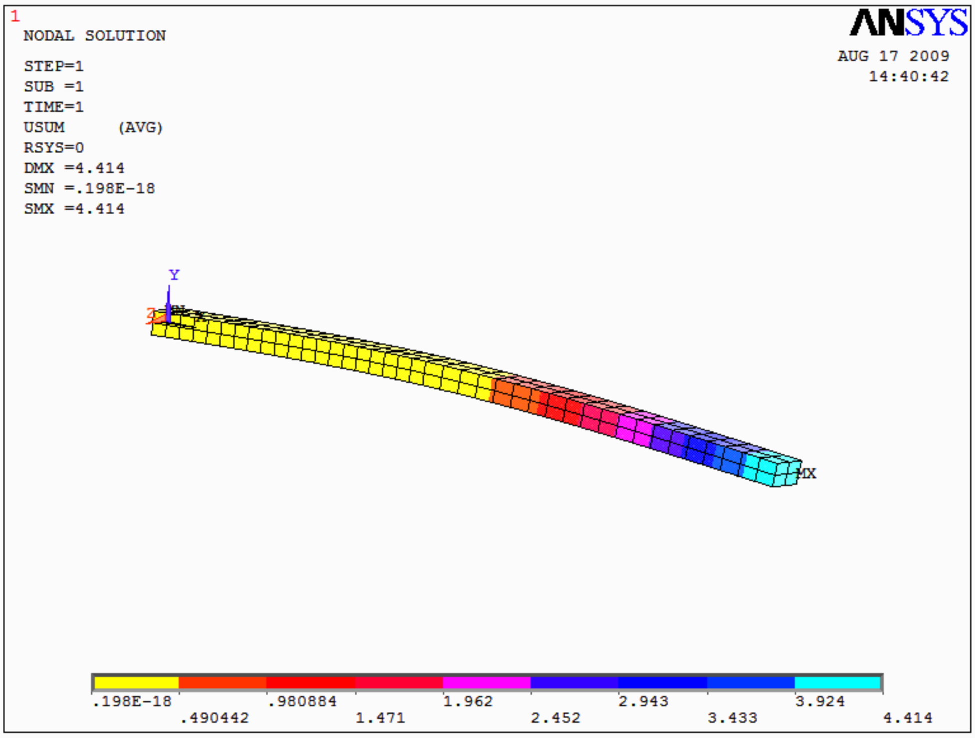


Figure 5.35 Displacement vector sum

a) Stresses

The maximum stress is of 65MPa. The reaction solutions can be seen in the *Table 5.2*.

Table 5.2

PRINT REACTION SOLUTIONS PER NODE

***** POST1 TOTAL REACTION SOLUTION LISTING *****

LOAD STEP= 1 SUBSTEP= 1
TIME= 1.0000 LOAD CASE= 0

THE FOLLOWING X,Y,Z SOLUTIONS ARE IN THE GLOBAL COORDINATE SYSTEM

NODE	FX	FY	FZ	MX	MY	MZ
1		-2746.2	0.0000			
2		4846.2	0.0000			
TOTAL VALUES						
VALUE	0.0000	2100.0	0.0000	0.0000	0.0000	0.0000

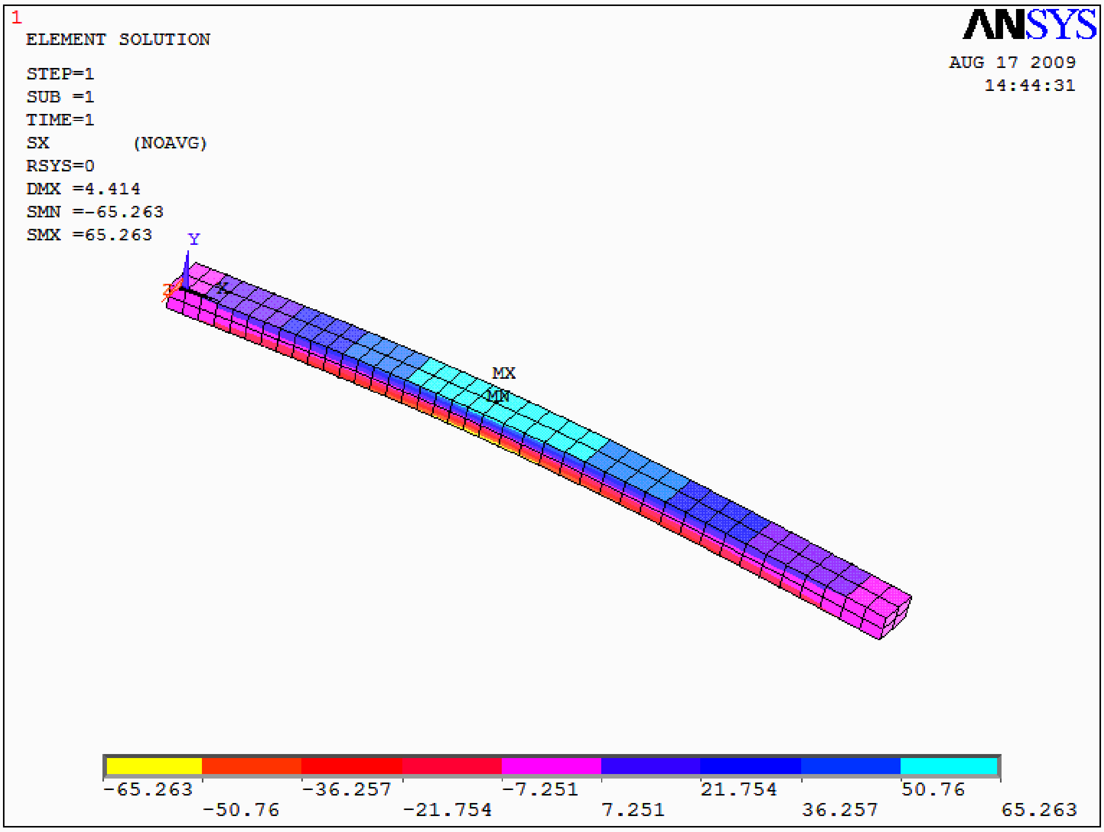


Figure 5.36 X-Component of stress. Element Solution.

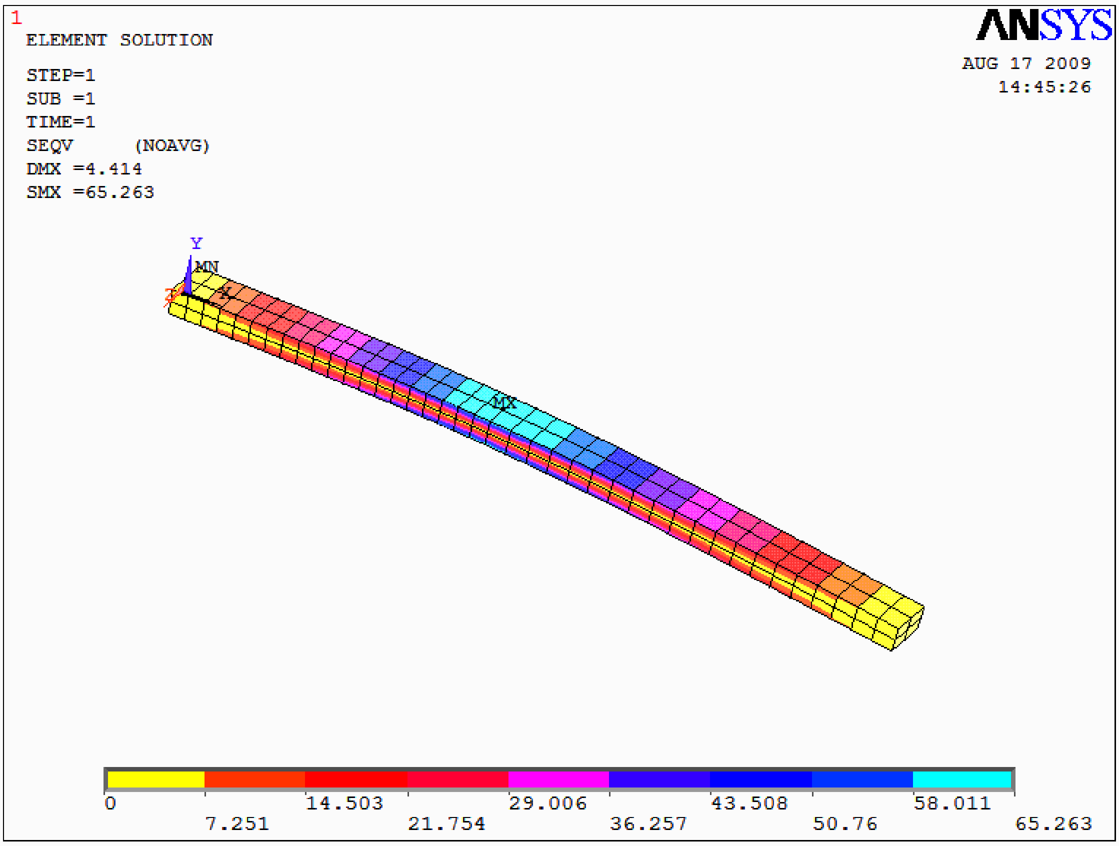


Figure 5.37 Sliding Arm: Von Mises stresses.

Conclusions

- the strength analysis has resulted in a suitable geometry and an acceptable mass – 30kg per arm.
- the von Mises stress reflect a maximum stress of 66MPa(see *Figure 5.37*)
- the above strength analysis contributes to the selection of the sliding mechanism due to the fact that the sliding arm is connected directly to the carriages of the mechanism and carries the platform.

