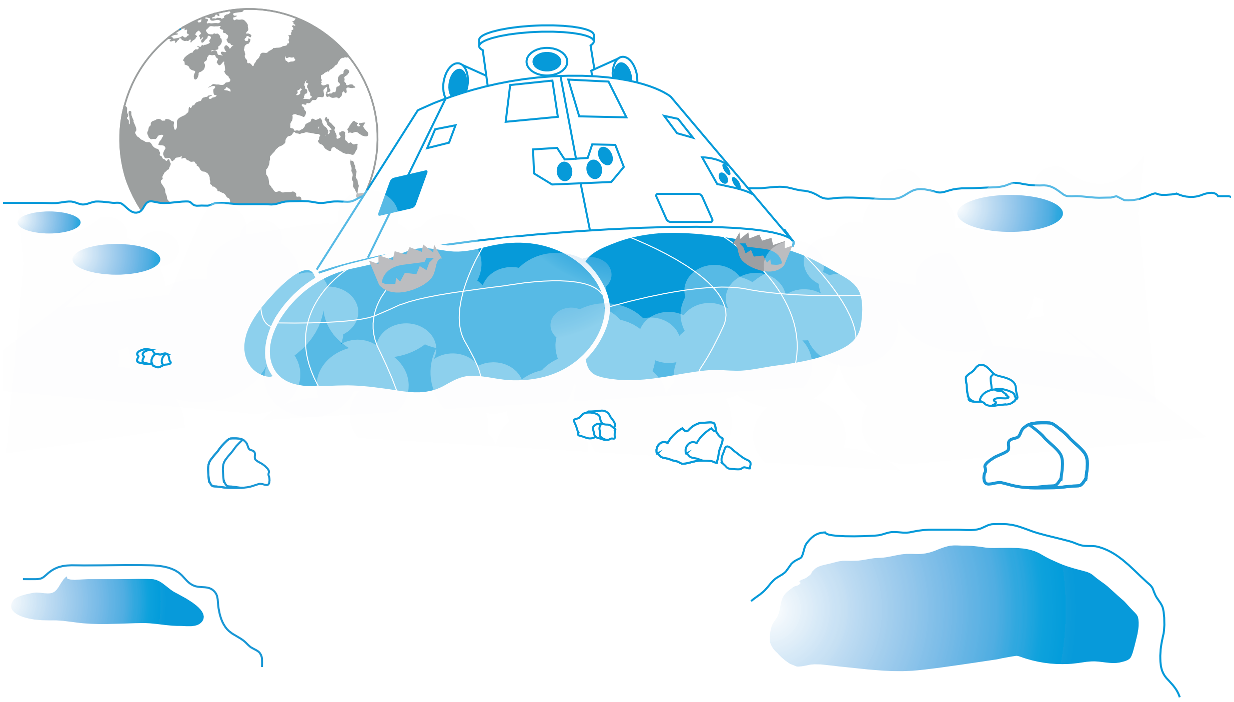
Expedition: Home

→ LANDING ON THE MOON

Planning and designing a lunar lander



European Space Agency

→ LANDING ON THE MOON

Planning and designing a lunar lander

FAST FACTS

Subject: Physics, Mathematics, Economics
Age range: 14-16 years old
Complexity: medium
Preparation time: 1 hour
Time required: 2 hours and 30 minutes overall
Cost: low (0-10 euros)
Keywords: Physics, Mathematics, Economics, Moon landing, Gravity, Friction, Force, Acceleration, Velocity, Newton's laws, Budgeting, Risk-analysis

Brief description

Plan, design, and build a landing module to secure the survival of the crew (in the form of an egg-naut) landing on the Moon.

