Topic Overview

Background and suggested aims

Aims

- Promote enthusiasm for science by presenting an exciting adventure that is happening right now: a private company planning to send crewed missions to Mars with the aim of setting up a permanent base on a new planet;
- Reinforce aspects of mainstream school physics in a new and exciting context;
- Reinforce and develop ideas from other subject areas in a novel context;
- Discuss aspects of the methodology and scope of science using the history of the belief in the canals on Mars as an example;
- Allow students to use skills from other subjects in the context of science, especially research, evaluation and presentation and writing skills that are not always expressed in the science curriculum.

Lesson summary

Lesson	Content summary	National Curriculum links	Activities
Lesson 1: *Mars*	Content summary. Introductory lesson exploring key facts about the planet Mars.		PowerPoint – Mars.
Lesson 2: *The Martians are coming 1*	Information about the history of Mars observations, the canals and the presumption of life on Mars.		PowerPoint – The Martians are Coming Discussions.
Lesson 3: *The Martians are coming 2*	Optional continuation lesson extending the discussion of lesson 2.		Discussions.
Lesson 4: *Colonising Mars*	The company Space X and their plans to send manned missions to Mars.		PowerPoint – Elon Musk and the Colonisation of Mars.
Lesson 5: *Research projects*	Living on Mars – student-led research project and presentations.		Teams working on different aspects of living on Mars.

Background

This topic includes a research and presentation exercise. Students will be divided into groups and asked to research and present on an aspect of Martian colonisation. Sufficient time needs to be given to this exercise, along with the necessary resources including access to IT. The topic presents an opportunity to work with colleagues from other subjects directly and would make an excellent cross-curricular project.

Teacher background knowledge

Teachers will be familiar with the specific syllabus aspects required of this topic, which are listed below and repeated later in this document:

Physics – basic astronomy, order of the planets, seasons and axial tilt, day and year, strength of gravity, generation of electricity from light, UV and the damage it produces, convection, ionising radiation and the damage to the body. Teachers will need to familiarise themselves with information about Mars, *SpaceX* and the plans for colonisation. Enough information is provided in the PowerPoints connected with this topic, in combination with the internet links provided below.

Cross-curricular links

Biology – crop growth, requirements for plants to thrive, nature of fertiliser, what is soil, human nutrients, balanced diet.

Chemistry – production of O_2 from water, reactions of hydrogen with CO_2 to produce methane and water, extraction of iron from ore.

History – key events and society in the mid 1800s to early 1900s.

Geography – volcanic activity, formation of lava tubes, sedimentary deposits, cross-bedding.

Design and Technology – the nature of materials, construction.

Student background knowledge

It is helpful for students to have experience of some of the topics listed above. In addition, some facility with the use of PowerPoint or a similar presentation tool and the use of the internet in order to carry out research would be beneficial. The topic calls on skills that are not generally required in school level science, such as research, presentational, artistic, public speaking and collaboration. It provides an opportunity for students not normally talented in science to show their strengths.

Useful internet sites

Canals on Mars

https://fivethirtyeight.com/features/a-mistranslated-word-led-to-some-of-the-best-fake-news-of-the-20th-century/

https://www.newspapers.com/clip/26201903/los_angeles_times_feature_about_mars/

https://blog.newspapers.com/mars-canals/

Colonising Mars

https://www.spacex.com/mars

https://futurism.com/spacex-starship-mars-landing-site

https://www.designboom.com/design/nasa-spacex-starship-mars-landing-sites-09-02-2019/

https://www.inverse.com/article/51291-spacex-here-s-the-timeline-for-getting-to-mars-and-starting-a-colony

https://www.reddit.com/r/SpaceXLounge/comments/82pg4g/spacex_plans_for_mars_habitats/

https://en.wikipedia.org/wiki/SpaceX_Mars_transportation_infrastructure

https://qz.com/1105031/should-humans-colonize-mars-or-the-moon-a-scientific-investigation/

https://www.space.com/28557-how-to-live-on-mars.html

https://www.inverse.com/article/32283-humans-mars-timekeeping

https://www.ted.com/talks/nagin_cox_what_time_is_it_on_mars/transcript?language=en#t-318570

https://www.popularmechanics.com/space/moon-mars/a21330/nasa-wants-martian-resources-for-martian-colony/

https://www.space.com/mixed-gender-astronaut-crew-mars-exploration.html

Landing site

https://en.wikipedia.org/wiki/Amazonis_Planitia

https://behindtheblack.com/behind-the-black/essays-and-commentaries/the-many-pits-caves-of-mars/