6 Technology Actuation and Detailed Operation Procedure

PART A

6.1 Sliding Mechanism

Taking into account the input data from ADAMS and ANSYS software I have chosen one type of linear motion system suitable for the final concept.
In choosing the sliding mechanism I took into account the design considerations (see *Figure 6.1*) and the following data:

a) Position Requirements
The stroke required is of 1200mm. The travel life is about 230km considering distance moved per cycle(1200mm), number of cycles that must completed each hour(8 – due to the fact that the device is mounted on a campus bus, with limited number of persons with disabilities resulted from the university's student database) .

b) Loading Conditions
The weight that the carriages or saddles support is of 4200N.
Maximum torque is 130Nm.

c) Environmental Conditions
The device works in clean conditions, using a standard steel ball guide and standard linear bearings with no cover and standard grease lubrication.

d) Move Requirements
Move time is 8 seconds – pulling or pushing the platform out of the bus.
Dwell time is 14 seconds – the time between pulling and pushing the platform when the latter is descended or lifted.
Acceleration rate is of 0.130m/s^2 and the corresponding speed is of 0.2m/s. (according to the refined time of operation of the mechanism).

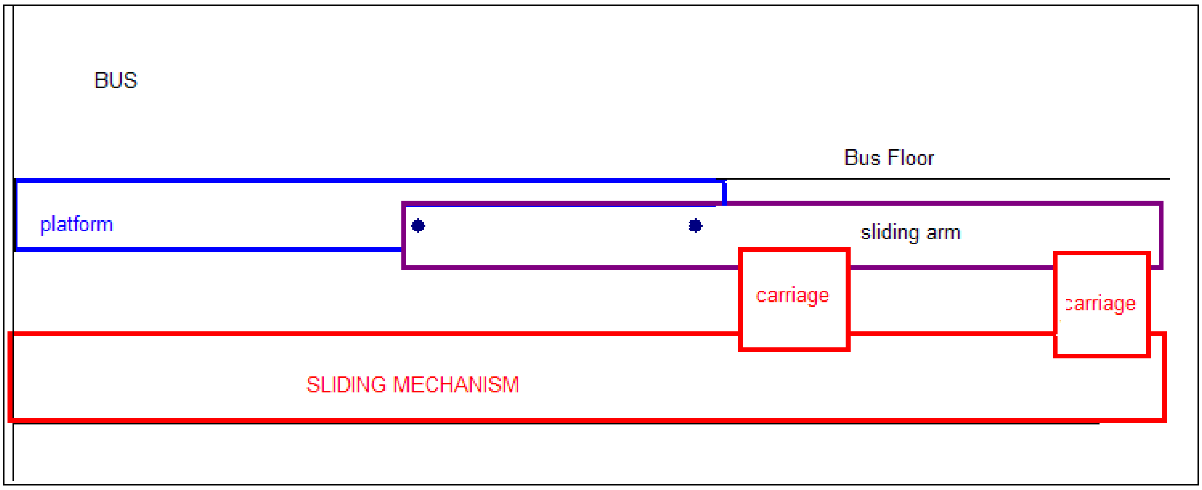


Figure 6. 1 Sliding Mechanism Positioning inside the bus

Therefore, after searching for linear motion systems I have selected the one that best suits all the necessary parameters of functioning.
The chosen system is a **Continuously Supported Ball Screw Driven System 2DB-16-JUB_L** with double carriage(see *Figure 6.3*) that is used in continuously supported applications when stiffness and rigidity are required. The T-Slot carriage provides quick and easy mounting and removal of the work piece. The acceleration profile can be analyzed in *Figure 6.2*.

The 2DB positioning table (formerly known as SuperSlide 2DB) is a continuously supported system designed for rigid applications moving medium to heavy duty loads. The table comes from the factory pre-aligned and preassembled for immediate installation with mounting screws through the base.
An integrated ball or lead screw assembly with standard NEMA motor mounting is supported in a dual Linear Race Rail package.

The modern design is highlighted though:
- fast and easy installation
- little or no maintenance required
- the high quality and modern production ensures long and reliable life.

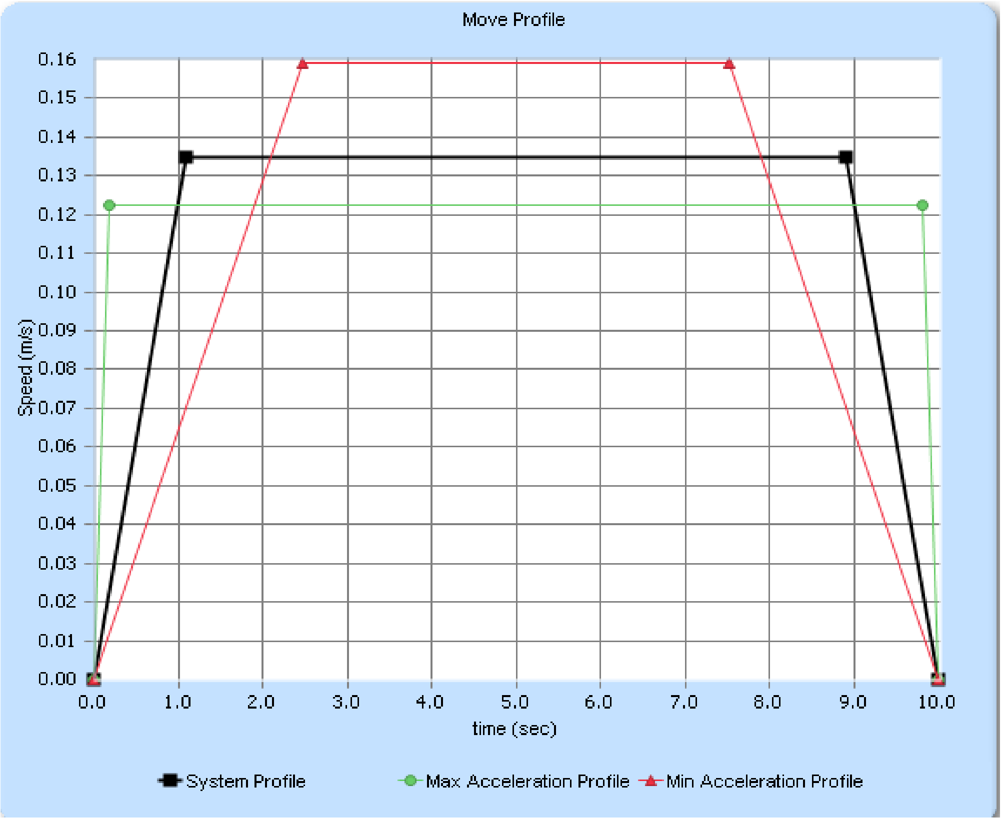


Figure 6. 2 Move Profile. Minimum and maximum acceleration profile

The **2DB-16-JUB_L** system covers all the necessary parameters of our mechanism, thus resulting the other dimensions that determine the overall volume of our device:
Profile Size(width x height): 152 x 65 mm^2;
Shaft Diameter: 19.1mm.
Information concerning the dimensions of the chosen device, are to be found in the *Annex 1*.

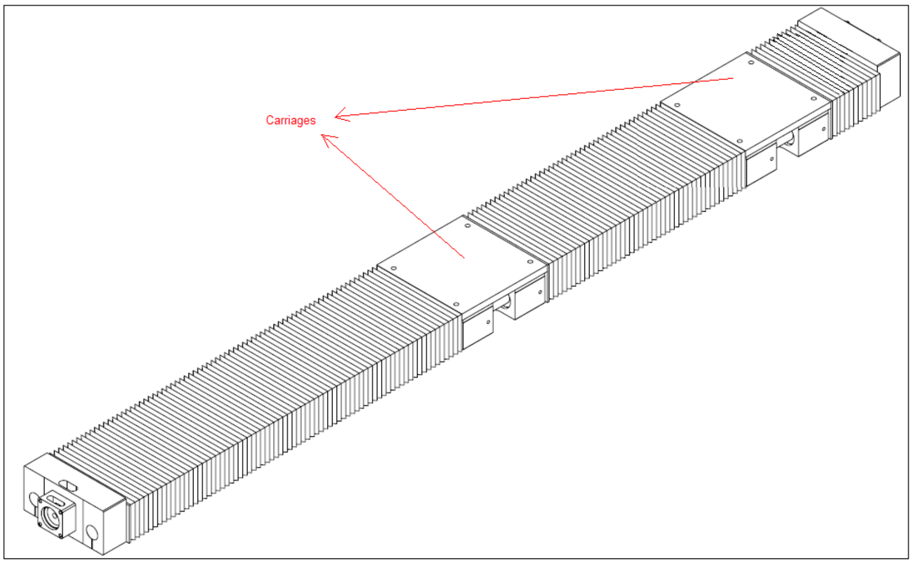


Figure 6. 3 Sliding System : Double Carriage – 3D model

<u>The motor</u>

The motor that actuates the sliding mechanism is manufactured by NEMA23 with the following characteristics: Pilot Diameter Dp=38.1mm; Pilot Length, Lp=3.04mm; Shaft Diameter Ds=6.34mm; Shaft Length, Ls=20.57mm.

Information concerning the motor sizing information and motor adapter are to be found in the annexes 2 and 3 at the end of the documentation.

A screw driven mechanism is usually recognized by high thrust and stiffness and can be based on a low cost lead screw with preloaded nut(*Figure 6.4*).

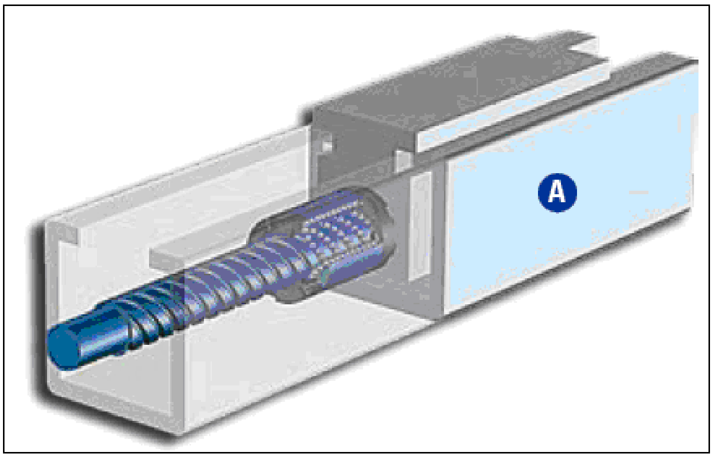


Figure 6. 4 Screw Driven Linear Unit – DANAHER motions producer

Band cover. Sealing the units from water, dust and other contamination is essential for a long and trouble free life. Either a stainless cover band (E) kept in place with magnet strips or a plastic cover band(F) that is self-locking to the aluminium profile.

