Design and Analysis of stair climbing wheelchair

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Abstract: The paper deals with studies carried *out* over different ergonomics, pre-existing models of wheelchairs, critical aspects, which usually influence smooth and stable transversion nature of wheelchair, while climbing stairs and moving through different terrains. Theoretical Dynamic analysis on motion of wheelchair is also carried out to bring a better view at the transmissibility of wheelchair. The design of a stair climbing all terrain wheelchair is endeavored and critical components of wheelchair are modeled using solid modeling software and analyzed using the finite element method.

Key Words: *Wheelchair, transmissibility, all terrain, finite element method.*

Introduction:

Over a few decades there is no great change in the availability of sophisticated wheelchairs to the common people. The economic or below economic classes of India are suffering with the exorbitant prices for sophisticated or the reliable models of wheelchairs. The basic issue, which is found these days is the inability of the wheelchairs to pass through different terrains. Furthermore, the common wheelchairs are not manufactured with purposes of climbing the stairs. The evolution of wheelchair has been governed by a notion of comforting diversified users and their accessibility. Many numbers of organizations have ventured into the transmissible systems.

The drawbacks for such insolvencies are complexity in building the systems, less standard buildings and uncertain problems those which are faced by a wheelchair user. To deal with all such aspects the deep study of pre-existing models and their disadvantages have been studied.

Extensive literature survey is carried out to study the pre-existing models of different types, it is observed that, Intermittent stair-climbing wheelchair models, developed, by various organisations have been searched and their limitations are found to be low transmission efficiency with difficulty in balancing. Auxiliary stair-climbing wheelchair models have huge occupancies and requirement of human assistance as limitations. The study carried out over tracked mechanism shows that there are slight issues such as exertion of pressure on the heads of stairs.

Out of the three major mechanisms tracked mechanism is most adaptable mechanism for stair climbing and all terrain wheelchairs. Hence in the present paper wheelchairs is developed with tracked mechanism, with following objectives:

To furnish an efficient, rugged and economical mechanism. Implement ergonomic aspects of the wheelchair user. Material identification and concluding over the shape of the structural unit member. Designing the wheelchair with respect to adapted mechanism. Theoretical analysis on dynamic aspects of the wheelchair.

Development of stair climbing and all terrain wheelchair:

The development proposed for all terrain wheelchair is initially carried out with a conceptual solid model using solid modeling software. Conceptual model is further modified considering the dynamic stability of tracked mechanism for all-terrain wheelchair. Elaborate analysis is carried out, considering the following.

1. Most importantly, the tracked mechanism not only helps in climbing stairs, but also most suitable for all the different terrains.
2. The mechanism must maintain the stability while climbing any gradient.
3. Climbing stairs comfortably without any possibility of toppling.
4. It should help in transmissibility through any different standard of stairs irrespective of their dimensions.

In tracked mechanism there are two major types those are single section tracked and double section tracked. Double section tracked mechanism is more suitable for climbing of stairs with no discomfort and greater stability considering the center of gravity of system. Although, double section tracked mechanism is complex, incorporation of some sophisticated technologies with better assessments can solve the complexity.

Adapting double tracked mechanism:

After thorough evaluation on concepts of different stair climbing mechanisms it is found that the integration of double tracked mechanism with tri wheel belt drive system is the more stable and economical solution.

The mechanism is demonstrated as shown in the figure below.

The wheel '1' is revolve able about the center of wheel 2 or adjustable, with respect to the angle of inclination made between tread width and rise of the stairs.