Material

- Worksheets
- Paper
- Egg (to be the eggnaut)
- Scales

The materials to build the landing module can be changed and adapted to the available materials at home:

- straws,
- marshmallows,
- cotton-balls,
- popsicle sticks,
- plastic bag,
- string,
- sticky tape,
- scissors,
- balloons

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→ Introduction

In 1969, Apollo 11 became the first manned mission to land on the Moon. After a four-day trip from Earth, the lunar lander, named Eagle, detached from the command module orbiting the Moon and touched down in Mare Tranquilitatis, a relatively smooth and level area. The lunar lander was manually controlled to avoid boulders and craters. "Houston, Tranquility Base here. The Eagle has landed." These words marked a new era of human exploration.

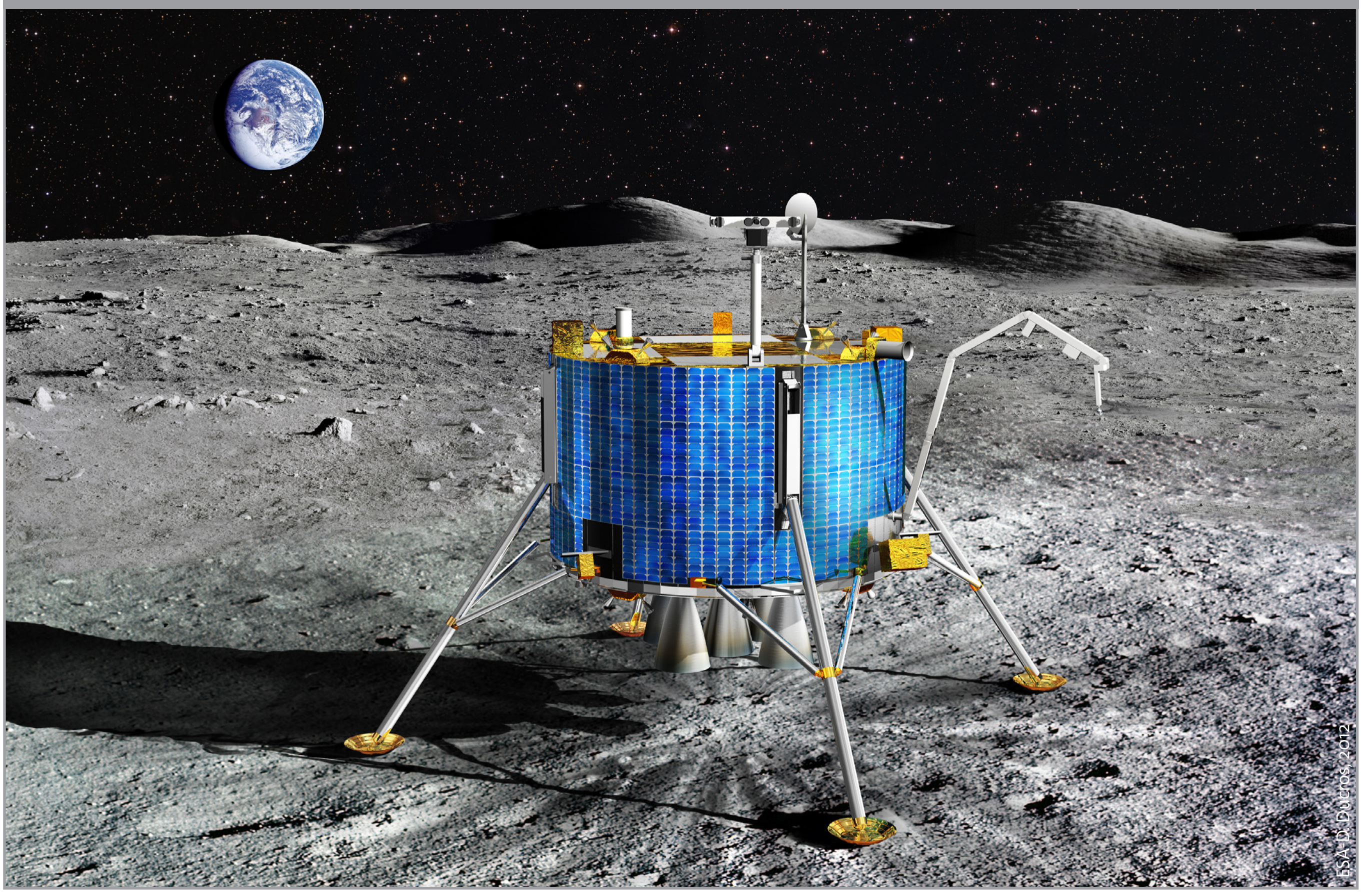
Apollo 12, the second manned mission to land on the Moon, was an exercise in precision landing; most of the descent was automatic and the precision landing was of great significance because it increased confidence in landing at specific areas of interest.