Another unique feature is the cover band stretching function eliminating any cover band slack thus increasing the life of the cover band(*Figure 6.5*).

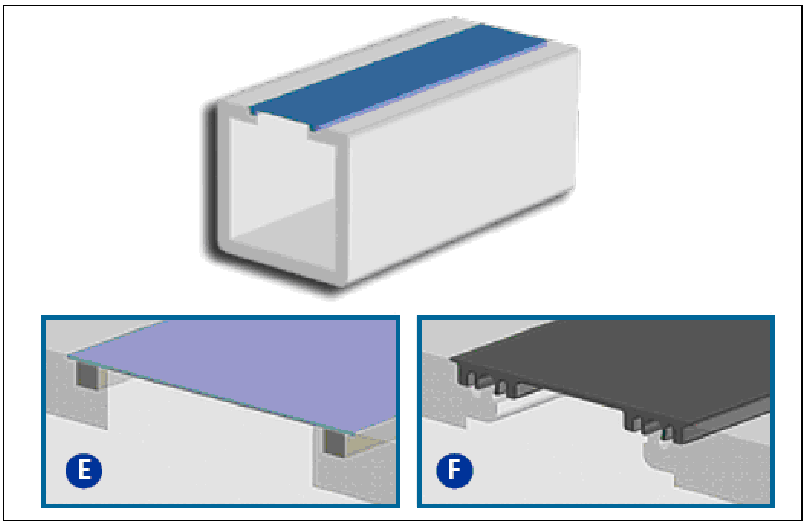


Figure 6. 5 Cover Band technology – DANAHER motions producer

Central Lubrication.

Easy and fast maintenance is very important, therefore, by choosing a unit with central lubrication the lubrication is applied at one point ensuring that guides as well as the drive screw is lubricated and kept intact throughout the lifetime of the unit(*Figure 6.6*).

Stainless units.

The unit is washdown protected which is a screw driven guided unit upgraded so that they can operate in wet and humid environments(*Figure 6.6*).

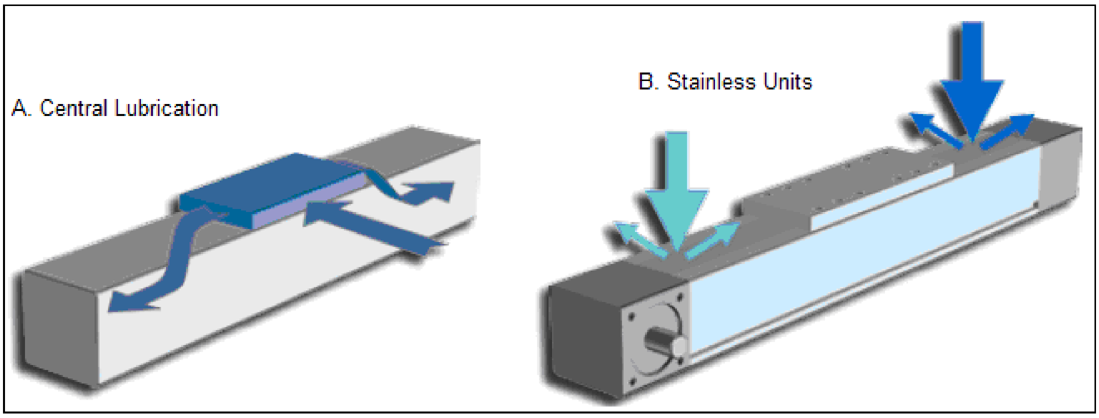


Figure 6. 6 Cover Band technology – DANAHER motion producer

The cost of such linear motion systems may exceed the average price of similar systems, but it is definitely highlighted by its set of advantages. Thus, the accessories **Continuously Supported Ball Screw Driven System 2DB-16-JUB_L** made by **DANAHER Motion** are various and can meet a wide range of client's needs.

6.2 Safety System

A very important product specification is related to the safety system which must cover the 2 main situations: inside and outside the bus.

a)Inside the bus.

Inside the bus, safety system must ensure the stability of the wheelchair during the transportation and a safe and comfortable journey. Taking into account the environmental conditions in which the bus travels, that is a big student campus placed in a flat and smooth zone, the safety conditions do exist, the safety measures are considered lighter then in other cases.

More exactly, in our project, the aspects we must take care of are(see *Figure 6.10*):

- *spot a special place in the bus* – space dedicated to the storage of the wheelchair such that the place left inside the bus will enhance a good traffic inside for the other passengers as well, including getting in and out of the bus, while a person in the wheelchair is inside. (see *Figure 6.9*.)

- *safety measures* : - a safety belt system - the belt will be fixed on the wall of the bus, on the right side of the wheelchair and will be blocked on the vertical bar placed at the right side of the wheelchair(*Figures 6.7- left, 6.8*).

- a floor blocking bar – an horizontal 50mm-height blocking bar placed at the back side of the wheelchair that will determine the limit for wheelchair placing.

- a locking system of the right wheel of the wheelchair – used only for particular cases, when the bus travels a bumpy road. It consists of a metallic shell that is mounted on the bus wall and connects manually to the wheel at the passenger's will.

- *mark the region* - the space needed for the person in the wheelchair to move inside the bus in order to reach the safety region(*Figure 6.9*).

- *warning button* – a button placed in the safety region for the passenger in the wheelchair to inform the bus driver with the fact that he is intending to get out of the bus at the next stop. This will prevent the driver to close the bus doors before the person in the wheelchair gets out.

Figure 6.7 Belt System: Left: Wall Component – source: CRPG. Right: Chosen System

The safety belt system chosen for our case is a 13102 Universal Automatic Safety Belt produced by Shenzhen A.T.R. Industry Co. with ctn size: 51.5 x 38.5 x 21.5cm(see *Figure 6.7 – right*).

As it it may be seen in *Figure 6.8* the retractor and the tongue of the belt system will be placed on the wall of the bus and the duckle will be fixed on a bar mounted at the left side of the wheelchair.

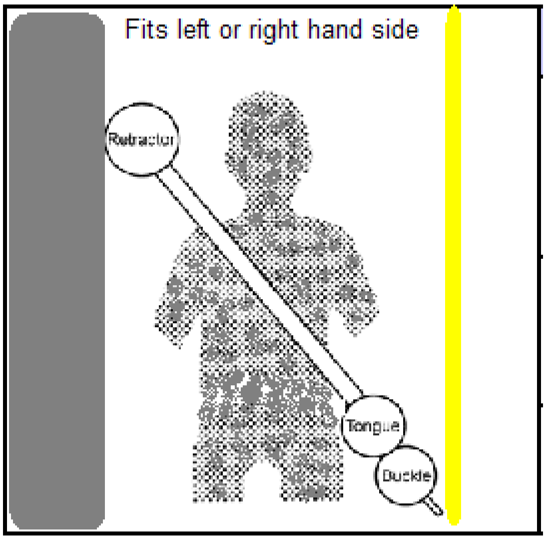


Figure 6.8 Position of the belt system.