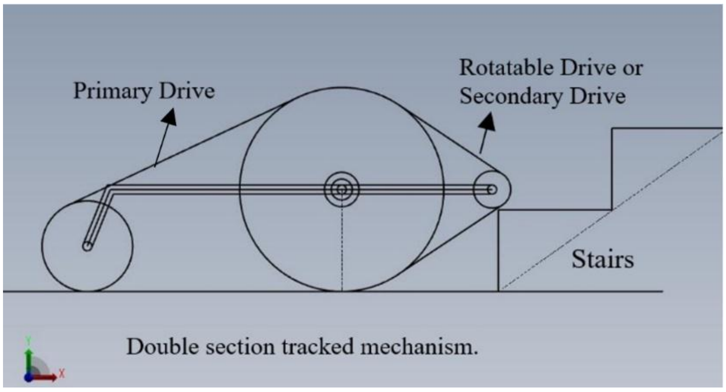


Figure 1. it outlines the double section tracked mechanism.

Wheel 3 is able to rotate with respect to its center at center of mid wheel or wheel 2 also helps the system to safely prepare itself in climbing the gradients and stairs as well. As there are requirements of the electro-fitted rachets at the linkages of the end wheels whose necessity is to maintain an angle of inclination with respect to the angle of inclination of the stairs or ramp upon which wheelchair system has to transverse.

Considerations made for double section tracked mechanism:

For the system to climb stairs whose inclination is α degrees, must be equal to the inclination of tangent of belt with the ground that which is θ degrees. To satisfy this, the length of linkage must be proportionate to angle of inclination required as shown in the figure. As the length of linkage 2 increases the angle of inclination θ degrees decreases, thus if θ is less than the α the heights, cannot be climbed by the system. The condition for the system to climb the stairs is $\theta > \alpha$ or $\theta = \alpha$.

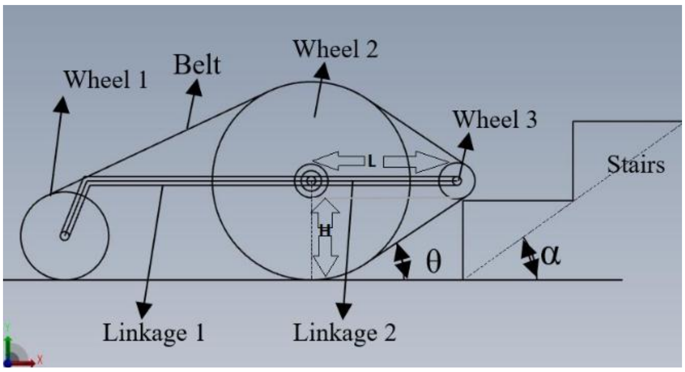
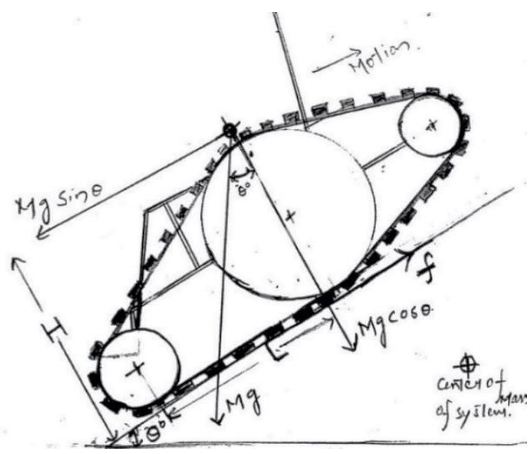
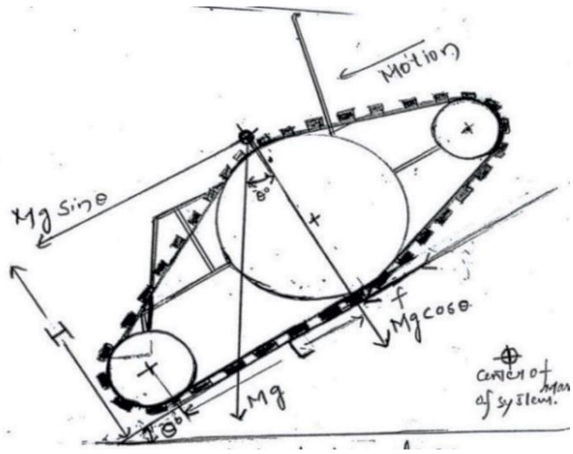


Figure 2, pictorial representation of the concept of climbing stairs.