Descending to the lunar surface is one of the most critical and difficult phases of a lunar landing. The spacecraft needs to decrease its speed from 6000 km/h in lunar orbit to a few km/h for a soft touchdown. Landing sites of interest for exploration are often hazardous, with craters, rocks and slopes, and therefore, difficult to access.

Only 12 people have walked on the surface of the Moon and the last time was in 1972.
The European Space Agency, in collaboration with other partners, is planning to return to the Moon with robotic and human missions in the next decades.

In this set of activities students will design a lunar lander and learn about some of the challenges of space exploration.

Figure 1



↑ Artist impression of a lunar lander.

→ STUDENT WORKSHEET

→ LANDING ON THE MOON

Planning and designing a lunar lander

→ Activity 1: Design and build a lunar lander

ESA has tasked you to design a lander that can bring an egg-naut safely to the Moon's surface.

Exercise

Like in the real world space industry, you are competing and/or collaborating with other organisations (your classmates) for a contract with ESA.

Your mission is to:

- Design and build a lunar lander to land an egg-naut safely on the Moon.

Requirements:

- The lander has to pass a drop-test on Earth and the egg-naut must survive the landing.
- You can only use the available materials.
- The lander has to be built within a set budget (a maximum of 1 billion €).
- The lander should be able to land accurately on an appointed landing site.
- You must present a risk assessment and design study.
- You must complete the design and build the lander in the allocated time: 60 minutes.

Did you know?

The total cost of the Apollo space program that took humans to the Moon was $25.4 billion – that is more than $200 billion in today's currency, adjusted for inflation. In 2018, ESA's total budget was 5.6 billion Euros. Currently, space agencies and industry are working together to develop a more sustainable Moon exploration programme. It should be noted that today, we will still use part of the infrastructure created in the 1960s: test chambers, launch pads, mission control centres, ground stations, engineering knowledge, technology, materials and thus a lunar exploration programme will be much more sustainable from the beginning.

Buzz Aldrin at work at the Eagle landing module on the lunar surface. →

Risk Assessment Study

When designing a space mission there are two main factors to consider: risk and cost. For your mission you want to make sure your egg-naut lands safely, but you still want an affordable mission in order to win the contract with ESA.

Place the risks listed on the right in the risk assessment matrix according to their likelihood of happening and the consequences if they do:

		Consequences				
		Insignificant	Minor	Moderate	Major	Catastrophic
Likelihood	Almost certain					
	Likely					
	Possible					
	Unlikely					
	Rare					

1. We do not land at the appointed landing site
2. There are unexpected changes to the requirements
3. The egg-naut does not survive
4. There are unexpected changes to the budget
5. Some materials become unavailable
6. Some materials become too expensive
7. The lander becomes very heavy
8. Another company (group) has an efficient and cheaper design
9. Continuously changing the design means the lander cost too much to build
10. We get delayed
11. The lander is damaged during testing
12. The lander is damaged during transportation
13. The lander is damaged during the final landing

Select three of the major risks and write down how to mitigate them:

1) Risk #: ___________ Mitigation plan: ______________________________

2) Risk #: ___________ Mitigation plan: ______________________________

3) Risk #: ___________ Mitigation plan: ______________________________

Design study

Name of landing module ______________ Name of egg-naut ____________________

Check the materials available and prices with your teacher. Make an accurate sketch of what your landing module will look like. Discuss how the different parts and materials work to protect the egg-naut. Make a budget for your lander, based on the prices of each material and do not forget to include the price of the launch and of the training of the egg-naut:

Material	Price per unit	Amount	Price

Price of lander	
Total mass (egg-naut + lander)	
Price of launch	
Price of training of the egg-naut	
Total price (lander + launch + training)	

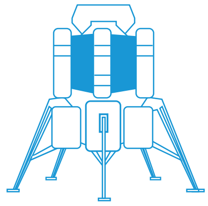
→ Activity 2: Test your landing module

Exercise 1

1. Before the launch, take note of the landing conditions (wind, rain, type of landing site, etc.).

____

____



Make sure your egg-naut is comfortable. Prepare for the test.

