

Exploring Mars Rovers

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Exploring Mars Rovers

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DCT 2006.18

Traineeship report

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Chapter 1

Introduction

ESA-ESTEC is interested in exploring Mars in order to find out if there is or was life on Mars. Before sending people to the Red Planet, first a Mars Rover will be sent. The development of this mission, called ExoMars, is started in 2003 and the first rover is planned to set foot on Mars in 2011. The time delay, 5-20 minutes depending on relative positions, makes real time control of the rover impossible. So the rover will move autonomously on the Martian soil. This makes it all a lot more complicated. Ground control will not be able to give feedback on short term, the rover will have to do this itself.

This traineeship is a start of the TU/e's contact with this mission. In February 2006 a Master Team Project is to start. The aim of this project is to develop a Mars Rover that is able to move at several kilometers an hour, contrary to NASA's current rovers that cover only a few meters per hour. To make this possible, control systems that can observe obstacles in an earlier stadium have to be considered, or ways to avoid obstacles in a quicker manner. Another item is the design of the mechanism on which the rover drives itself. This report is about the design of such a chassis. What does it need to be capable of? What is the configuration of the wheels? Are wheels indeed needed?

When starting this apprenticeship little information was known about the requirements of the vehicle's capabilities. The basic idea was clear. Design a wheel suspension mechanism for a Mars Rover which can move forwards, backwards, turn on spot and also has the ability to move in lateral direction. The level of detail is determined by time. The aim is to develop a suspension mechanism as detailed as possible.

Chapter 2

Required and Desired Performance

2.1 Objective

The objective is to design a suspension mechanism as light as possible with efficient energy consumption for a Mars Rover with a length varying between 200 and 1500 mm. The Mars Rover is to locomote autonomously with several kilometers an hour on the Martian surface and must have the ability to overcome steep slopes. Many of types of obstacles can be overwon by smart control. The rover will have to be very intelligent, but to make control (software) less advanced and complicated, the issue is to design a chassis (hardware) with highly mobile capability.

First of all the conditions on the Red Planet have to be taken into account. Mars is a small, dry and rocky planet, situated one planet further from the sun than us. For those reasons the temperatures and gravity are much lower. The atmosphere, consisting mainly of CO_2 , N_2 and Ar , is very thin because of the low pressure. It is hardly 1% of the Earth's atmosphere. Extreme storms often occur with wind speeds gaining up to 40 m/s¹, but because of the thin atmosphere they feel like a smooth breeze. So air resistance is negligible, certainly at these low speeds.

Advantage can be taken about the fact that the gravity is three times lower than on Earth, so lower torques or less stiff materials are possible.

Martian days last 24 hours and 36 minutes, while Martian years last 687 days. This has to be considered when using solar power, but also because of the fact that Martian night's are very cold. Communication to Earth takes 5 to 20 minutes, depending on the relative position of Earth and Mars.

The conditions on Mars are recapitulated in table 2.1.

¹Winds like these are much faster than hurricanes (12 Bft) at our planet Earth.

<i>Conditions on Mars</i>	
Gravity:	3.693 m/s^2
Average temperature:	218 K = -55 °C
Surface temperature:	150 - 310 K; -123 °C - 37 °C
Average pressure:	7 millibar (9-1 millibar varying)
Atmospheric density:	0.015 kg/cu m
Winds:	40 m/s
Day duration:	24.6 hours = 24 hours 36 min
Year duration:	687 days
Atmospheric components:	CO_2, N_2, Ar
Highest point:	24 km
Communication to Earth:	5 - 20 min

2.2 Assumptions

Here follow some assumptions that have been made. Solar power is a very common energy source in space engineering. On Mars this is also the best option. The thin atmosphere and the fact that winds mainly blow at day times² make wind energy very inefficient. Combustion engines are neither an option because the vehicle will run out of fuel. The sun is an inexhaustible energy source (at least for this mission). The disadvantages of solar energy are low capacity and availability. The energy source is only half a day applicable and energy obtained by solar arrays is approximately $200W/m^2$.

The financial restrictions are mainly caused by the total mass of the construction that is needed to launch, descend and drive the rover. This is the payload of the rocket that is to send the rover to Mars.