Theoretical dynamic analysis of the wheelchair while ascending and descending gradients:

Firstly, the center of mass of the whole conceptual model is found out theoretically using the method of average for the moments generated by the center of masses of the fragments which constitute to the whole complex system. The center of mass of the system is found first then the center of mass of the human body in sitting posture is found after which the center of mass of the system having human seated is found. As the mechanism involves the rotation of the seating by 35 degrees, while climbing gradient or stairs, the center of mass of the system when the seating is rotated by 35 degrees of angle is found. The basic theoretical dynamic analysis is done based on the center of mass and its stability. The toppling becomes unavoidable if the balancing of center of mass fails. The following analysis is made.





While ascending the gradient While descending the gradient

As show in the figure while climbing up on the gradient (or) stairs. The system is dynamically moving up, friction acts in the same direction up on the plane due to the track trying to push itself up by moving down.
f = mgsinθ
(if and only if the upward force is greater than mgsinθ it can move upwards)
The toppling occurs when the moment created by mgsinθ is greater than (or) equal to moment created by mgcosθ (or) normal reaction along the distance from centre of gravity to the centre of the front wheel.

mgsinθ + 1 ≥ mgcosθ + 1

the point of the equilibrium is where the toppling starts,

mgsinθ × H = mgcosθ × L

cotθ = H/L

for maximum designed angle $\theta = 35°$

H = 455 mm

L= (580 - 30) = 550 mm

If cotθ = H/L. Then toppling may occur, cotθ = 455/550

2.127 ≠ 0.87

Hence, it is theoretically proved that the designed wheelchair will not to be toppled while ascending stairs. Similarly, it is proved for the wheelchair while descending stairs.

Design considerations:

The design of a usual conventional Wheelchair involves number of factors involving the loading conditions, basic estimated terrains, its prospects into accessibility of any different disability of patient, ergonomics and many other factors as such. Our design of the wheelchair with special abilities as mentioned needs integration of factors like requirements of the mechanism adapted for climbing terrains and the factors those influence design of usual conventional wheelchair. Some of the factors those which are important are illustrated below.

1. Human dimensions.
2. Outer dimensions with respect to safety oriented and space restricting factors.

Human dimensions:

Human dimensions of 85 percentile of Indian men are considered, according to the Global Anthropometric reference data. These dimensions specified in the data books of anthropometry were studied and both the internal and external dimensions of wheelchair are factorized.

Outer dimensions with respect to the following factors:

1. Safety oriented factors.
2. Space restricting factors.

Safety oriented factors:

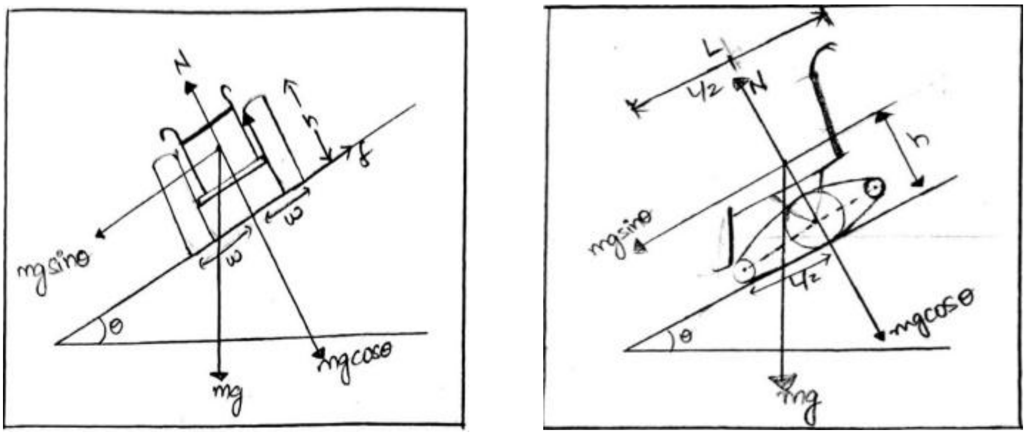


Figure 3, illustration of forces acting on wheelchair and effects of dimensions on the stability.