Ready! Steady! Drop!!

2. Did the egg-naut survive the drop? **Yes**__________ **No**__________

3. How far from the centre of the target did your lander come to rest? ________________ **cm**

4. How well did your design plan work? Would you do something differently now?

____

____

5. After observing the drops of each group, did you notice any recurring design characteristics of the landers in which the egg-naut survived?

____

____

____

____

Exercise 2

For this exercise, you will need to use the displacement of the lander as a function of time.

1. Calculate the impact velocity of the lander using a graph of displacement in the y-direction vs. time

2. Plot velocity in the y-direction as a function of time. Estimate the impact velocity from the plot. Does it correspond to the same value calculated in question 1? Explain the difference, if any.

3. Use the graph of velocity in the y-direction as a function of time to calculate the acceleration of the lander in the y-direction.

4. The gravitational acceleration is 9.8 m/s^2. Explain why you do not retrieve this value.

→ Activity 3: Landing on the Moon

Time to prepare for the landing on the Moon. You have tested your lander on Earth, but what is going to happen when it has to land on the Moon?

1. There are several differences between landing on the Moon and on Earth. List 3 factors that can influence a landing on Earth and on the Moon:

Landing on Earth	Landing on the Moon
1. ______________________	1. ______________________
2. ______________________	2. ______________________
3. ______________________	3. ______________________

2. The gravitational acceleration (g) of a planet is given by:

$$g = G\frac{m}{r^2}$$

Where m is the mass of the planet (or moon), G is the gravitational constant and r is the radius of the planet (or moon). Use the values below to complete questions a) and b):

$G = 6.67408 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$

$r_{Moon} = 1737$ km	$m_{Moon} = 7.35 \times 10^{22}$ kg
$r_{Earth} = 6371$ km	$m_{Earth} = 5.97 \times 10^{24}$ kg

a) Calculate the gravitational acceleration on the Earth and on the Moon.

$g_{Earth} =$

$g_{Moon} =$

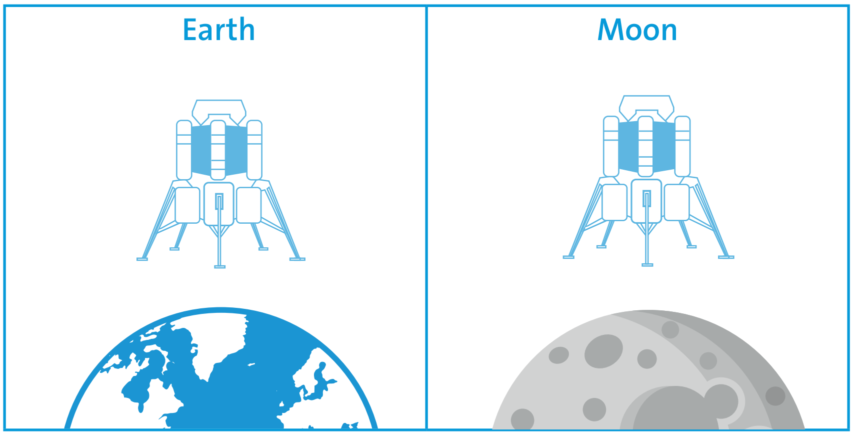
b) Using Newton's Second Law of motion $F = m \cdot a$, calculate your lander's gravitational force on Earth and on the Moon.