On board of the vehicle a lot of instruments and actuators require electrical power. In order to save power it would be pleasant if the locomotion didn't demand too much of the power source. Weight reduction would be pleased. Because the rover is to move in all kind of directions, symmetry seems to have many advantages, but there will be a preferential direction because of the tooling and visual elements. Neither does it seem useful to make the rover top-bottom symmetric, so it would be able to drive upside down. Because solar arrays are placed on top of the rover in order to gain sun light and a camera will probably be mounted on upper part of the rover. To make the locomotion of the rover more efficient it is recommended to drive less wheels on a smooth surface. Theoretically the same power is need, but it can be applied more efficient. Because this is all the known information the dimensions of the rover will be scaled to the wheel diameter, d . This will also be the attempted climb height. The wheel suspension supports the rest of the rover which is reproduced as a rigid box ($l \times w \times h$). It is not desired to have a rover made up of several sections because the load also has to be split up. Cameras and sensors will make a 3D map of the terrain. In the design of the chassis it is assumed that the terrain is known and als the location of the rover on the map is assumed to be known. The latter is a very important issue in controlling the vehicle.

²Winds at Mars are mainly thermal.

2.3 Restrictions

The rover is restricted on three areas. Mass, energy and volume. For every kilo that goes up to space a lot of money is paid (payload). Solar energy is used as energy source, as described before. Energy is needed for image analysis, research, heating, communication etc. Reduction to the required power for locomotion gives the rover more abilities for other purposes. Since there is limited and scarce space on board of the Ariene 5 (this is the rocket that is planned to sent the rover into space), a less voluminous rover is desired. The same holds for the descent unit. It has to be kept in mind while designing that these three aspects should not get too large.

Chapter 3

Designing a Mars Rover

3.1 Terramechanics

Terramechanics is the physical mechanics of land locomotion. It concerns the interaction problems that occur between terrain and various kinds of mobile plant (Muro2004). It is a rather empirical theory. The problem is that terramechanics is based on knowledge of the soil. And the Martian soil is just the thing that is not known and we want to discover.

Bekker uses his bevameter¹ (Bekker1969) to determine the so called Bekker parameters. They give a relation between the applied pressure and shear stress.

The thing I learned from the terramechanics, in a Martian perspective, is basically that if too much sinkage occurs, it is better to walk than to drive. This is a situation that is most likely to occur very often, because of the windy climate and sandy soils there are many dunes. These dunes are very light (airy).

Bekker classifies two failures: hung up failures (HUF) and nose in failures (NIF). The first one occurs when the obstacle collides with the belly of the vehicle when it is trying to climb over it. NIF happens when the nose of the vehicle touches the ground, before the wheels. Placing the wheels in front of the nose, makes a NIF impossible.

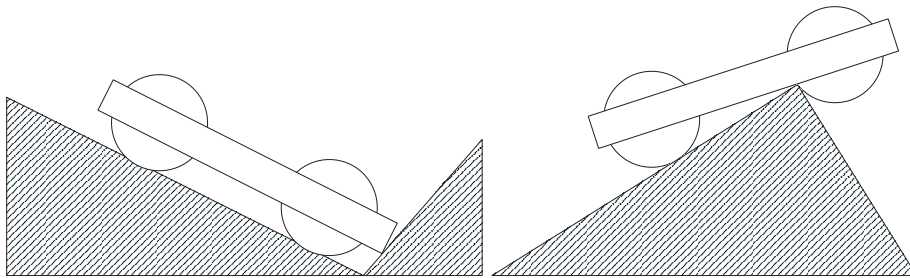


Figure 3.1: Nose In Failure (NIF) and Hang Up Failure (HUF)

¹The acronym (BEkker VAValue METER) introduced in 1955 by S.J. Weiss.

3.2 Locomotion

There are many ways of locomotion. Not all of them are efficient enough to use on Mars. On a relative flat and hard terrain, driving (rotating wheels) is the best option considering energy use. When the surface is rocky and/or steep, driving will not sustain. Walking would be great to overcome large obstacles, but it would take too much energy on flat surfaces.

Tracks seem to have great opportunities on rough terrains, but since we are interested in consuming as less fuel as possible, tracks don't come around so well. The vehicle is steered by driving the left and right track(s) in opposite directions. Besides, lateral movement (from rest) is not possible. The same holds for skiing movement.

