Design Report on NASA Challenge: A Common Restraint and Mobility Aid System for Multiple Gravity Environments

Designed by a team of two:

1) Vivek Gupte.
2) Aniruddha Nayak.

Few things that we considered while designing the RMA system.

We have avoided using electronics and motors in our design. Our main goal was to keep the design as simple as possible and focus more on the mechanism. Because electronics use power and in space systems power is one of the most important resources. We also tried to make the system as lightweight and compact as possible.

Our Understanding of Problem Statement

The RMA system should achieve the following things

a) Restraint the motion of the astronaut when required in all the gravitational conditions.
b) Allow mobility in the work domain freely.
c) Help in hands free carrying of equipment.
d) Also should help in translation from deck to deck vertically as well as horizontally
e) The provided RMA system should also avoid astronauts from accidentally falling from one deck to another.

Our RMA system consists of two primary components and one secondary component.

Primary Components:

a) Restraint Seat.
b) Folding ladder.

Secondary components

a) Handrails.

Restraint and Mobility Aids:

1) <u>Restraint Seat</u>:

<u>Working</u>:

The restraint seat is designed to keep an astronaut restrained to a place while working onboard. The seat fixes the body at hips **using a belt and buckle** on the two loops present on both sides of the seat, close to its center of mass, thus allowing the body to be stable under different gravity conditions without reconfiguration. The use of foot restraints has been avoided as we believe fixing the center of mass of the person's body will prevent any moments about the restraint and provide better restraint. The top of the seat is provided with a cushion for comfort of the user.

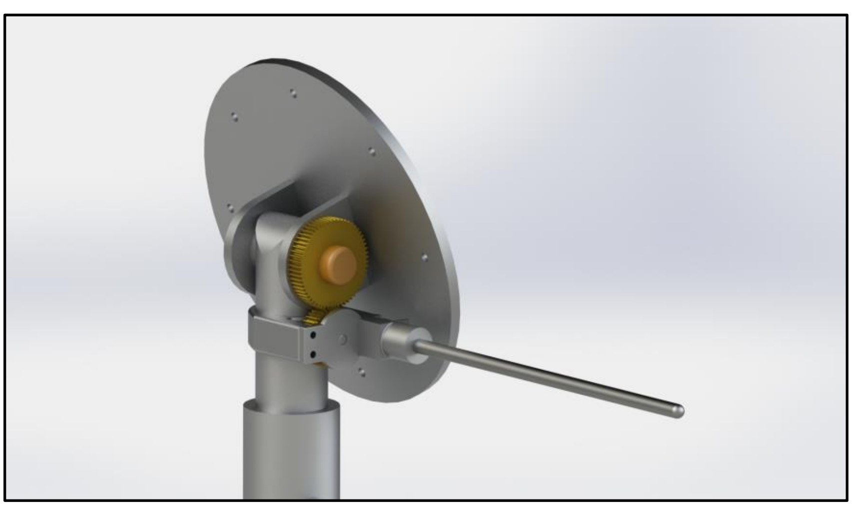
The seat can be adjusted to different heights as per the user's need. It also rotates a full 360 degrees about its lower base. At the desired height, the seat can be fastened using a screw. The seat rests on aluminum rods giving it the necessary amount of strength.

The retainment requirement in different scenarios.

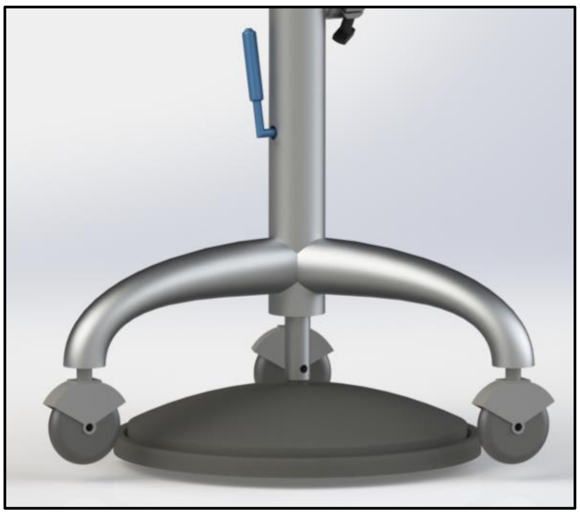
1) In 0g case the retainment is required so that you don't fly around.
2) In all other gravitational cases the retainment should be such that you should also be able to sit so that there is no muscular strain.

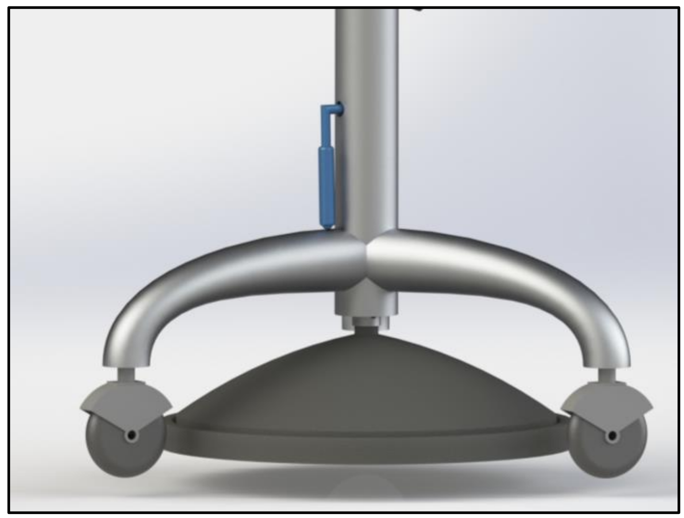
The seat pitches about its upper base allowing the user to use it as a seat or only as a restraint while standing or in microgravity. The pitch of the seat is controlled by a gear train and a 'lock' that slides into the teeth of the gear locking them in place. The lock can be disengaged by the astronaut just by pulling it. After obtaining the desired position, the astronaut can let go of the lock which, by the help of a spring, is forced back into the gear teeth locking the seat. Brass gears are used which make sure that the mechanism does not fail even under an unlikely impact.