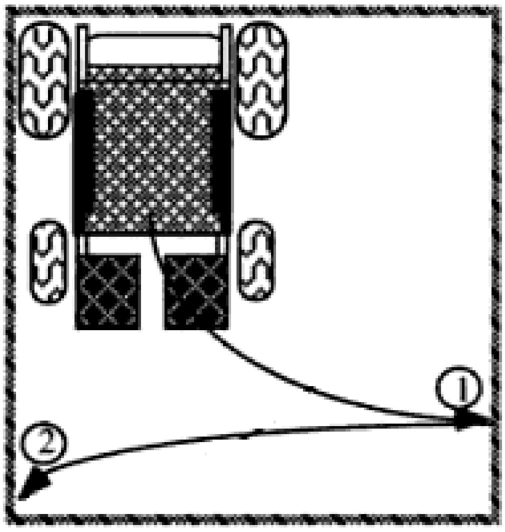


Figure 6.9 Safety Zone Reaching Maneuvering

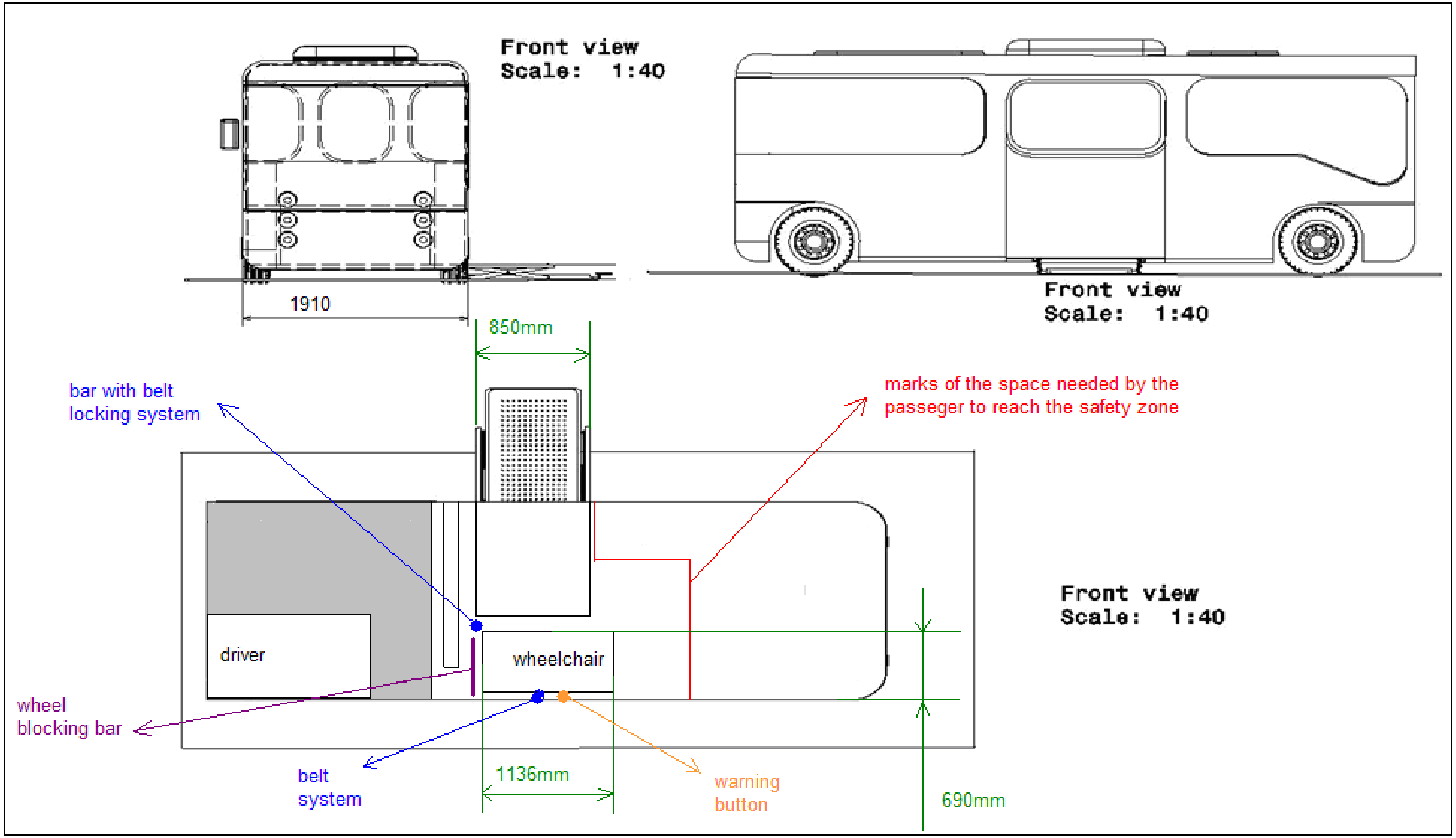


Figure 6.10 Safety System inside the bus

b) Outside the bus - on the platform

As mentioned in the first chapter, the safety of the passenger when using the lifting device is of a great importance and has to be treated separately.

To start with, before getting inside the bus, the passenger in the wheelchair will place himself on the left side of doors, next to the start button. Once the button has been pushed, the doors open on the exterior and the platform gets out. The passenger must stay in that lateral position until the platform is out of the bus, reaching the ground.

The measures taken in what concerns the safety while using the device are the following:

- *vertical wall at the front of the platform* – it is meant to prevent the sliding of the wheelchair backwards. This wall has a double function, more exactly it is also a movable ramp that ensures the smooth passing on/out of the platform when it is placed on the ground.

Thus, when the person gets on the platform, the ramp is in vertical position and contributes to a safety condition of the wheelchair(*Figure 6.11-source: Braunability*).

Figure 6. 11 Front Safety Wall: *Left*: Vertical position; *Right*– ramp position

- *handle* - this handle is placed on the platform, on its right side and has the role of supporting the passenger during the lifting or descending of the device. An example of safety handle mounted on a similar lifting device can be seen in *Figure 6.12*. What is to be mentioned is that on this handle there is placed a remote with 2 buttons: Lift and descend buttons. Therefore, once safely placed on the platform the passenger decides by his own the actuation moment by pushing the corresponding button(*Figure 6.13*).

Figure 6.12 Example of safety handle placed on a lifting platform

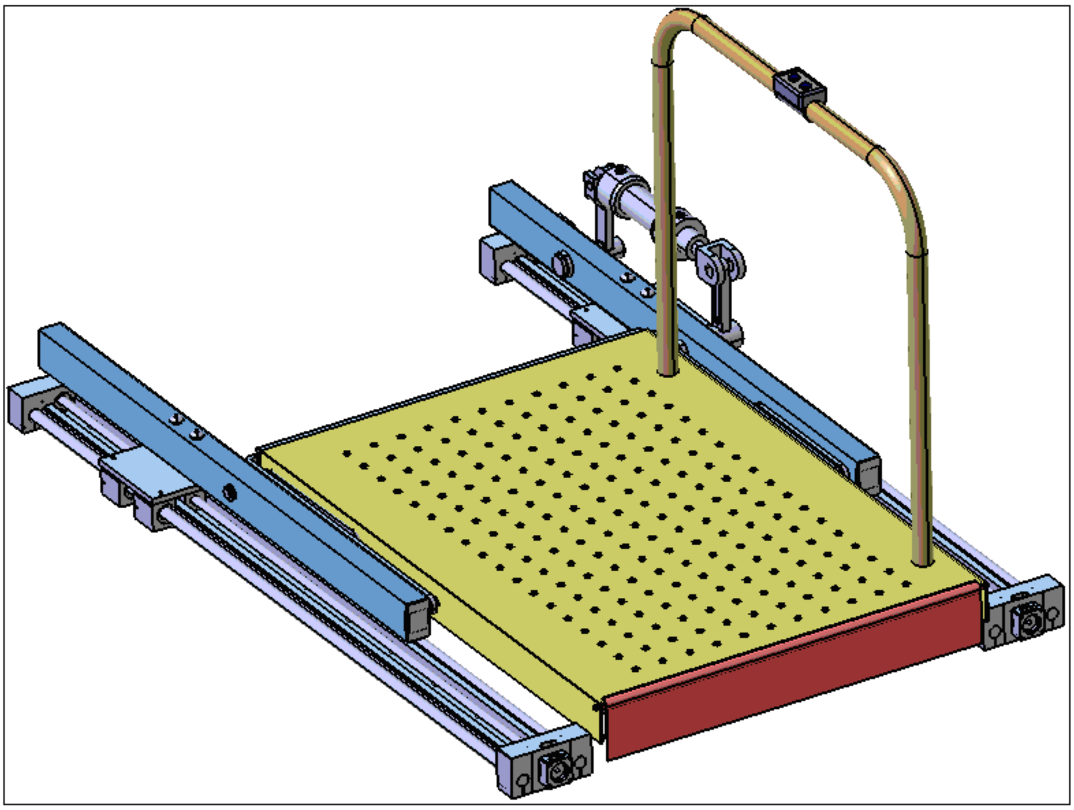


Figure 6. 13 Platform and Handle Structure with remote – 3D CATIA model

The handle has 700mm height, 700 mm length and 40mm diameter. Its cross-section is hollow with a inner diameter of 35mm. The connection wires of the remote control are passed through the interior of the handle until inside of the bus.

6.3 Manual Back-up System for the Sliding Operation

Like any other lifting device used in similar applications, it may deal with a set of failures. This aspect must be carefully analyzed and treated separately considering each possible cause of failure on each of the mechanisms involved.

In what concerns the sliding mechanism, the failure can be caused by lack of lubrication, wear or damage of various components or motor failure.

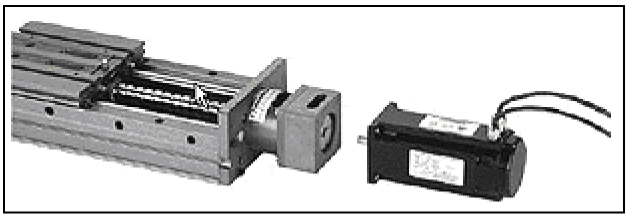


Figure 6.14 Motor mounting on the Sliding Mechanism – source: DANAHER motion producer

Analyzing all the above situations, a back-up manual system has to be developed for mechanism failure situations. Therefore, the method we thought of is that of dismounting the motor from the sliding mechanism and actuate manually the carriage(see *Figure 6.14*).

The actuation will be performed manually using a wheel and a lever that will slide the carriage and the platform consequently. The lever will be mounted at the end of the sliding system, at opposite end to the motor. This specification will be transmitted to the manufacturer of the sliding system to enhance the easy access to the screw and the necessary tools for the manual actuation(*Figure 6.15*).

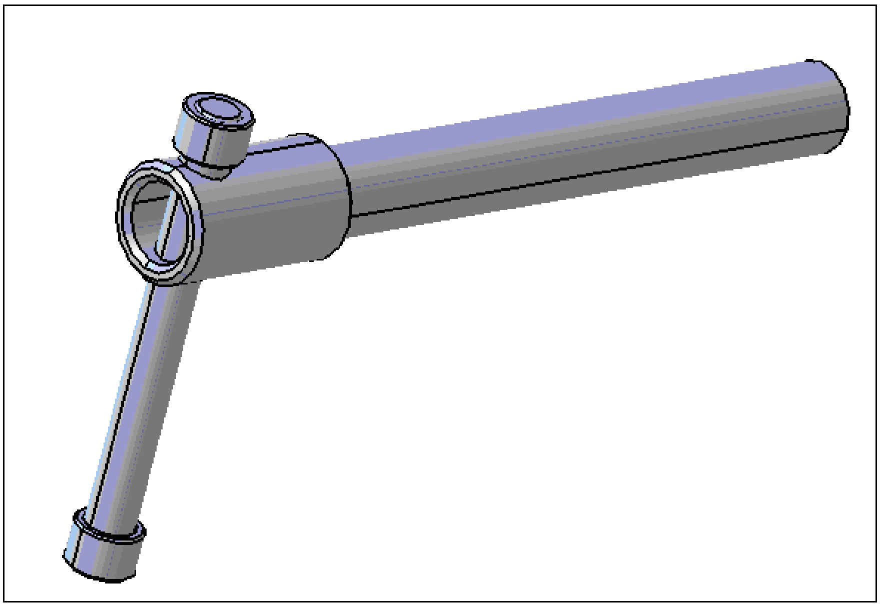


Figure 6.15 Manual Back-up System, 3D CATIA producer – Rotating Lever

6.4 Front Ramp Actuation

The small ramp that is mounted on the front side of the platform has the role to ease the passing of the wheelchair on/out of the platform, but mostly it has a safety function.

When the platform is in the initial position (inside the bus), the ramp will be in vertical downwards position (see *Figure 6.16* , Case A). At the moment of actuation, when the doors are opened, the ramp is performing a rotation of 180 degrees around the rod mounted on the front upper side of the platform. As a consequence, before getting the platform out of the bus, the ramp becomes a vertical wall that fulfils now a safety function (see *Figure 6.16*, Case B).

After the platform has reached the ground, the next action is the descending of the ramp from the upper vertical position to the ground level (see *Figure 6.16*, Case C).