When it comes to rotating wheels, the question rises how many wheels are needed. Four wheels are not enough if we also want to climb by walking. So how many wheels extra are needed. Six wheels give the ability to walk with 2 and stand/drive on the other 4. Eight wheels can do the same, probably even better, but the extra mass and actuators give the benefit to a vehicle with 6 wheels.

Another possibility of locomotion is hopping or flying. But since the rover is visually oriented, the dust created by hopping brings many disadvantages. Flying also has the disadvantage that there aren't any smooth runways on Mars (yet), so vertical take-off is required. This is a very tough thing because the principle of a helicopter is not so easily realized since only 1% of the Earth's atmosphere is available. Another important thing is the position reference. Flying or hopping, locomotion without contact is more vulnerable for reference loss, than rolling or walking.

This leaves us to a design with wheels and the ability to walk. To classify the way the wheel units are arranged at the chassis the following notation is used: (total number of wheels) x (number of powered wheels) x (number of steerable wheels) + (number of wheels equipped with walking capability)W. So a passenger car has typically a 4x2x2+0W chassis configuration, while a very good Mars Rover would have 6x6x6+6W configuration.

3.3 Conclusion

Three degrees of freedom (dof) are required per wheel. Rotation on the driving axis, rotation on the steering axis and rotation on the axis for walking. The best place to mount the driving motor is in the wheel itself, this is the shortest possible transmission and prevents as much energy losses as possible. The actuator for the steering rotation is best to be placed just above the wheel, because more than 360° of rotation is required. The electric power of the driving motor can be transmitted through slip rings. Many commercial slip rings can be found on the Internet.

Considering the information as stated in the previous section, driving (rotating wheels) combined with wheel walking is the best option to locomote on Mars. The required 3 dof for the wheel, result in a chassis design with a wheel unit using slip rings for steering, as depicted in figure 3.2. The next chapter, about the concept designs, will only focus on such chassis.

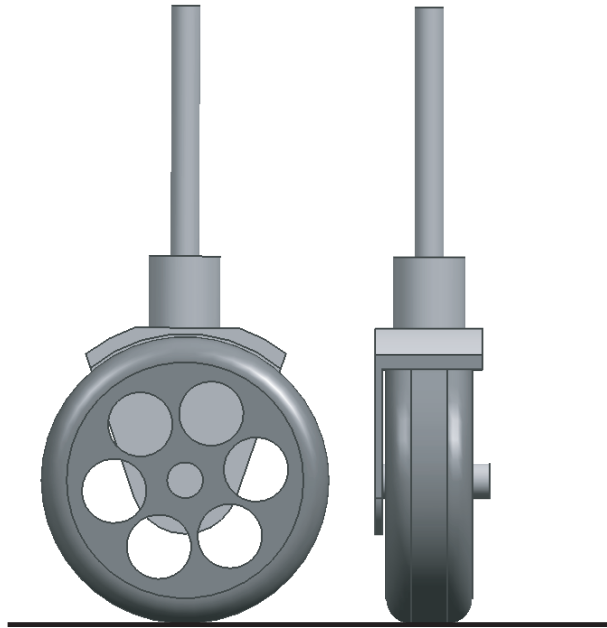


Figure 3.2: Wheel unit with slip ring

3.4 Obstacles

When using "wheel walking" relieved with driving (using rotating wheels) as locomotion technique, all obstacles can be classified into two types: dikes and ditches. In the following figures (figure 3.3 and A.2) they are shown with varying driving directions. The radii of the corners (R_1 and R_2) and the height h and width w can vary. The dikes and ditches are most likely placed on a slope. Now all obstacles that occur, while using the combination of wheel walking and driving, are covered.

3.5 Classification and Evaluation Criteria

There are many ways of classifying and comparing rover concepts. While designing concepts I basically tried to make a model that meets the requirements and finally came to one design. But in future rover development, while working out the details, when more parameters are known, there are many performance models for off-road vehicles that can be very useful [Bekker and Wong].