(In figure below, Left: Seat assembly, Right: Locking mechanism using gears.)



The seat can be moved under gravity using caster wheels that can move in any direction. For restraining the seat, a rubber vacuum cup is used. It is pressed down using a crank shaft that can be rotated by the astronaut. It has been designed such that the astronaut mounted on the seat can easily reach it. This mechanism of the vacuum cup can be used in different gravity conditions because the chamber where the astronauts will work will always be pressurized so we can utilize the suction of the vacuum cup as the restraining mechanism. The legs (and wheels) provide structural support to the entire assembly even when the vacuum cup is fastened.
(In the figure above, left: Seat fixed as vacuum clamp is pressed down, Right: Seat released as vacuum clamp is disengaged.) Handrails can be used, in case the vertical force required to fix the cup is less in low gravity situations.





A conventional vacuum cup.

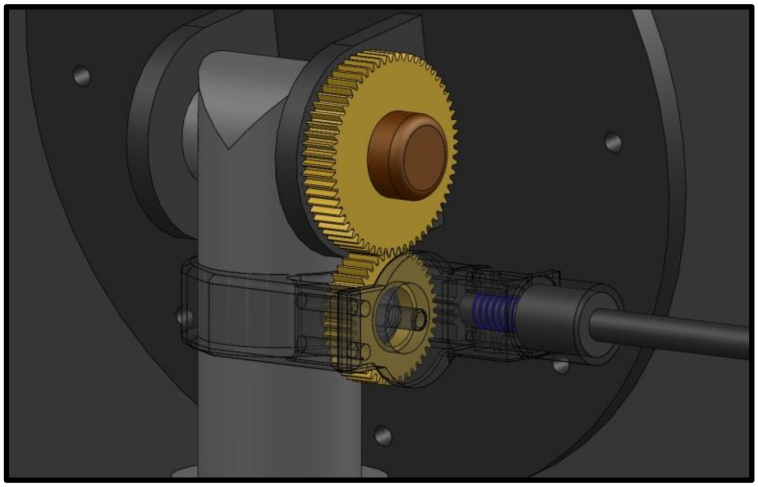
The seat has been provided with a composite utility arm. This arm can be used to keep certain objects (like computers, small equipment) that the astronaut needs to keep at hand while working. The arm joints can be fastened using a screw. The arm can be easily removed from the seat assembly, in case a mission does not require it. When not in use, it folds into a compact shape and does not take any extra space (Right).
The overall profile of the seat is also very small so that it does not take up large space.

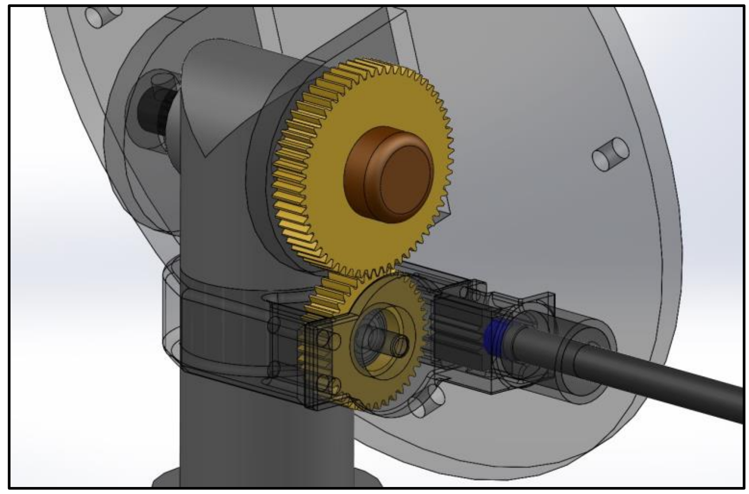
There are a total of 3 caster wheels and form a stable base, The COM of the person attached to the seat will be directly in between the three caster wheels and hence a stable configuration.

From a mobility point of view also this design works,
A person can work in this seat in a standing position as well as a seated position, say, if a person wants to move from one point to another location then he/she will simply disengage the vacuum cup and then move to the new location using their feet (using their feet to pull along the floor) and then again engage the vacuum cup to restrain themself, these methods will work in 1g or slightly lower than earth gravity gravitational case but will not work in 0g or in microgravity because in microgravity you cannot pull on the floor using your feet. It is here that we utilize our secondary component of RMA setup, the hand rails. In microgravity condition if you want to move from one point to another then the person would disengage the vacuum cup then use the hand rails which will be scattered throughout the workspace and at the new location again engage the vacuum cup.
One advantage of this system is that you need not have a working plane defined, since in 0g there is no such plane as a ground plane you can easily mount this seat on any wall using the vacuum cup and that plane becomes your ground plane. The attached arm also is a crucial component as it can carry tools, some component hands free.