The actuation is made by the use of an electric motor at the signal of a proximity sensor.

The sequence of ascending movement is developing similarly: once the person is on the platform, he/she starts the ascending by pushing the button on the handle. The button activates the ramp movement as well, which is brought in the upper vertical position – safety issue.
When the platform has totally entered in the bus, the electric motor brings the ramp in the down vertical position for storage. This enables the access of the other passengers in the bus without any potential small obstacle.

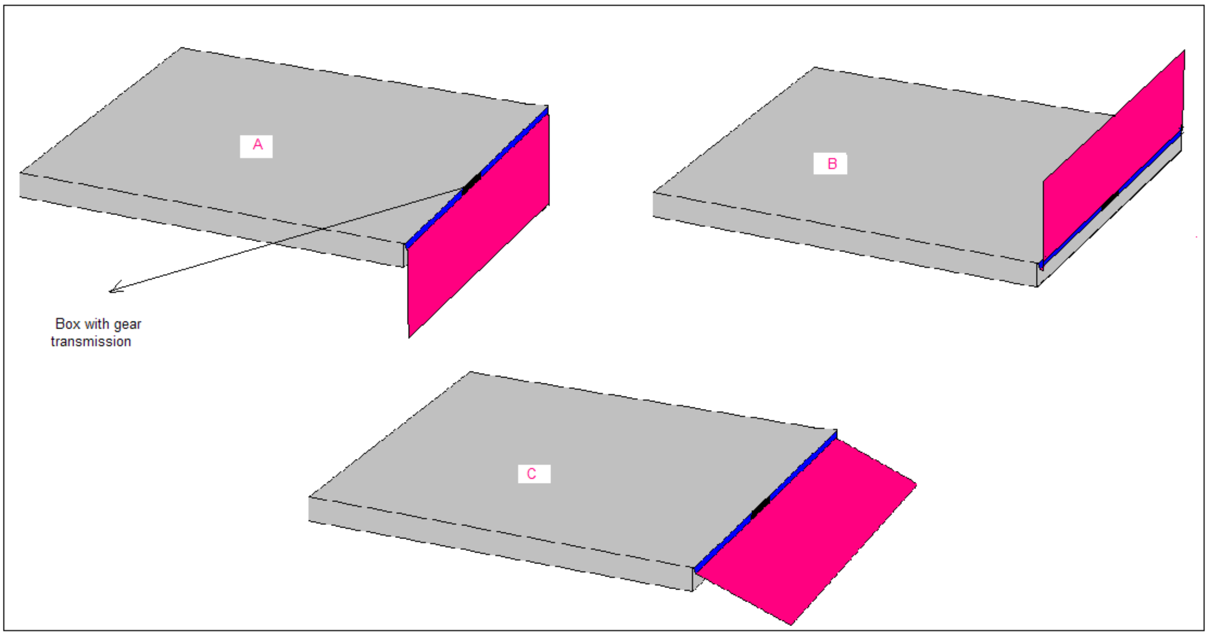


Figure 6.16 Ramp: Actuation Positions.

Actuation.

The front ramp will be actuated by an electric motor mounted under the platform and a gearbox directly connected to the rod that is moving the ramp between its extreme positions.

The rod that connects the ramp to the platform will have an integrated gear connected to another gear and in the end to the electric motor. As a consequence the gear box will also be mounted under the platform, at the middle of the rod that is linked to the ramp – see the black box in *Figure 6.16*.

Special sensors prevent the platform from raising if the roll stop is not fully engaged(*Figure 6.17*).

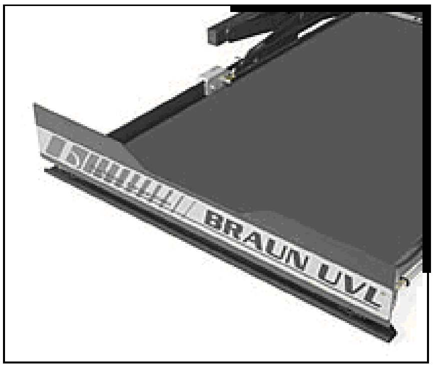


Figure 6.17 Front Ramp Actuation – source: Braunability producer

6.5 Safety Movable Floor

Another necessary element is the safety floor whose function is that of covering the empty space left behind by the platform when it gets out of the bus.

It also isolates the mechanism parts from bellow the platform level inside the bus, it may sustain a potential weight although it is not its main role and this should be avoided. Last but not least, the safety floor has also an aesthetics function.

<u>Safety Floor Structure.</u>

The safety floor must cover a surface of 850mm x1200mm, from the bus floor level to the doors level. Its total length is of 1250mm(*Figure 6.18*).

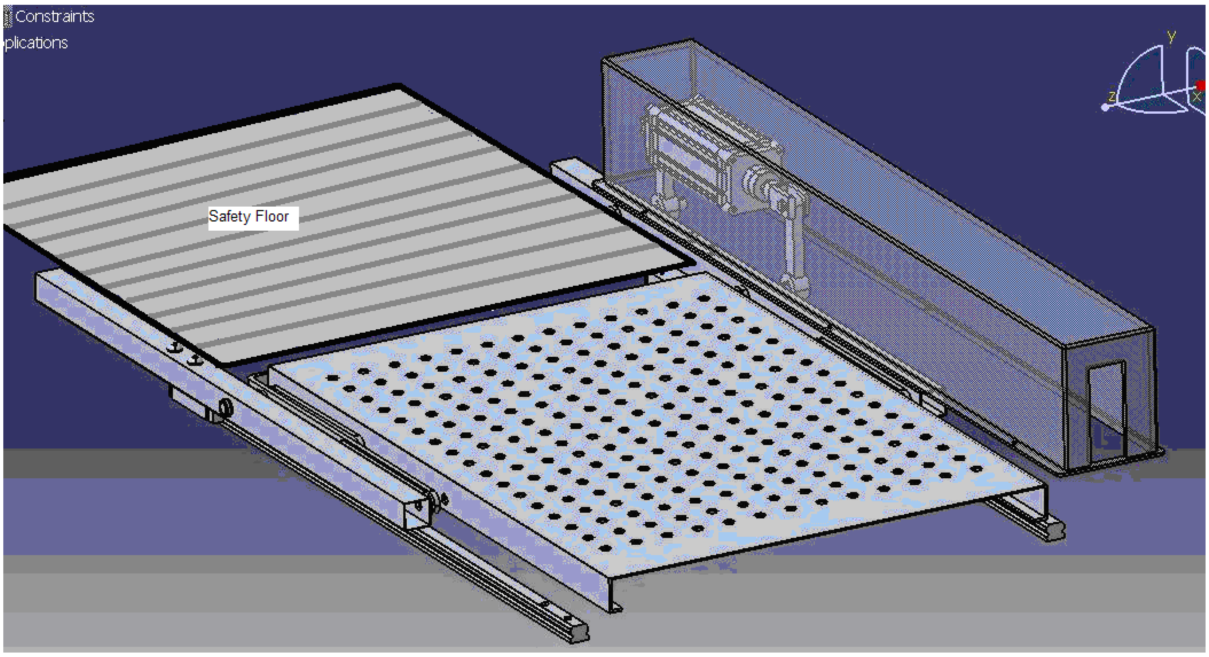


Figure 6. 18 Platform and Safety Floor Connection – 3D CATIA model

Initial position: the safety floor is stored in folded state under the bus level in the continuation of the platform(see Case A in *Figure 6.19*). The length of the safety floor in folded position is of 50mm consisting in the approach of 16 metal(steel) plate elements of 100mm x 850mm x 3mm volume each.

Once the platform starts to get out of the bus, the folded plate is pulled simultaneously with the same speed. This is ensured by the fact that the plate is linked on its front and lateral sides to the cantilevers who slides on the linear motion system.

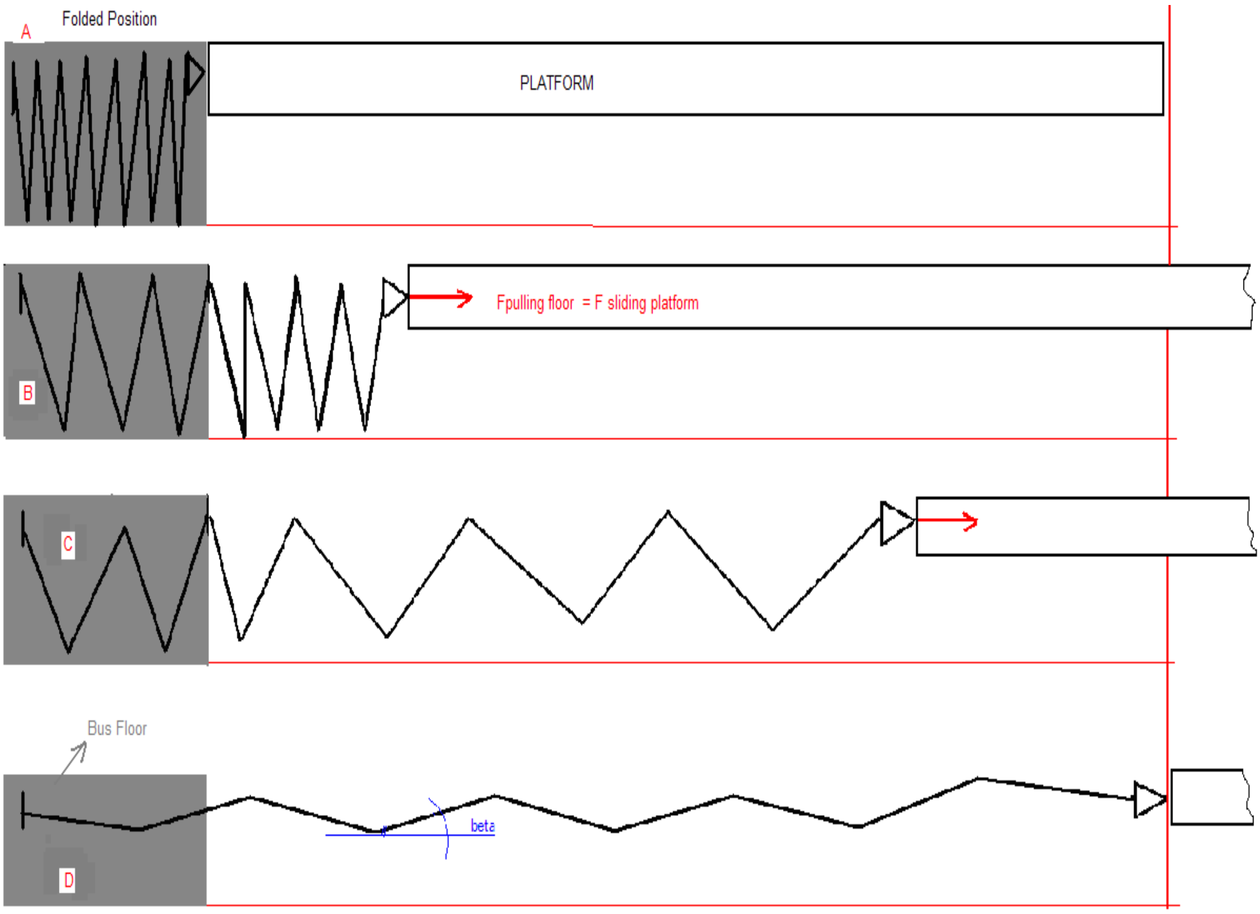


Figure 6.19 Safety folded Floor – hand sketch

The elements of the safety floor are connected alternatively to the cantilever through the common rod. Therefore, the plate is unfolded from beneath the bus floor until the maximum sliding distance of the cantilever.