The length, height and width of wheelchairs are factors, those which effect stability of wheelchairs.

If w×mgcosθ > h×mgsinθ only then the wheelchair can pass across a steep as shown in the first figure.

If L/2 ×mgcosθ > h ×mgsinθ only then wheelchair can transverse, descending the steep.

There are many such other considerable safety factors, upon statistical analysis of them the conclusion of the length, width and height.

Space restricting factors:

The width of the staircases on the notes of universally accepted standards is 0.9 meters (900 mm). for one way while 1.5 meters (1500 mm). these are minimum widths. Length and width of the lifts on the universally accepted standards are 1.25 m and 0.95 m, respectively. These are minimum acceptable width and length. Universally accepted standards of width of the doorways are 32 inches (813 mm).

With respect to the mechanism the widths, diameters and offsets of each individual wheel has been studied and dynamically evaluated to design wheelchair with better safety and comfort of the user. The shape and size of the unit structural element of chassis has been concluded upon the survey of pre-existing models and the efficient weight management & evaluation techniques. Upon integrating all the factors shown above a basic design is outlined.

Development of the virtual 3D model:

3D solid models of individual components were designed, considering the conceptual model and adapted modifications. All the components were assembled and were checked for the compatibility. The assembled model and its exploded view are shown in the figure below. The software used for modeling is SOLIDWORKS 2019.

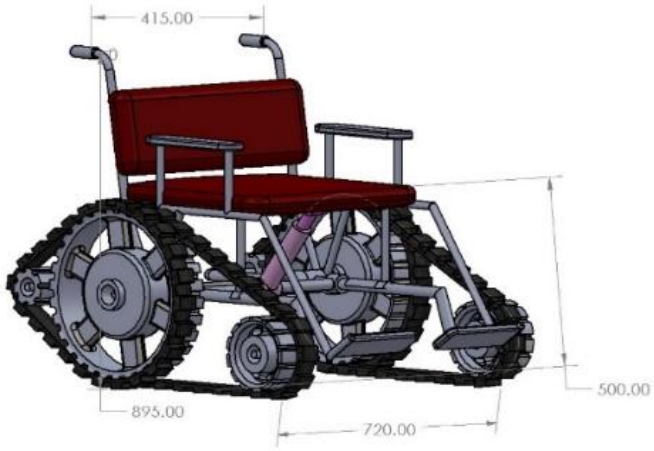


Figure 4: Assembled view of wheelchair Figure 5. Exploded view of the model.

ANALYSIS OF WHEELCHAIR

The analysis and simulation of the critical components of wheelchair. In order to ensure that critical components developed using solid modeling software withstands the static loads and to ensure that materials selected are allowing stresses developed in components to be in permissible limits, the finite element method of static structural analysis is carried out.

Type of analysis**:**

Static structural analysis.

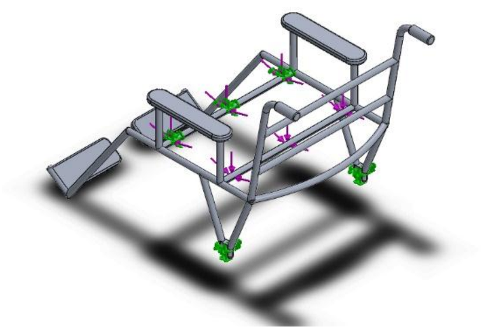
List of critical components analysed are Chassis, Coupling Rod and Axle.

Assumptions:

The properties of the materials are homogeneous throughout the component. There are no cracks or blow holes present in the materials used. The material is static in nature. The forces applied are uniformly distributed along the specified planes.