Constrained at a seating position

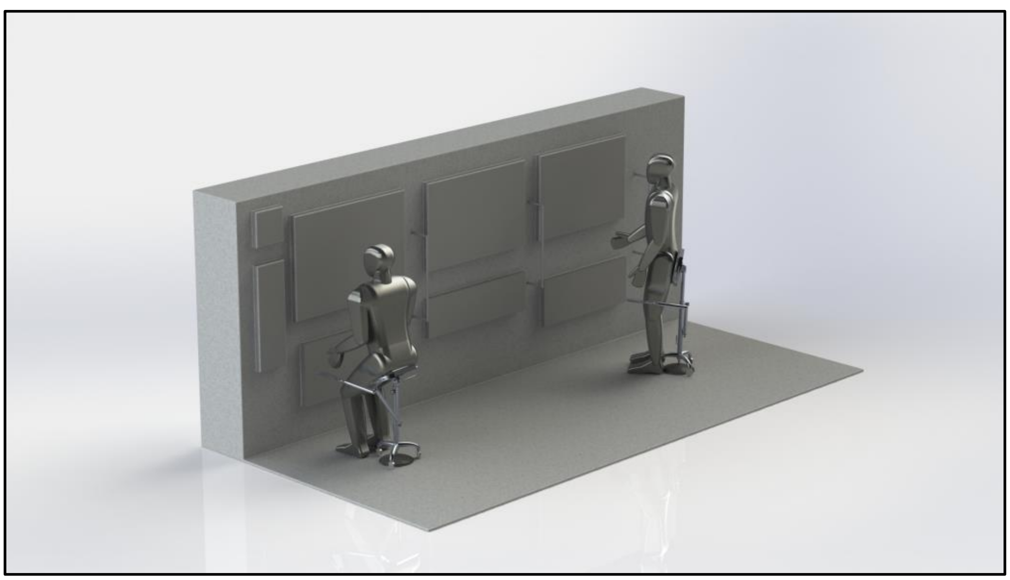
Constrained at a standing position



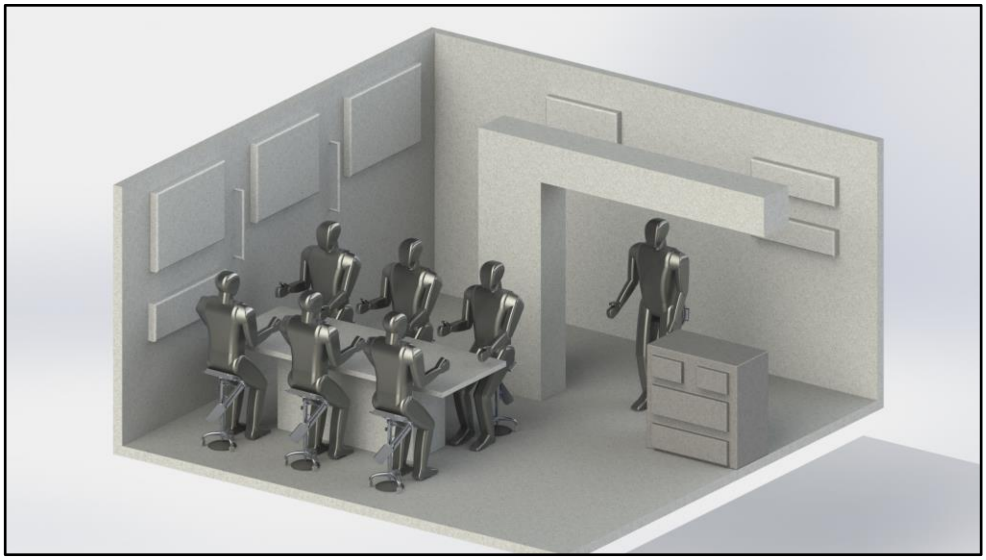


Figures: Left- Gears locked; Right- Gears free to rotate.

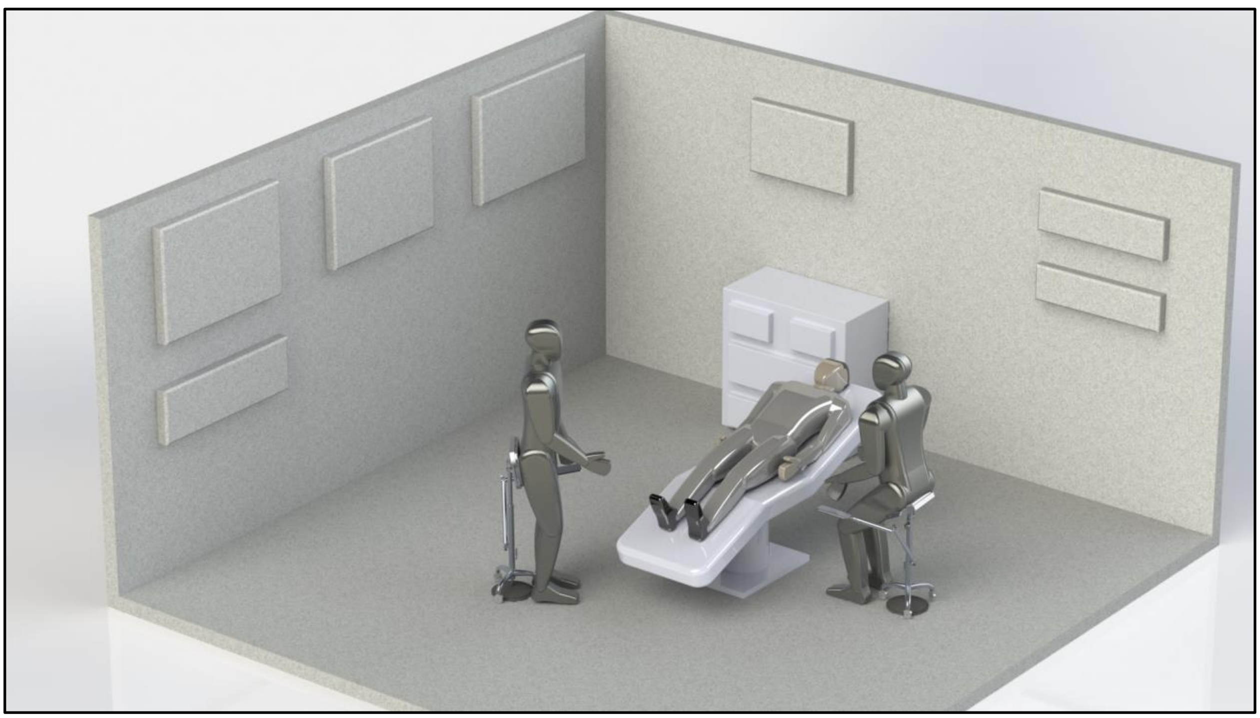
The above figures show the mechanism for control of pitch of the seat.
The assembly has been designed to be reliable and thus part count has been kept to minimum. The assembly is also designed to be lightweight yet strong. Its parts are designed considering the available manufacturing techniques. The parts are easy to replace in case of a failure. The seat is comfortable to use and does not require continuous muscular exertion by the astronaut using it. It can be used in all gravity conditions without reconfiguration. The seat can be folded and stored in very small space.