Final Position. When reaching the final position the safety plate will have its elements aligned under a safety angle(thus not completely horizontal) such as to prevent undesirable folding effects when the platform retracts. This angle (beta in the *Figure 6.19*) is around 10 degrees(see case D in *Figure 6.19*)

The metal elements of the plate are linked to each other through hinges. For instance, two successive elements are connected by a rod and alternative hinges belonging equally to both plated. This successive connection develops the effect of folding under the action of the pulling/pushing force of the sliding actuation(see *Figure 6.20*).

The safety floor is mounted at one end using a rod that is connected to the 2 sliding arms(cantilevers) and at the other end it is fixed on the bus floor at a lower level.

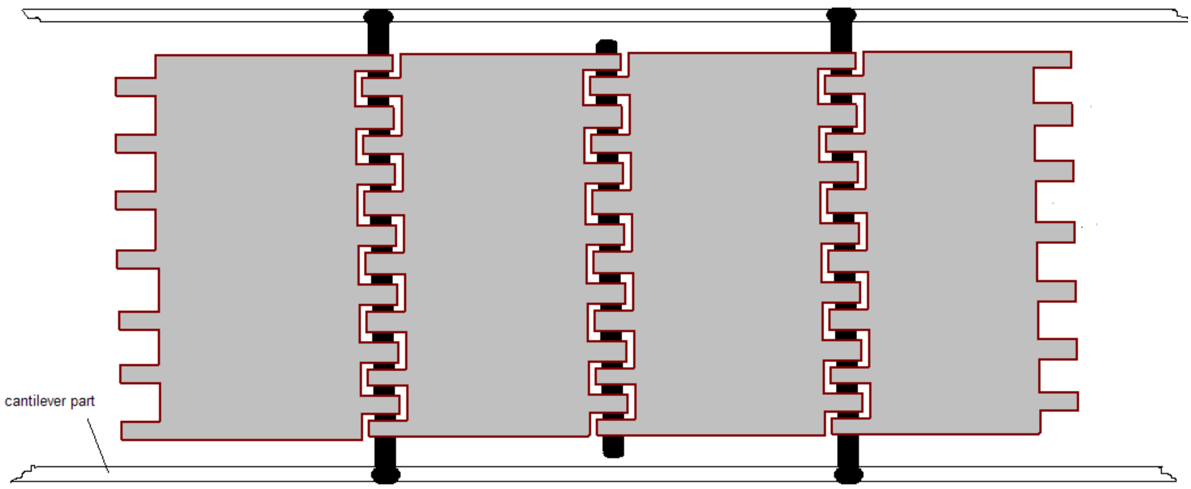
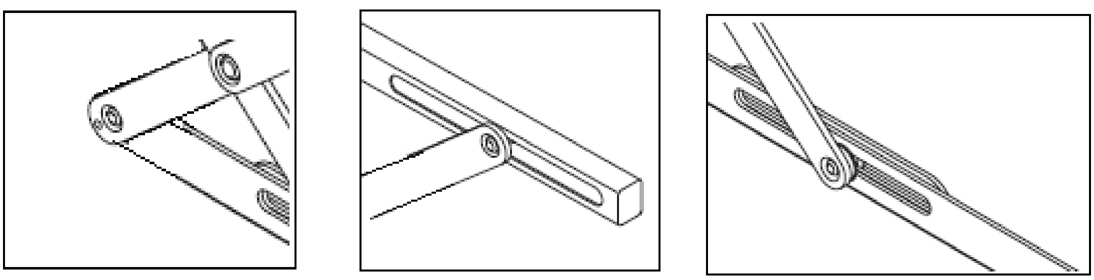


Figure 6. 20 Safety Floor element – Mode of folding – hand sketch

6.6 Scissors Linkage. Main and Secondary Joints.

Analyzing the scissors linkage we came across three types of different joints that link the arms among themselves or to the other components(sliding arm or platform). We have classified them as follows:

1) Secondary Joints.



A B C

Figure 6. 21 A. Joint that links the secondary arm to the cantilever. B. Joint that links the principal arm to the platform. C. Joint that links the secondary arm to the platform.

First type of joint is the rotary type joint(*Figure 6.22*) that is used to link the main arms to the sliding arms and one set of secondary arms to the platform(see *Figure 6.21* A) . Therefore, there mechanism implies four rotary joints, two on each lateral side of the platform.

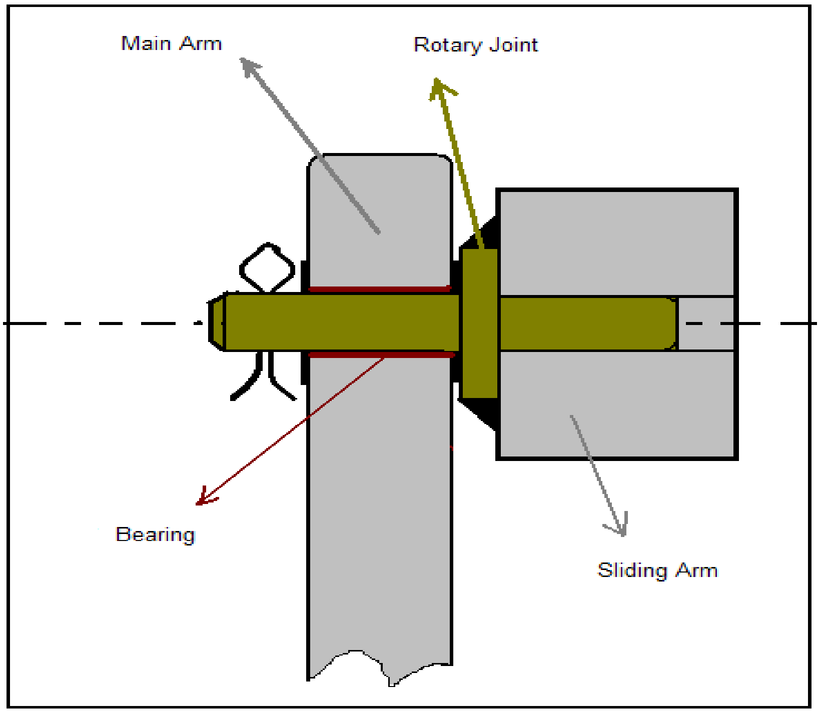


Figure 6. 22 Rotary Type Joint – Hand sketch

The second type is the rotary-sliding joint that links the principal arms with the platform and the other set of secondary arms to the cantilevers(see *Figure 6.21* B and C). There are also 2 joints of this type on each lateral side of the platform.

2) Main Joint.

The joint between the three arms of the scissors linkage is referred to as the main joint (see *Figure 6.23*). This joint has a specific profile in order to realize the descending and lifting movements. More exactly, the two secondary arms that are mounted on both lateral sides of the main arm have to be synchronized and thus their rotation will enhance the necessary angle for the mechanism to function efficiently.

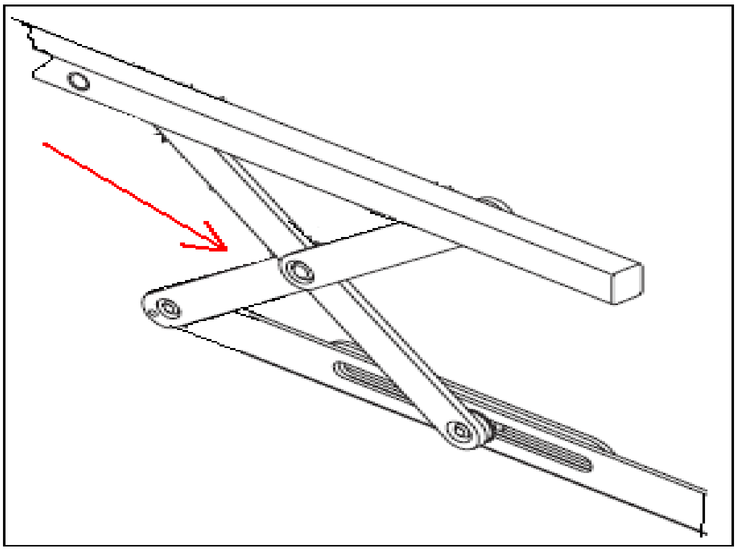


Figure 6. 23 Scissors linkage – Main Joint

The profile of the main joint takes into account the mounting of the three arms and the synchronization of two secondary arms. The main arm is fixed on the main joint using a key. Its lateral sides have also circular cross-sections, but with smaller radii for mounting and manufacturing purposes (see *Figure 6.24*, Left Side).

The 2 secondary arms are rotating freely on the main join using bearings and they are fixed at the end using appropriate nuts.