A house on Mars

https://mars.nasa.gov/resources/7206/lava-flow-near-the-base-of-olympus-mons/

https://en.wikipedia.org/wiki/Martian_lava_tube

https://www.inverse.com/article/36777-mars-moon-human-colony-lava-tubes

https://phys.org/news/2017-09-lava-tubes-hidden-sites-future.html

Living off the land

https://www.skyandtelescope.com/astronomy-news/some-plants-grow-well-in-martian-soil/

https://www.nasa.gov/feature/can-plants-grow-with-mars-soil

https://earthsky.org/space/mars-express-spacecraft-finds-evidence-of-subsurface-lake-on-mars

Curiosity Rover

https://mars.nasa.gov/msl/

Exoplanets

https://exoplanets.nasa.gov/what-is-an-exoplanet/how-do-we-find-life/

https://en.wikipedia.org/wiki/List_of_potentially_habitable_exoplanets

https://www.nationalgeographic.com/science/2019/09/first-water-found-in-habitable-exoplanets-atmosphere-hubble-kepler-k2-18b/

Resources

Lesson resources

- Lesson Resource 1 – *Mars* PowerPoint
- Lesson Resource 2 – *The Martians are Coming* PowerPoint
- Lesson Resource 3 – *Elon Musk and the Colonisation of Mars* PowerPoint

For students

- Student Resource 1 – Research Topic Hints

Activities

The following notes are based on lessons of approximately 50 minutes' duration.

The teacher is free to rearrange content in a manner that best suits the curriculum context and the students involved.

It is advisable to discuss the teaching of this topic with teachers in biology, chemistry, history, geography and DT, at least to forewarn them of the content and the questions that students may raise in their lessons. Colleagues from other subject areas may wish to take part in cross-curricular activities and make the delivery of this topic a theme for the week or similar.

Lesson 1: Mars

This lesson is used to establish some basic facts about Mars. The PowerPoint *Mars* has been provided for this purpose. There are several useful learning points that can be emphasised:

- Day length: A Martian day is referred to as a 'sol'. How beneficial would it be for people living on Mars that the day is very similar in length to that on Earth? You could discuss sleep patterns in this context. Colonists could continue to use a 24-hour clock, possibly with an extra-long weekend day to compensate for the ~40-minute difference. Alternatively, clocks and timers on Mars could be set to run slightly slowly, so that their seconds were longer than an Earth second. Hence they would count through 24 Martian 'hours' in the Martian sol. The class could discuss different possibilities and come to a conclusion as to how best to deal with the

time on Mars. Such a discussion might help set the scene for the work on Martian colonisation, which is the main aspect of this topic. There is a highly recommended and amusing TED talk by NASA engineer Nagin Cox, where she discusses controlling a rover on Mars while working on Earth and the problems resulting from the different 'time zones' being used by people on shifts: https://www.ted.com.talks/nagin_cox_what_time_is_it_on_mars/transcript?language=en#t-318570.
A version of the Mars time app mentioned in the talk can be found at: https://apps.apple.com/gb/app/mars-watch/id1221014167.

- Seasons: Mars has longer and more extreme seasons than Earth, although the two planets' axial tilts are broadly similar. Students sometimes have the wrong impression that the seasonal variations from summer to winter come about due to the Earth being at different distances from the Sun (they are not thinking about the other hemisphere!). Earth's orbit is elliptical, but the distance from the Sun does not vary that markedly. In the case of Mars, the orbit is much more elliptical, giving rise to more extreme temperature variations. Due to the axial tilt, the southern hemisphere is pointed away from the Sun when Mars is at the extreme end of its orbit, so it experiences far colder winters than those of the northern hemisphere. The flip side is that the southern summers are warmer. Someone living in the northern hemisphere would cycle through about seven months of spring, six months of summer, five months of autumn and four months of winter.

  Do not allow the variation in distance from the Sun to be confused with the figures in the slides, which show the change in distance between Mars and Earth, that arises from the elliptical nature of Mars' orbit.

  - Earth to the Sun: 147 million km to 152 million km = 3.3% variation
  - Mars to the Sun: 206 million km to 249 million km = 21% variation

- Slide 10 has the variation in Earth-Mars distance over time and highlights the dates of the planned *SpaceX* colonising missions and the projected NASA manned orbital mission. The *SpaceX* plans will be discussed in a later lesson, although a taster of what is to come can be provided this lesson.