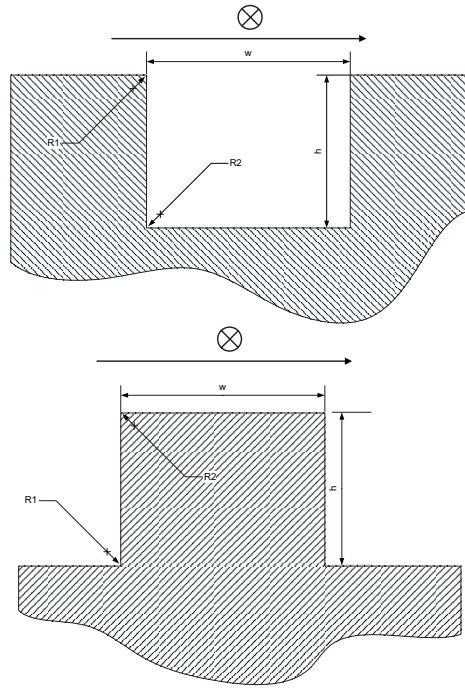


Figure 3.3: Ditch and Dike

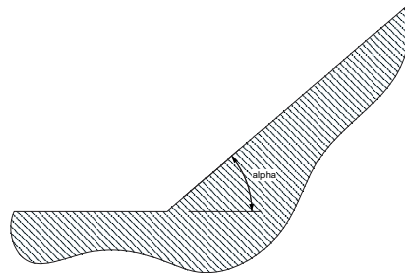


Figure 3.4: Slope under angle alpha

Chapter 4

Concept Discussion

4.1 The concept

The aim is to design a 6x6x6+6W chassis because this has the highest mobile capacity for a 6 wheeled vehicle. To overcome obstacles while driving it is important to have wheels with a diameter as big as possible, but when wheel walking it is better to have small wheels because this way the point of action can not be so high anymore. This is shown in figure 4.1 where two wheels try to overcome two obstacles. So a fine wheel diameter would be somewhere in between. To prevent HUF it would be nice to keep the relative positions of the wheels as close as possible.

The high mobile capacity is gained when walking. To be able to overcome large

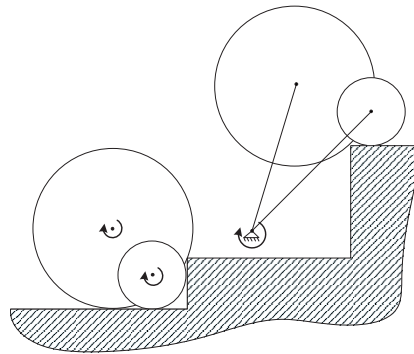


Figure 4.1: Large and small wheel compared, while clearing a small and large obstacle

obstacles, the point of action (the point on top of the obstacle where the linked wheel can lean on) must be as high as possible, so the link should be long and connected to the box in the middle (with respect to the height). To lift the front (or back) wheels, the following principle of semi straight guidance is used (figure 4.2). The buckle in the lower link allows the mechanism to turn further upwards, with all links in the same plane. To fit this mechanism on the rover it has to be turned a few degrees to the right, in order to prevent collision of the two upper links of the front and rear mechanisms with each other. When lifting the front or rear wheels, the center of gravity becomes very critically. The center of gravity is assumed to be

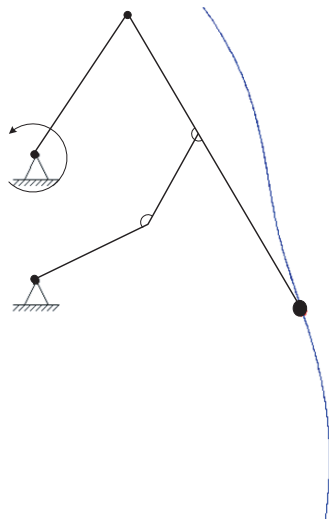


Figure 4.2: Semi straight guidance for lifting front and rear wheels

in the middle of the box, so when the wheels are lifted, this has to be compensated by a slight rotation of the link of the centrewheel (figure 4.3). This can also be done in combination with the rear wheels. When descending the same can be done: supporting the box with the rear- and centrewheels and lowering the linked front wheels.