There is also another profile that we analyzed that involves a circular cross-section for the main arm rotation, without a key, splines or any kind of fixed contact between them, allowing the free rotation. The lateral cross-sections are squared in order to synchronize the secondary arms. Based on inertial considerations the actuation of the main arm should imply the movement of the other two arms and the correlation of the scissors linkage (see *Figure 6.24*, Right Side).

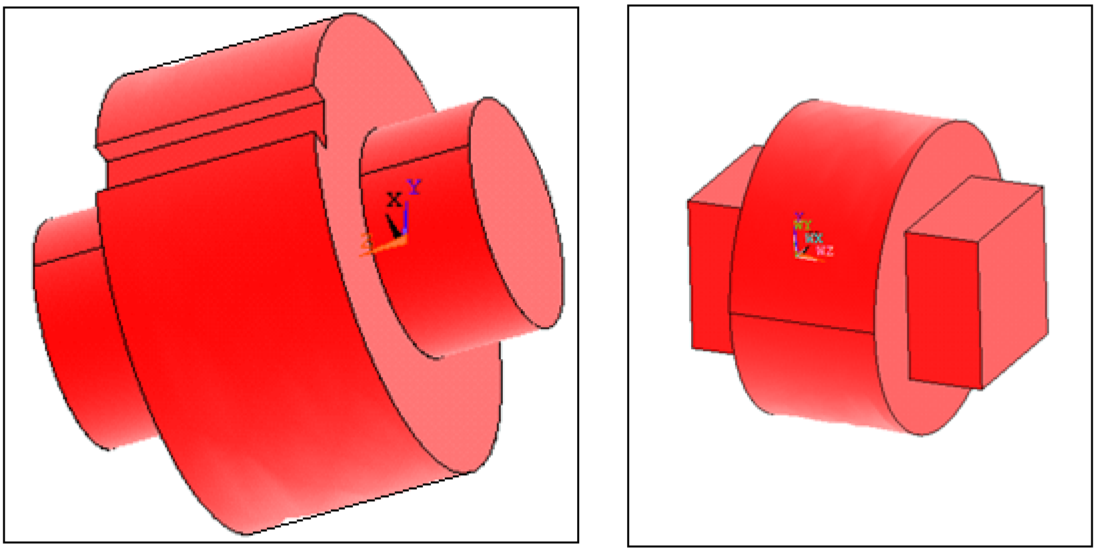


Figure 6. 24 Two possible joint profiles for the Main Joint. Left: Fixed centre and Movable sides; Right: Fixed Sides and Movable Centre.

The chosen profile with the key component will be fixed at its end with safety pins and the arms will be separated by sleeves.

Note: Most of the components described above are concepts of the solutions I found for the needs of the final mechanism. They are achievable and functional and call for production. The models are not complex but most probably are unique from the point of view of the design and therefore, a special demand for manufacturing is needed.

PART B

6.7 Briefing on the rest of devices used in the mechanism

The rest of the devices needed by the mechanism were analyzed by my colleague Ioana Adina Neacsu in the project *Concept generation and integration of a lifting mechanism on a campus bus* in the chapter with the same name and involves the following:

6.7.1 Selection and design of the hydraulic equipment

a)Principal actuation system-hydraulic cylinder

Table 6.1.Chosen cylinder parameters

Cylinder code	Manufacturer	Pressure [MPa]	Load [kN]	Piston diameter [mm]	Rod diameter [mm]	Length [mm]	Weight [kg]
63/36.01-Hub/G3/4"/A/N	HYDROPA	250 bar	77.9	63	36	373	18.5

b)Secondary actuation system-hand pump

Table 6.2.Characteristics of the chosen hand pump

Hand pump code	Manufacturer	Cylinder Capacity [cm^3]	Max. Handle effort [kg]	Piston stroke [mm]	Weight of the device [kg]
P-392	ENERPAC	901	42.2	25.4	4.1

6.7.2 Electric control of the mechanism

What: The controls will consist of simple switch mechanisms (buttons) located in different places in the bus, in accordance with their purpose. Five main push buttons are to be implemented.

How: The functions of the buttons will be defined using PLCs, known by their whole name as Programmable Logic Controller.

PART C

Detailed Operation Procedure of the Mechanism

1.Getting inside the bus

- The person in the wheelchair pushes the button at the exterior of the bus, placed at the left side of the doors and also on the exterior side of the left door – when the doors are opened prior to the activation of the lifting device.
- The doors open
- The additional ramp goes from initial position to vertical safety position
- The platform slides from inside the bus until it is completely outside
- The platform descends until the ground level
- At the end of the descending, the additional ramp goes from the vertical position to the ground level
- The person in the wheelchair gets on the platform
- The passenger holds the handle and pushes the LIFT button placed on the handle
- The additional ramp goes to vertical safety position
- The platform start to ascend until it reaches the bus floor
- The platform slides completely in the bus
- The person leaves the platform and goes to the safety zone/area inside the bus
- The ramp goes from vertical position to the initial storage position
- The doors close
- The passenger in the wheelchair places his/her wheelchair next to the safety bar and fastens the seat belt
- The fastening of the seat belts informs the bus driver(through a warning sensor) that the passenger is ready for the travel.

2. Getting out of the bus

- When the passenger in the wheelchair plans to get down at the next station, he/she will push the button placed in the safety zone/area that informs the driver about the upcoming use of the lifting platform, thus paying the necessary attention to the doors actuation and the whole process.
- The bus stops, the doors open
- The passenger goes from the safety zone/area on the platform
- Holds the handle and pushes the DOWN button
- The additional ramp goes from the initial position to vertical safety position
- The platform is translated outside the bus
- The platform descends to the ground level
- After the platform has reached the ground, the additional ramp goes from vertical to ground level
- The passenger leaves the platform
- Once the passenger is out of the platform, the driver pushes the LIFT button placed near his control panel
- The additional ramp goes in vertical position
- The platform ascends to the level of the bus floor
- The platform is translated inside the bus
- The ramp goes to the storage position
- The doors close

7. Conclusions

The whole work of the project has lead to the conclusion that the concept of the mechanism is achievable. The dimensional, dynamic and strength analysis have shown that the selected mechanism is functional and most likely reliable for its purpose. It can be implemented on the bus for which it was designed, but it also can be sold as an individual product, to companies in search of solutions for transportation of disabled people, successfully fulfilling the safety standards and the design constraints(Annex 4).

The final concept enables an extremely easy accessibility from the user’s point of view. Thus, the passenger in the wheelchair is doing a minimum effort to action the mechanism and get inside the bus. This function has been one of the main targets of this project and it has proved to be fulfilled as well.

The stage of this project leaves open the possibility to improve it and requires thorough work for establishing the final details of all the components and its optimum installation in the CIVITAS bus as well as on any other mean of transport.

Nevertheless, the design stage will prolong during the manufacturing and practical testing, but the analysis presented so far will represent the fundamental data for such a project.

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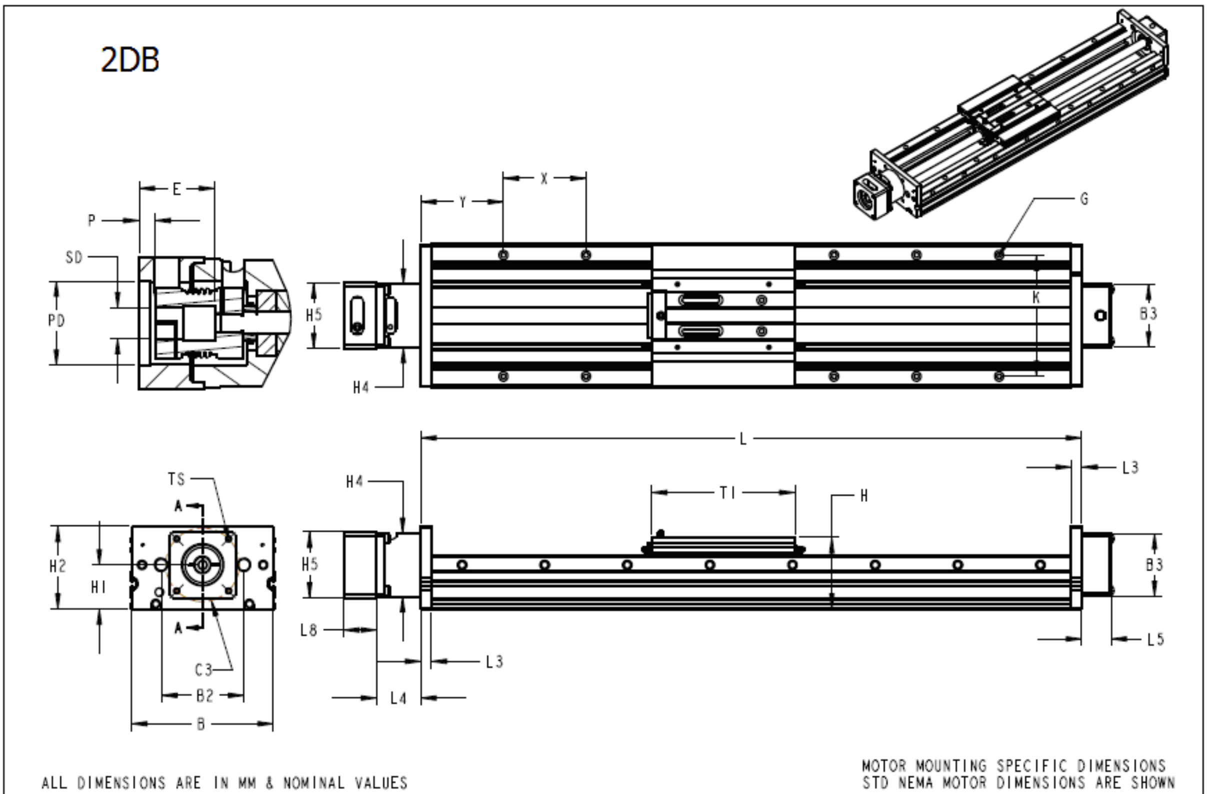
9. Annexes