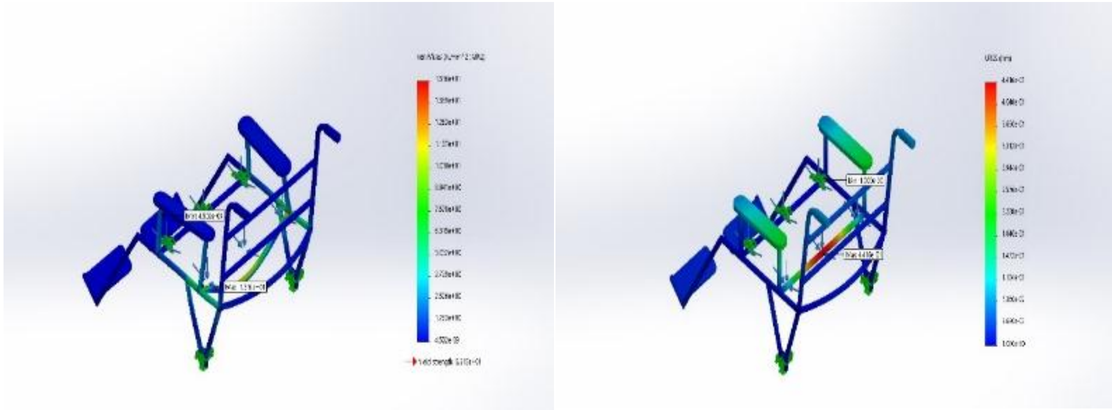
Chassis:

Boundary Conditions:



The displacement of chassis where axle is mounted is restricted in all the degrees with zero displacement. Static loads were applied on the top frame while the average load (i.e., 1500 Newtons divided by 2), while the fixtures are encircled at the conjunction of rods connecting chassis with axle.

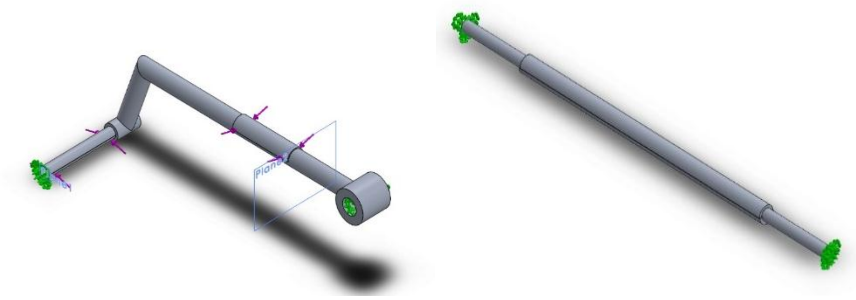
The load is uniformly distributed over frame. The element used is 4 node 3D tetrahedron (curved). Other specifications of the results are enlisted below.



Von – Misses Stress Displacement

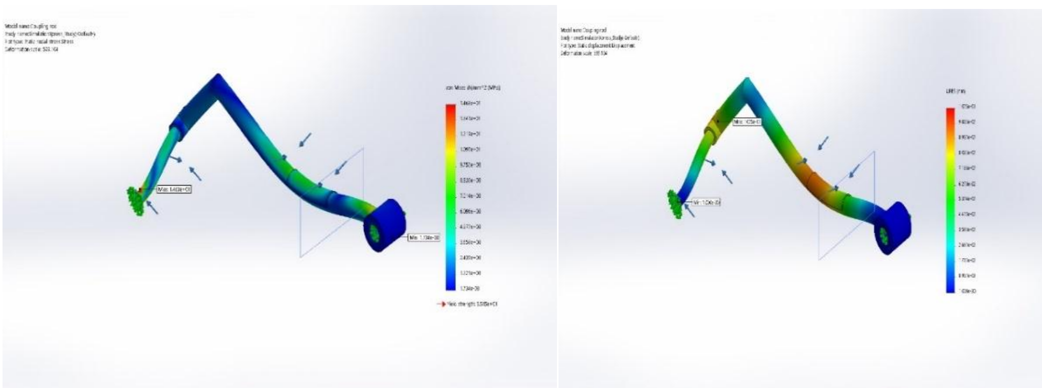
Material considered for all structural members is Aluminium (Al 061) with Tensile strength as 124 N/mm^2, Upon completion of FE analysis the results are Max deflection is 4.416e-01 mm, Max stress 1.56e+01 N/mm^2 and Factor of safety is 3.63. As the stresses generated in the members of chassis are in the permissible limits, the use of certain material and structural unit's shape is justified. Similar considerations are employed for all the other components and the results are studied and presented.