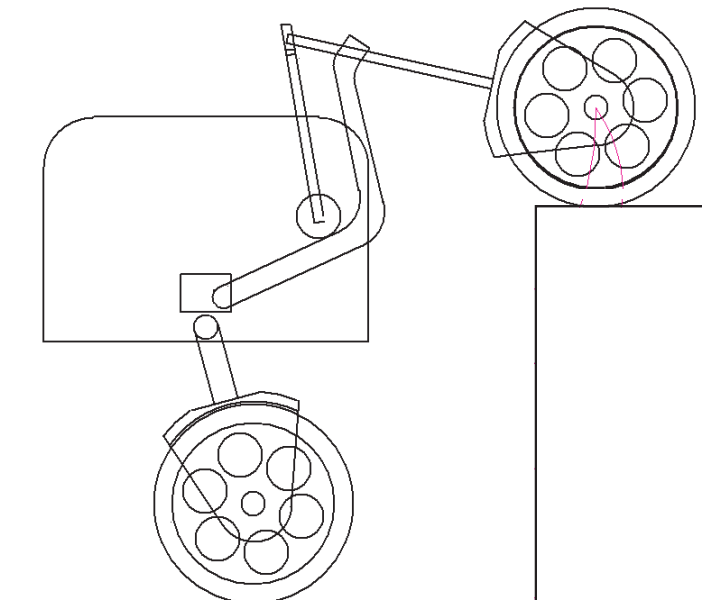


Figure 4.3: Climbing with the front wheels

Walking movement can be realized by elongation of the upper or lower link. The best link to vary in length is the one where it has the most effect. In the configuration of figure 4.3 this would be the upper link because the vertical link acts as a lever. There are many ways to extend the upper link. It can be done inside the link. Cutting the link in two halves and controlling the distance between them with another actuator. Another possibility is shown in figure 4.4 where the upper link is eccentrically connected to the rover.

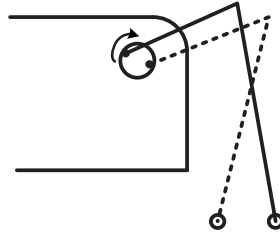


Figure 4.4: Eccentrically connection of the upper link to the rover

4.2 Concept design reviewed

The concept design has a high mobile capacity, which was one of the major requirements. The 6x6x6+6W configuration makes it possible to handle almost any situation when the height of the obstacle is not higher than 4 times the wheel diameter d . A 3D representation of the design is shown in figure 4.5. The design is symmetric, except for the symmetry in the XY-plane (so it cannot ride up-side-down). When approaching a large obstacle of which is known that the wheel diameter does not allow driving over it, the centrewheels will rotate a little bit to the front until the center of gravity lies in a safe area. The front wheels will be raised and put on top of the obstacle. Now the vehicle can pull itself up.

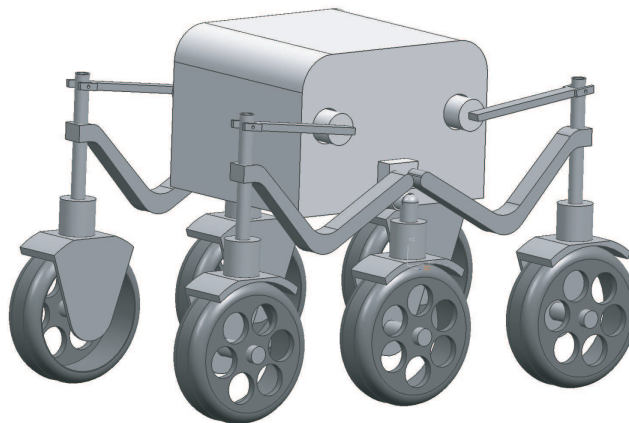


Figure 4.5: Concept design (3D view)

When driving long distances on flat surfaces the centrewheel can be pulled in and the rover drives on 4 wheels. Another way to save energy is to switch of actuators and let the wheels rotate with as less friction as possible. The same power is still requested, but the suspension is much more efficient (less losses). When driving on a slope or irregular grounds, the left or right wheels can be lowered/raised as shown in figure 4.6.

Something that requires more research is the passivity of the rover. Because the

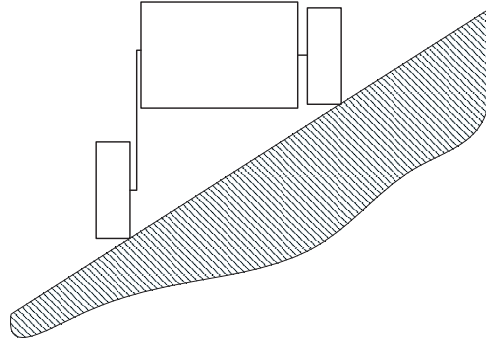


Figure 4.6: Driving tangent to a slope

rover has limited power, the actuators may not always be active, i.e. for compensating the balance of the vehicle.