In this above picture you can see two people working, constrained to their location. You can also spot the hand rails along the wall that can be utilised for repositioning.

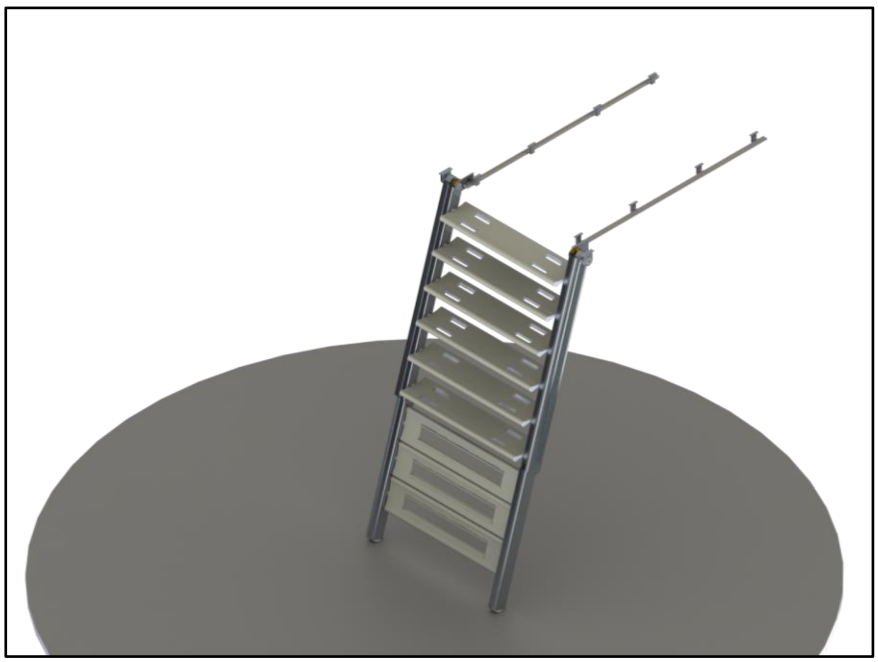


People sitting around a table.



This system can be engaged and disengaged very easily and you can reposition yourself easily.

2) The Folding Ladder System:



We decided to go for a conventional ladder instead of any electrical elevator system or any other electrical system because adding electrical systems for activities which need to be performed very regularly and can be achieved using simpler mechanical systems wastes a lot of resources like power which we should avoid.

Our main goal while designing this ladder was that it should be as <u>compact as possible</u>, <u>It should not always block the entire deck</u> and also <u>it should be such that it avoids people from falling as an added safety measure</u>.

So in our design we have developed a mechanism in which the rungs of the ladder flatten to form a surface when in closed position this surface covers the hatch and hence no one can fall.

When in an open position the ladder is like a normal ladder.

In an open position the ladder is at a slight angle for easy climbing.

We designed the ladder in such a way that it will fit in the smallest domain which is under test.

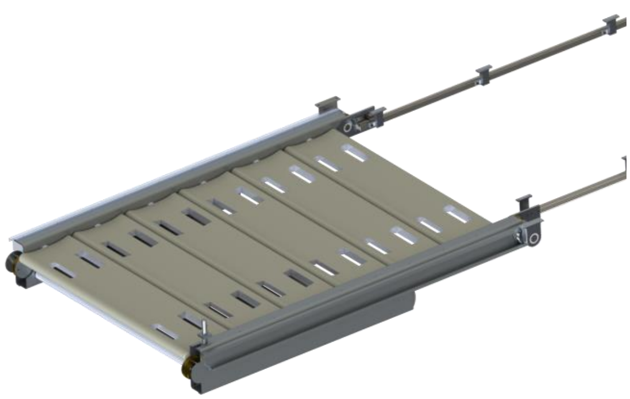
5.2m diameter cylindrical deck.

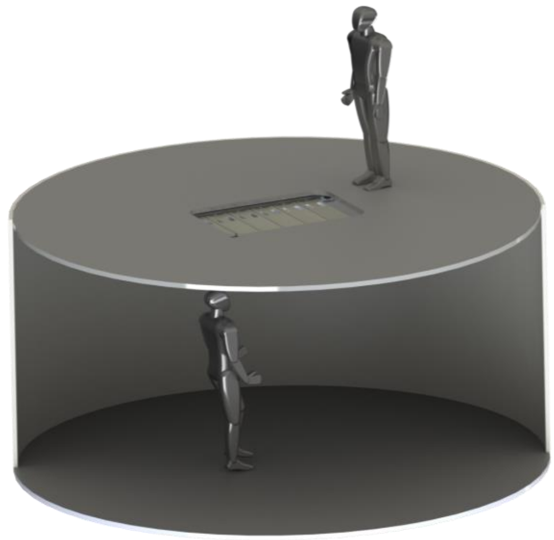
In this picture the upper deck has been hid to show the tracks.