Coupling Rod:



Boundary conditions for coupling rod and axle

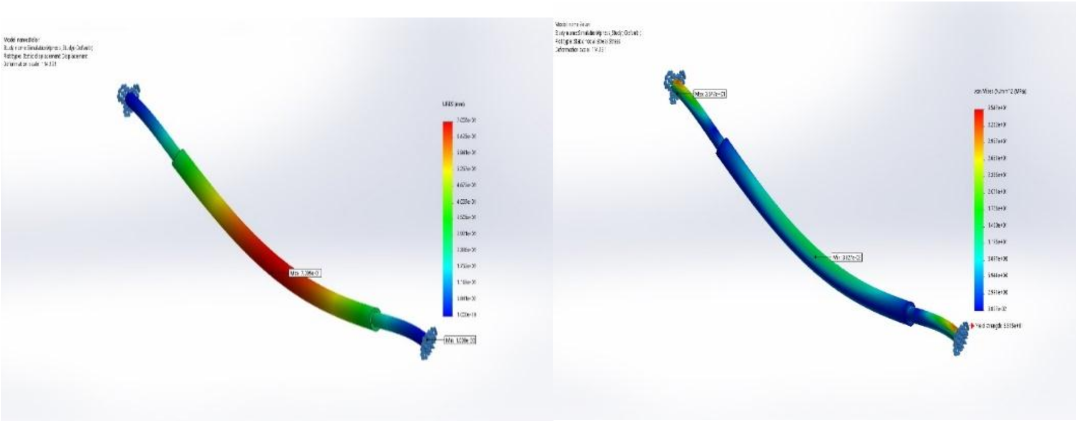
The load assumed is uniformly distributed over structure of coupling rod whereas the load assumed is 335N at the shaft of the front wheel. While 250N on rod connecting the coupler with the shaft (the place of loading is just adjacent to the plane). The displacement is made zero at two places one is at the coupling place with axle (that which is in the back) and the other is at the front the place where the small or front wheel of the system is mounted. The element type is 4 node 3D tetrahedron. The aspect ratio of 98.6 percentage of mesh was less than 3. The total number of nodes were 13677 while size of each element in mesh was 8.537mm.



Von – Misses Stress Displacement

Axle:

The displacements at ends of the axle are made zero. The load that which acts on the axle is considered, to be outside the stepped geometry. The type of load that which happens to develop over the axle while it is static is a uniformly distributed load throughout the curved surface of the ends of the solid axle. The load is considered, to be one fourth of the load due to weight on each side of the axle. The element type used is 3D tetrahedron.



Von-Misses stress Displacement

Results: Maximum stress and factor of safety values are tabulated as follows:

Material: Aluminum alloy AL 6061, Tensile Strength: 124.08 N/mm2

S.no	Item Description	Material	Maximum stress (N/mm^2)	Factor of safety
1.	Chassis	Aluminium alloy 6061	1.516e+01	3.63
2.	Coupling rod	Aluminium alloy 6061	1.463e+01	3.76
3.	Axle	Aluminium alloy 6061	3.547e+01	1.55

Conclusions:

A mechanism for a wheelchair, which can transverse in most of the different terrains and by nature can ascend and descend the stairs, has been very optimally designed considering various influential factors. This can solve the problems of a common patient to get into access into any remote. The optimal conceptually designed model is theoretically analyzed with its dynamics. The conceptual model is then analyzed using finite element method, detailed study of stresses induced and deformations that are to be caused also their loads is carried out. The study carried out enables us to clearly convey that the model is surely safe for manufacturing.

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