- Slide 11 shows the temperature recorded on the surface of a solar panel attached to the Spirit rover (which is no longer in service). Discuss with the students what the actual temperature would feel like. Point out how thin the atmosphere is, with the consequent issues for convection and heat capacity. The thin atmosphere also presents challenges as there is very little absorption of UV radiation.

- The quality of modern data about Mars and the images produced far exceeds that which was available only a few decades ago, never mind in the 19th century. In the next lesson we will pick up on this when discussing the canals on Mars.

- There have been several roving vehicles remotely controlled from Earth that have been exploring the surface. Currently the *Curiosity* rover is still operational, a number of years after its expected end of mission: https://mars.nasa.gov/msl/

- Ask the students if they can think of any issues with controlling a roving vehicle from Earth. Get them to calculate the variation in time delay of a radio signal from Earth to Mars, given the change in distances involved (180 s to 1340 s). Surface roving vehicles have to have sophisticated systems to help them recognise and avoid obstacles.

Lesson 2/3: The Martians are Coming

This introductory lesson can be coupled with a second lesson in which further discussion takes place.

The PowerPoint *The Martians are Coming* details some aspects of the past history of Mars observations. While it is hard to credit in modern times, at the end of the 19th century there was a broad belief among the public and parts of the scientific community that a civilisation existed on Mars. The link https://www.newspapers.com/clip/26201903/los_angeles_times_feature_about_mars/ leads to an online version of a 1907 newspaper article, which includes the sentence: *'Scientists now declare that the many lines and spots on Mars represent verdure along a most wonderful canal system, which the inhabitants of the planet have constructed for purposes of irrigation'.*

The prevailing narrative had the native Martians subject to a planet-wide decay in their climate, rendering the surface a desert. Consequently, the civilisation was surviving by constructing massive canals to bring water from the poles in order to sustain plants and life in general. Telescope observations were thought to have shown (with the modern interpretation in brackets):

- Polar ice caps varying in size. *{Correct, but due to the seasonal temperature variations, the South cap being frozen CO_2 (with water ice beneath) and the North cap being water ice.}*

- Seasonal variations in plant growth. *(Geological features on the surface were probably mistaken for vegetation due to their darker colour and lesser reflectivity. As the planet rotates on its axis, so different features are visible. More importantly, dust storms blow up either locally or in some instances across the whole surface, obscuring the features below. As these storms also vary with the seasons, this is the probable explanation for what was observed.)*

- Linear features criss-crossing the planet's surface, interpreted as canals. *(The first use of the word 'canale' to refer to a large feature, Syrtis Major Planum, was almost certainly mis-translated into canal, rather than channel. A channel, being a groove or gulley, can be cut by natural processes, whereas a canal is an artificial construction. This seemingly simple misinterpretation had a profound influence*

on thinking. From there, we can only account for the intricate observations and maps produced via the optical quality of the telescopes, which were quite good, fluctuations in our atmosphere affecting the images of Mars and the imaginations of the observers leading to 'wish fulfilment'.)

It was not until satellite observations of the planet started in the 1970s that the existence of canals on Mars was definitively disproved.

All of these points should be discussed with the students, either in response to their questions during the PowerPoint, or as prompted discussion topics directed by the teacher.

It is useful to have the timeline from the year 10 topic *The Scope of Science* available so that comparisons can be made between the eras in the PowerPoint and the broader events of history at the time. Students may also wish to discuss this with their history teachers.

It is important to note that observations in the 19th century were being made 'by eye'. Maps of the surface were hand-drawn from a combination of memory, or via sketches made during observations. The first photographic image of the Moon was taken in 1840 (as the brightest object in the night sky). It was not possible to take pictures of stars until the late 19th century. Consider the image of Lowell at the telescope (slide 12) and how he might set about making a drawing of the surface of Mars (how much background light would he have been able to work in, for example?).