Use of stairs in open configuration.

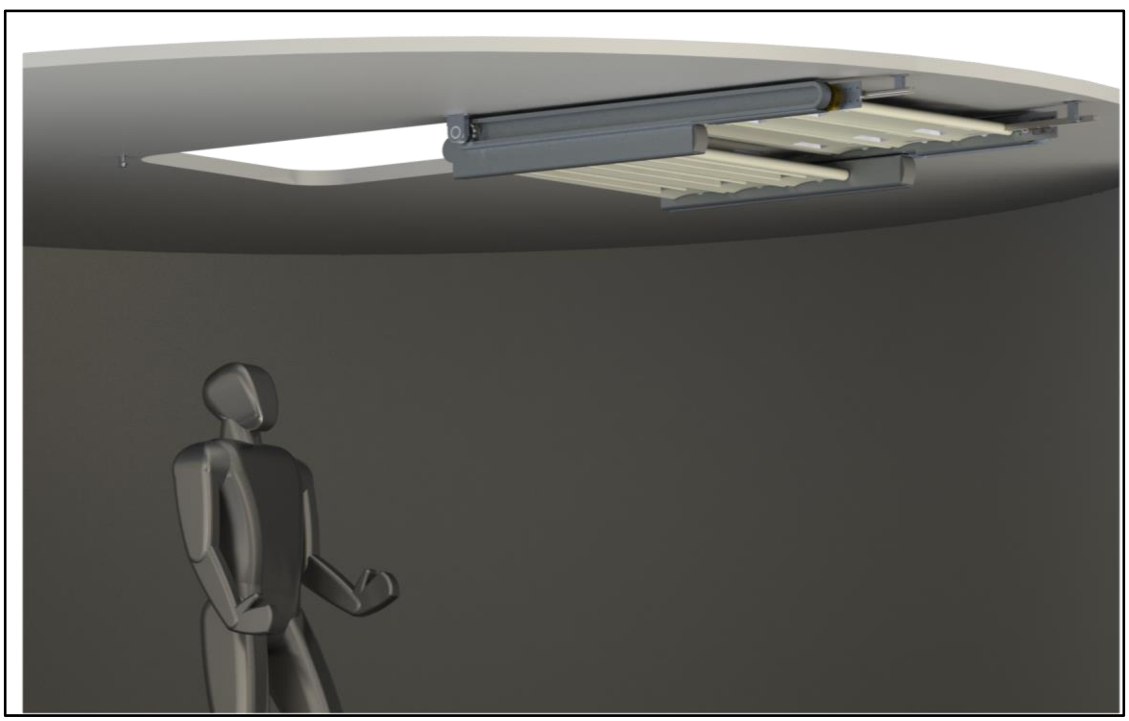
There are four configurations in which this ladder can be used

1) In the fully open position: In the fully open position the ladder can be used to move from one deck to another vertically in all the gravitational cases 0, 1/6th, 3/8th and 1 g.
   (Refer to the above image for fully open configuration.)
2) In fully closed position: In fully closed position the ladder covers the hatch opening this can be used in all gravitational scenarios to avoid any object/person to fall in the lower deck.
3) Open Hatch: In the closed position the ladder can slide on the track and move aside thus opening the hatch. This can be used in 0g case as you do not need anything for vertical traversal, also this configuration can be used so that any large object can be transferred through the hatch without any interference from the ladder.
4) Half Ladder: in the open hatch configuration if you drop down the lower part of the ladder then it gives you the half ladder configuration. In moon and mars gravity you don't actually need the entire ladder to climb up, our arms have enough strength to pull us up so having a half ladder will also suffice the purpose easily. Having this configuration will keep the deck floor clear and is more compact.





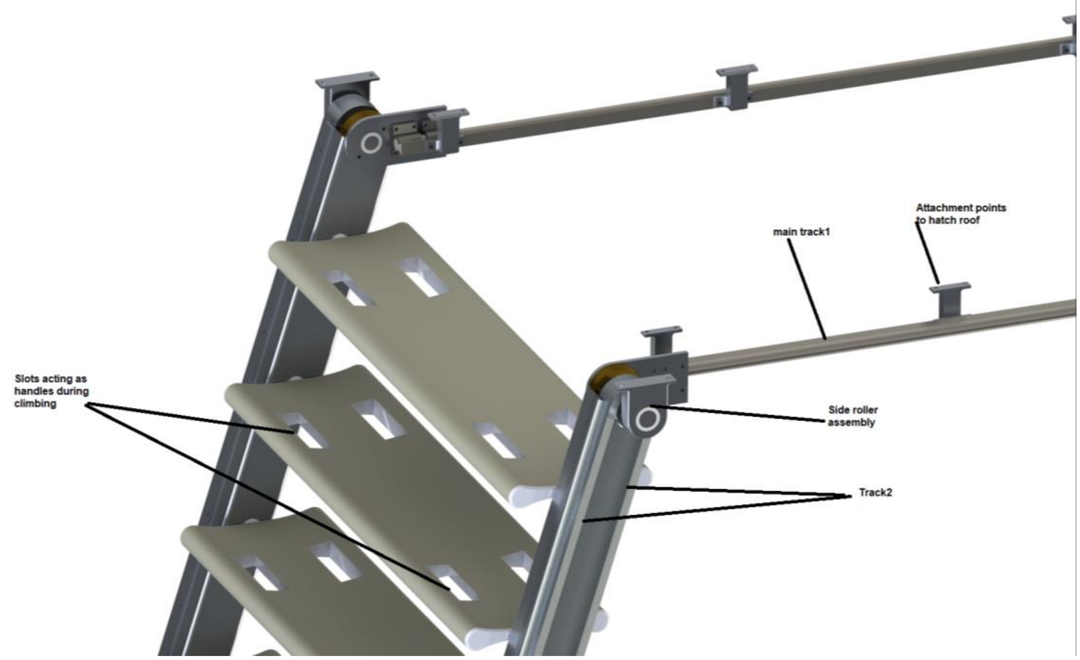
Fully closed configuration avoids falls.