Chapter 5

Final Review and Recommendations

The aim is to design a 6x6x6+6W chassis for a Mars Rover. Such a design is made. The basic idea of this design is that it meets all requirements. It can drive (with rotating wheels), walk, turn on spot and move in lateral direction and it is symmetric. There are no alternatives that also meet all the requirements. Some alternatives are included in the appendix.

For reduced energy consumption it is important to drive the rover as passive as possible. This means that the walking mechanism needs to be deactivated when driving. This is an important issue that still needs to be tackled.

Because this traineeship was a just a start to the design of a rover, much more detailed research should be done. Because a lack of time a lot of aspects have not been examined. These are things like: what kind of actuators are best? How would the transmission look like? What kind of material are the best to be used? When it comes to solar energy in space, Dutch Space is a very good player.

A vehicle consisting of 2 frames with 3 wheels seems to be very efficient and passive, but such a design was not found, although it is very interesting to do some more research in that direction.

For future research (i.e. TU/e's Master Team Project) I am prepared to provide the animations, simulation files I created concerning the design of the mechanism and the CAD files. Just contact me at J.J.Slob@student.tue.nl.

Appendix A

Alternatives

Here follow some alternative models/designs to the final one that is reviewed in chapter 4.

A.1 First alternative

This variant has the advantage, that it is completely passive when it is driving on a relative flat surface. The symmetry though is lost. It would be possible to make it front/rear symmetric, but then another pair of wheels should be included.

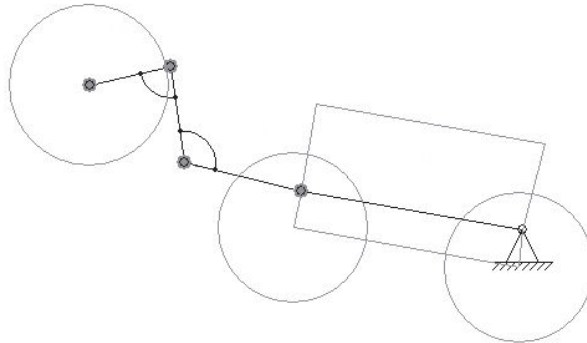


Figure A.1: Alternative 01, driving/climbing to the left

A.2 Second alternative

Here we see a design which is very easily capable of moving the center of gravity. When the front wheel is raised, the mass will automatically move backwards because it is linked to the wheel and the rover (figure A.2). The disadvantage is that the gained height of the front wheels is not so high and that the mass will also (automatically) move forward when descending (figure A.3) whereas we would like

to keep the mass in the back so the rover can sense the ground where it is going to drive.

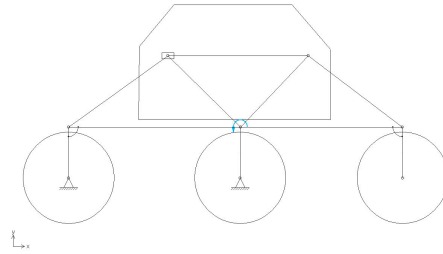


Figure A.2: Alternative 02

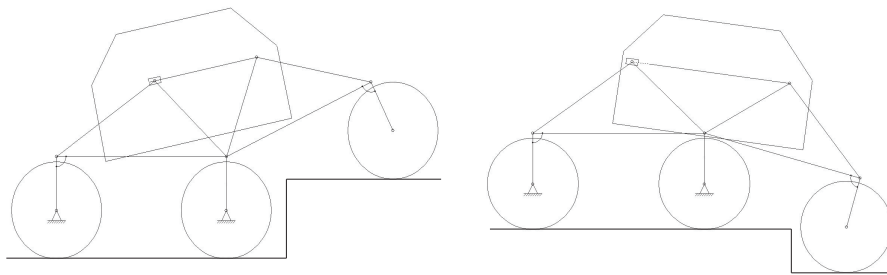


Figure A.3: Alternative 02 climbing and descending

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