$F_{g,\ Earth} =$

$F_{g,\ Moon} =$

→ STUDENT WORKSHEET

3. a) Draw the forces acting on the lander, on the Earth and on the Moon.



b) Explain your force diagram.

4. What could you change to make your lander better suited for a Moon landing? Explain.

→ ANNEX 1

Activity 1 - Design and build a lunar lander

Mandatory costs:

Training of egg-naut	300 million €
The cost of the launch	1 million € per gram

Materials:

1 piece of A4 Paper	50 million €
1 straw	100 million €
1 marshmallow	150 million €
1 popsicle stick	100 million €
1 plastic bag	200 million €
1 m of string	100 million €
1 m of tape	200 million €
1 balloon	200 million €

→ ANNEX 2

Activity 2 - Test your landing module

Lander name	Drop height (m)	Distance from target (cm)	Cost (million €)

→ ANNEX 3

Activity 2 - Test your landing module

This part of Exercise 2 can be performed either as a demonstration or as a continuation of the student group activities, depending on the availability of computers or smartphones in your classroom.

Video motion analysis will be used to track the landing. There are several video analysis programs available online - some are free and others require a license. We suggest the use of:

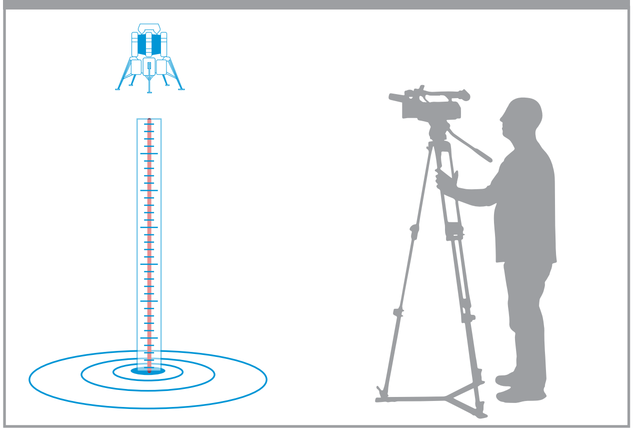
- The "*Tracker program*" is free to download from the http://physlets.org/tracker/ and is well suited for use on a computer.
- The app 'Video Physics' in combination with "Graphical" (both available for Android and iOS) are ideal for tracking with tablets or smartphones.

You can perform the experiment and distribute a single set of data to the students, or they can perform the measurements for their landers individually.

Setup

1. Fasten a meter stick (or a ruler) as a reference next to the landing site.
2. Position the camera in such a way that the drop site and meter stick are in the same frame.
3. Keep the camera steady while filming, ideally using a tripod.
4. When dropping the lander, make sure it is at the same distance as the meter stick from the camera.

Figure A5



↑ Representation of the test drop setting.

Figure A6

↑ Example of a test drop video motion analysis from approximately 2 m height.

5. Track the lander in your selected program by setting marker points manually.
6. Save the data.

Sample data for the lander drop.

Time (s)	Y Displacement (m)	Y Velocity (m/s)
0.000	1.84	-0.406
0.067	1.82	-0.547
0.100	1.79	-0.843
0.133	1.76	-1.148
0.167	1.71	-1.453
0.200	1.66	-1.748
0.233	1.60	-2.096
0.267	1.52	-2.420
0.300	1.44	-2.725
0.333	1.34	-3.006
0.367	1.24	-3.274
0.400	1.12	-3.638
0.433	0.99	-3.931
0.467	0.86	-4.123
0.502	0.71	-4.428
0.535	0.51	-4.734
0.568	0.40	-4.877
0.602	0.22	-4.623
0.668	0.00	-0.798
0.702	0.03	0.457
0.735	0.06	0.614
0.768	0.08	0.386
0.802	0.08	0.135
0.835	0.08	0.066
0.868	0.08	0.115
0.902	0.09	0.207
0.935	0.10	0.151
0.968	0.10	-0.019
1.002	0.10	-0.125
1.035	0.09	-0.201
1.068	0.08	-0.294
1.102	0.07	-0.375
1.135	0.06	-0.426