Open hatch configuration

Half ladder configuration.

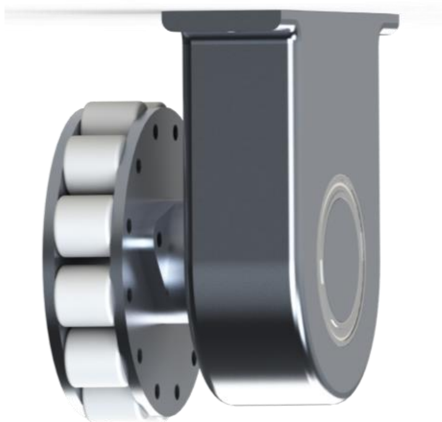
The half ladder configuration is such that the ladder does not block the view as the rungs are parallel to the floor and you can see through the ladder and the deck is visible.


main track1
Attachment points to hatch roof
Slots acting as handles during climbing
Side roller assembly
Track2

Before coming to the folding rung mechanism first let me explain the sliding mechanism.
There are two tracks as you can see

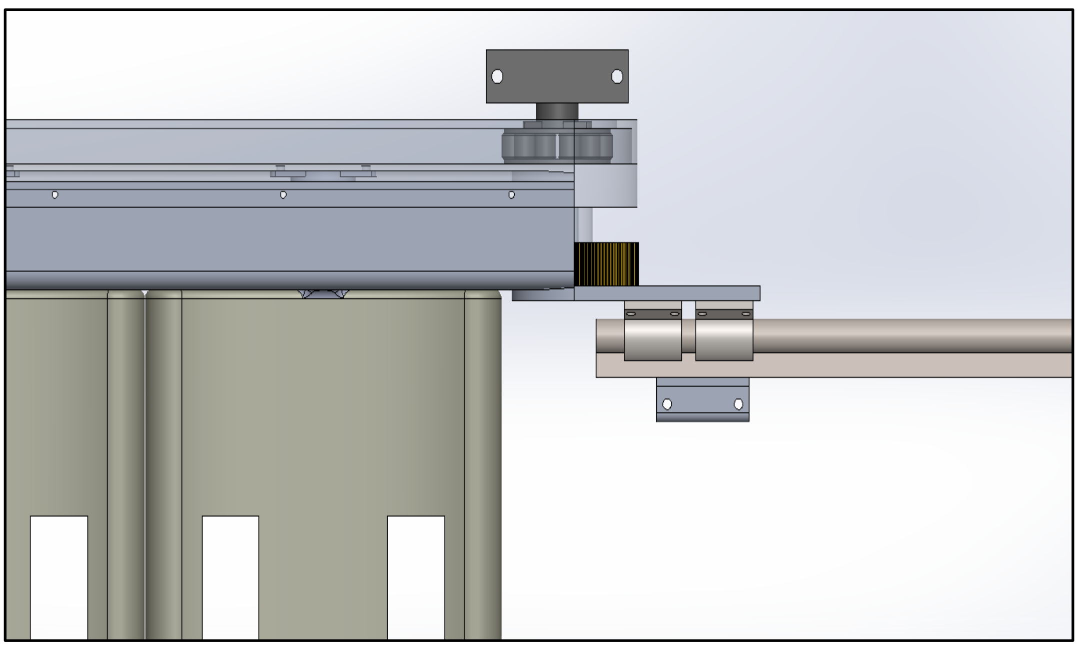
1) The main track is attached to the deck roof.
2) The secondary track is along the side of the upper part of the ladder.

For the sliding motion to happen it is always stable to have two points where the sliding takes place.



This is the side roller assembly. It has small rollers along the circumference which can rotate freely; also, the entire circular plate can rotate.
These rollers sit along the inner track of the ladder.
Due to such design this assembly can allow sliding motion in which the main shaft remains stationary while the smaller rollers on the upper and lowermost point rotate in the same direction and the track slides.
It can also allow rotational motion about the main shaft, during this the rollers don't move and only the shaft turns.

The inner track is simply a sector of a cylindrical shaft and the sliding mechanism consist of two linear bearings on each side.



This is the top view of the mechanism.