P/N	B	B2	B3	G	H	H1	H2	H4	K	L3	L4	L5	T1	X	Y	L MAX.		SD	PD	E	P	C3	H5	L8	TS
2RBM12	130	75	60	M4 CL	65	40	75	60	110	9.5	40.2	26.5	130	75	75	2100		6.35	38.1	34	7	66.68	60	30	M4
2RBM16	160	95	60	M5 CL	80	48	79	60	135	12.5	40.2	31.5	160	100	100	3000		6.35	38.1	34	7	66.68	60	30	M4

Annex 1 Sliding Mechanism – Dimensions for a Single Carriage System

Motor Sizing Information

Screw Parameters

Diameter:	12.7mm
Length:	56.2 in
Lead:	12.7 mm/rev
Nut Preload:	9.6 oz-in
Efficiency:	0.9

Forces

Thrust Force:	0 N
Continuous Force:	0.00 lbf

Load Coupling

Inertia Direct Entry:	1e-005
System Inertia:	0.001789 kgm^2
Applied Force Torque:	0 Nm
Friction Torque:	0.04 Nm
Continuous Torque:	0.07 Nm
Speed @ Cont. Torque:	567.21 RPM
Peak Torque:	0.27 Nm
Speed @ Peak Torque:	637 RPM

Slide Information

Slide Weight:	1.78 kg
Elevation:	0 degrees
% of Weight CounterBalanced:	0
Gib Force:	9.6 oz
Speed at Thrust Force:	0
Speed Maximum (Traverse):	0.1593 m/s
Coefficient of Friction:	0.002

Part Information

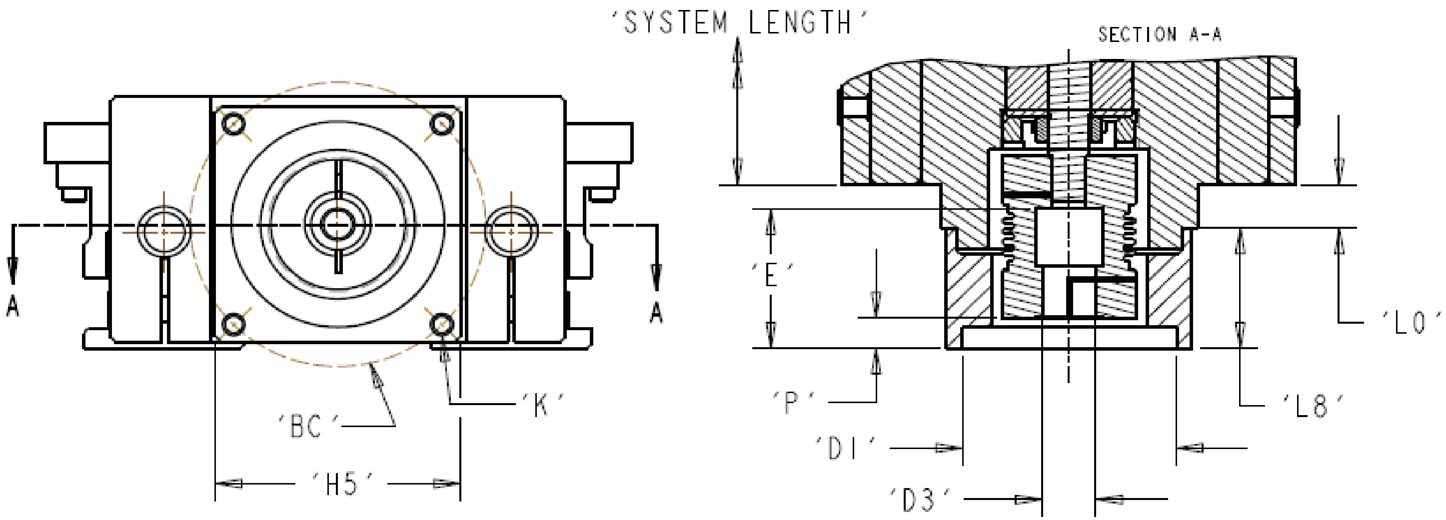
Part/Tooling Weight:	4200.00 N

Profile Information

	Segment 1	Segment 2	Segment 3
Beginning Speed:	0.0 RPM	637 RPM	637 RPM
Ending Speed:	637 RPM	637 RPM	0.0 RPM
Time:	1.10 sec	7.81 sec	1.10 sec
Torque:	0.271 Nm	0.041 Nm	-0.189 Nm
Dwell Time:	20 sec		
Dwell Torque:	0 Nm		

Annex 2 Motor Sizing Information

STANDARD NEMA MOTOR ADAPTERS

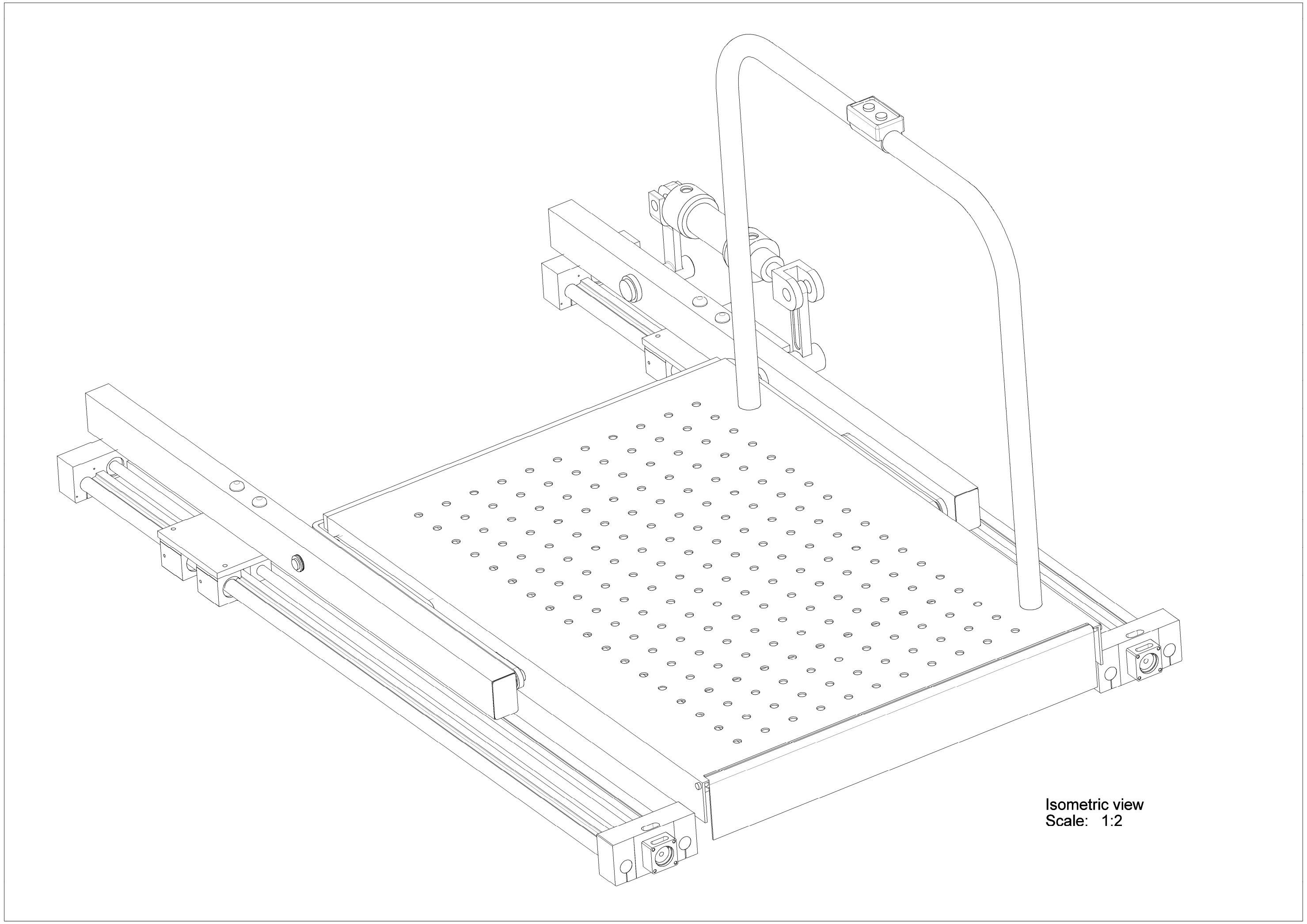


ALL DIMENSIONS ARE IN INCHES & NOMINAL VALUES

SYSTEM	STD MOTOR *	MTR ID	H5	L8	BC	K	D3	D1	E	P	L0
2DB08	NEMA 23	001	2.25	2.20	2.625	M4	.25	1.50	1.37	.50	N/A
2EB08	NEMA 23	001	2.36	1.17	2.625	M4	.25	1.50	1.30	.24	.42
2DB12	NEMA 23	001	2.36	1.17	2.625	M4	.25	1.50	1.36	.29	.42
2EB12	NEMA 23	001	2.36	1.17	2.625	M4	.25	1.50	1.30	.24	N/A
2DB16	NEMA 23	001	2.36	1.17	2.625	M4	.25	1.50	1.36	.29	N/A
2EB16	NEMA 34	002	3.40	1.69	3.875	M5	.375	2.875	1.75	.35	.51
2EB24	NEMA 42	003	4.53	2.43	4.950	M6	.625	2.188	1.90	.40	.41
2RB12	NEMA 23	001	2.36	1.17	2.625	M4	.25	1.50	1.34	.27	N/A
2RB16	NEMA 23	001	2.36	1.17	2.625	M4	.25	1.50	1.34	.27	N/A
2HB10	NEMA 23	001	2.36	1.17	2.625	M4	.25	1.50	1.34	.27	N/A
2HB20	NEMA 34	002	3.40	1.69	3.875	M5	.375	2.875	1.97	.35	N/A
MS25	NEMA 17	505	1.57	1.85	1.725	Ø.13	.197	.866	1.12	.41	N/A
MS33	NEMA 17	505	1.57	1.85	1.725	Ø.13	.197	.866	1.12	.41	N/A

* DIMESIONS WILL VARY DEPENDING ON MOTOR MOUNTING.
DIMENSIONS LISTED ARE FOR MOUNTING STD NEMA MOTORS.

Annex 3. NEMA motor adapter



Annex 4. Isometric view of the mechanism