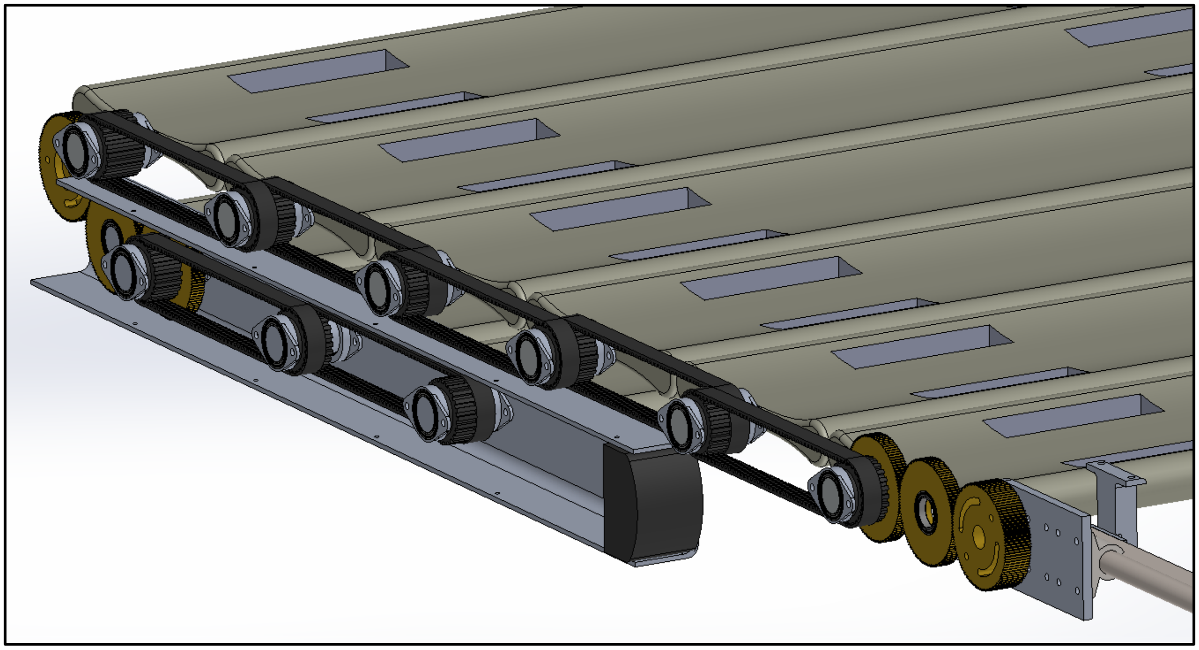
In the top view we can see how the side rollers sit in the track on the ladder.
The linear bearings are attached to a plate and a gear is attached to the plate. The plate along with the gear slide along with the linear bearings.
At the furthermost point (when the ladder is in closed position and closing the hatch). The centerline of the gear and the side rollers become the same and only at this point the ladder can rotate and open.

This is a safety measure as

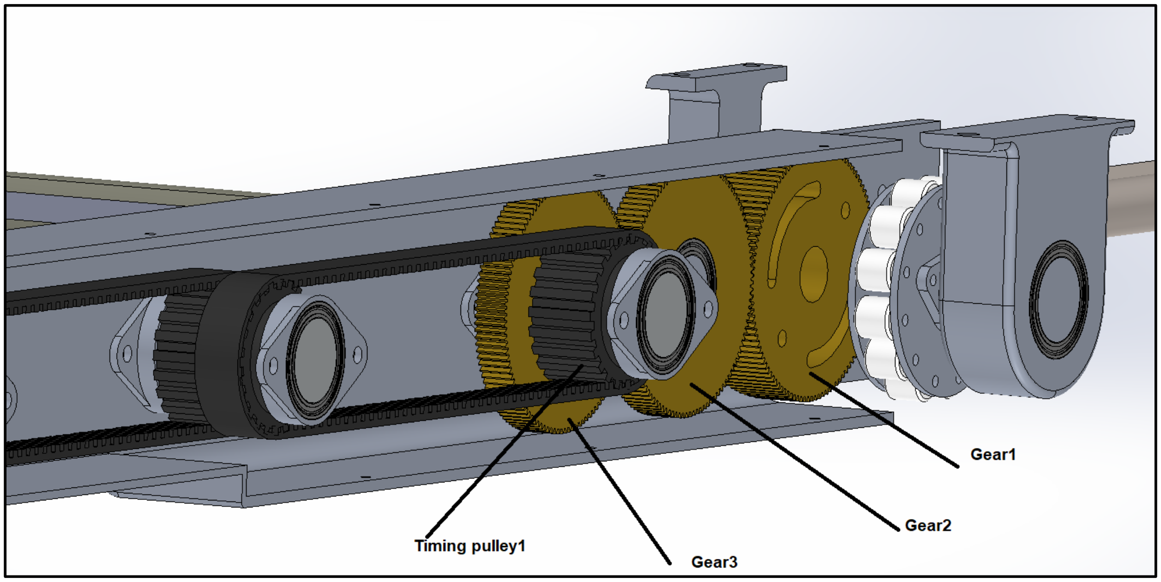
1) When the ladder is in a closed position and is slid back so that the hatch is open, there are 4 total attachment points for the ladder so it won't accidentally open.
2) When the ladder is in open configuration the ladder cannot slide back, as the ladder can slide only when the ladder is parallel to the primary track.

To keep the ladder in the closed position there is a small sliding lug on the deck roof which slides into a slot in the ladder to prevent it from falling.

Now coming to the mechanism of the motion of the rungs of the ladder.

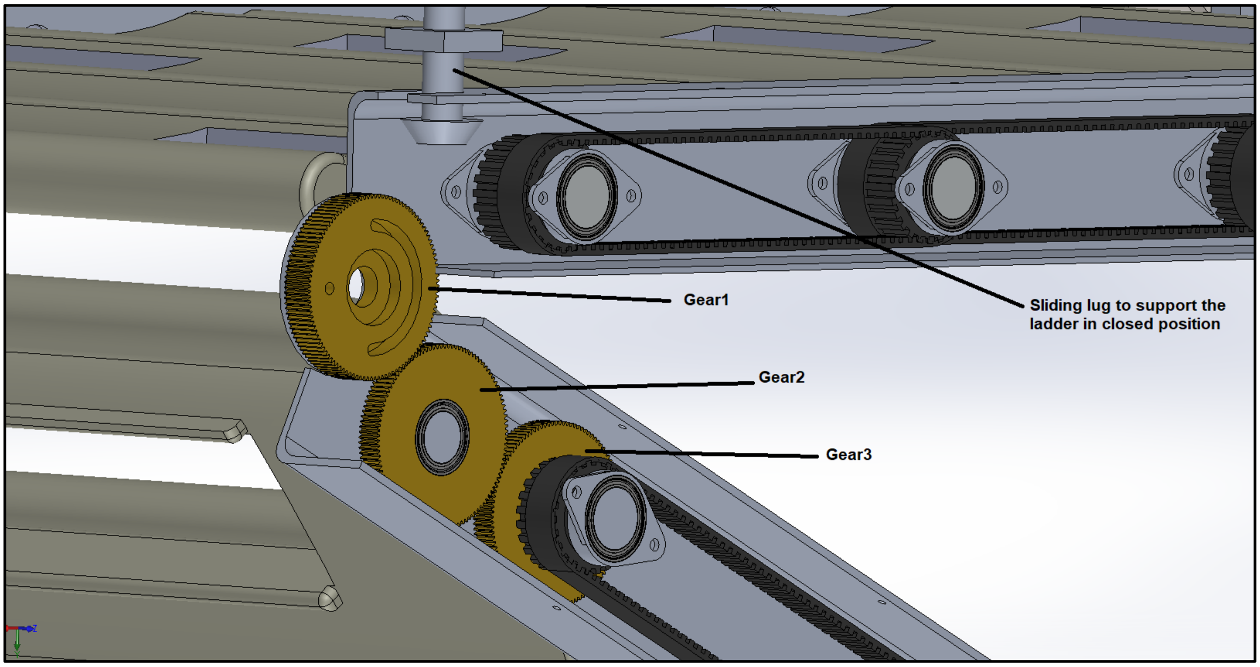


The internal mechanism of the ladder (under the aluminum housing)



Here we can see the front mechanism. Gear1 is attached to the sliding plate and is fixed (does not rotate when the ladder turns)

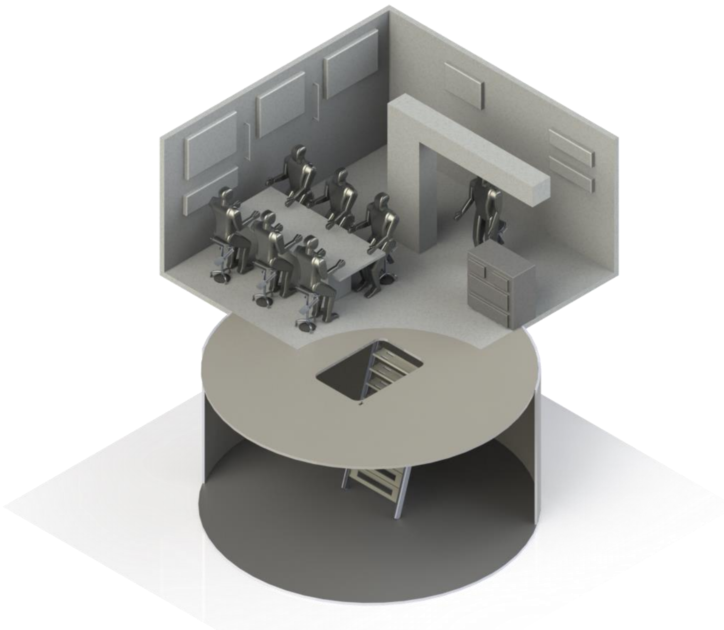
Gear2 is attached to the ladder frame and Gear3 is attached to the shaft of the first rung.
When the ladder is rotated (assume anti clockwise) the first gear does not rotate but as the ladder rotates the gear2 rotates in an anticlockwise direction and the gear3 which is attached to gear2 rotates in a clockwise direction. All the subsequent shafts are connected using timing pulleys and timing belts. Because all the remaining shafts are connected by belts, they also have the same sense of rotation as the gear3.
Since the gear ratios of all the gear connections is 1:1 the angle of rotation of the rung is the same as the angle of rotation of the frame but in the opposite direction. Hence it will always remain parallel to the floor.



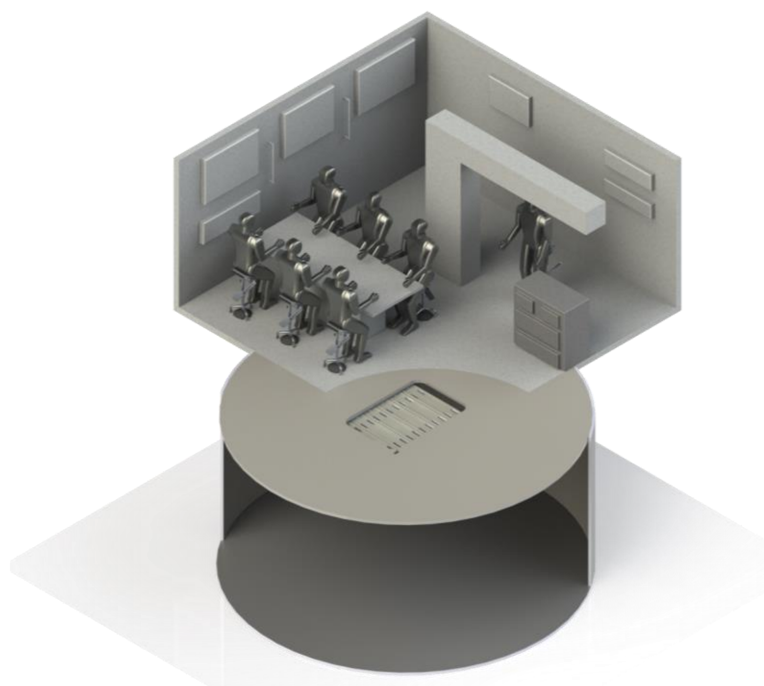
The same mechanism is used at the lower part of the ladder too.
You may have observed slots on the Gear1, These slots act as a track for two struts which are in the aluminum frame; these slots guide the struts so that the range of motion is confined to what is required.

This system can be easily implemented in multiple deck environments as the only connection that is required is the deck roof.

Combined Renders



Hatch open.



Hatch closed.