Discussion points that can be used (all or some depending on the time available) include:

- Get the students to carry out some brief research on canal building on Earth. Find the dates of significant canal construction such as the *Suez Canal* (1859-1869), *Panama Canal* (first attempt: 1881-1894). Consider the overlap between these dates and the observations of Mars. Does this help us to understand how *canali* became *canals* and how it came to be accepted that Martians were busy constructing irrigation networks? To what extent is science influenced by the prevailing ideas in popular culture at the time? There are other examples – the prevailing metaphor for brain function often aligns with the dominant technology of the time. In Victorian times, the brain was thought of as a clockwork-like mechanism, whereas now we often hear it referred to as a computer. The students could do some follow-up research on this.
- Was Lowell making the canal story up? Consider what Lowell's motivations might have been. He was already wealthy and well-known. He invested a considerable amount of money in his observatory and telescopes. As a result, he carried out some worthwhile observations and made valuable contributions to astronomy. Other astronomers also reported observing linear markings on Mars, although some were unable to confirm the observations and remained sceptical. To what extent can people influence what others see? Did other astronomers also see canals or were they concerned about their reputations if they disagreed with some of their colleagues and Lowell? Are we influenced in this way in daily life? Should we expect scientists to be immune to such influence?

- Slide 14: why should we be *'pleasingly surprised to find all our manual labor suddenly lightened threefold'* on Mars? (Consider the surface gravity.)
  What were *electrophones* and *kinetoscopes* (brief student research). What do you think Lovell was referring to when he said, *'Certainly what we see hints at the existence of beings who are in advance of, not behind us, in the journey of life'*?
  (Consider the relative sizes of the canals on Earth and those that had been mapped on Mars. Some scientists of the time suggested that we were actually seeing the plant growth around the canals, which were themselves too narrow to be seen. However, the length of the canals would still have been very impressive.)
  What do you think Lowell meant by the following: *'Even on this Earth man is of the nature of an accident. He is the survival of by no means the highest physical organism. He is not even a high form of mammal. Mind has been his making.'*?
  (There are two significant aspects here – the evolutionary 'accident' that has given rise to the species and the role of mind in our evolutionary success. Lowell is indicating that mind has trumped other physical characteristics such as speed, strength and hardiness, leading to our dominance of our planet. Discuss this with the students – suggest that they raise it as a discussion point with their biology teachers.)

- H G Wells' book *The War of the Worlds* was heavily influenced by the idea that Martians were facing a dying planet lacking water and *'regarded this earth with envious eyes, and slowly and surely drew their plans against us'*. Again, this illustrates the general level of popular acceptance of Martians, or at least the power that the idea had over the imaginations at the time. The account of the radio broadcast is an amusing side note.

  What sort of background ideas influence our thinking in current times? One 'threat' that is part of popular culture is artificial intelligence (AI). Elon Musk himself has said that AI may represent humanity's *'biggest existential threat'* and that developing true AI would be like *'summoning the demon'*. If you wished to develop this into an extension exercise, then have the students consider issues such as:

  - Should AI computers have certain rights?
  - Would you allow an AI computer and a human to marry?
  - Could an AI computer be baptised?

- Longer term influence: The first satellite to travel to Mars was *Mariner 4*, which was launched in 1964. Is it possible that the people who planned that mission, constructed the satellite and approved the money for its development grew up under the influence of the idea that there was a civilisation on Mars? To what extent do the students think that ideas like this in childhood influence the choice of career in later life? Ask them to think about their own possible careers in the light of the experience so far. It would be interesting to repeat that question after showing the students the video in the PowerPoint *Elon Musk and the Colonisation of Mars*, which shows his own reactions as well as those of some of the people working at *SpaceX* to the launch of a new rocket. Are they excited to get involved with aerospace engineering and rocket research?

- Life on other planets: do the students believe that life exists on other planets? There is no scientific consensus on this topic (lack of data), but an interesting extension would be to discuss the discoveries of extra-solar planets (exoplanets), an increasing number of which are found in the habitable zone around their parent star (for websites containing information relevant to such a discussion, see the internet links above). What would be the influence on society if extra-terrestrial life was discovered? Consider a range of discoveries: a microbe alive on Mars (demonstrates at least that life has evolved on other planets. Would it have DNA like our life?); a fish-like multicellular organism living in a sub-surface lake on Mars (a great deal of evolution must have taken place); an intelligent creature visiting Earth (what knowledge might it bring, consider not just scientific or medical knowledge – what would it think of politics / economics / religion?). What aspects of society would change as a result?

Lesson 4: Colonising Mars

In this lesson, the students are introduced to current plans to colonise Mars. In order to do this effectively, some background knowledge about Elon Musk and his company *SpaceX* must be established. This can be done using the PowerPoint *Elon Musk and the Colonisation of Mars*.

NB: Some videos in the PowerPoint are embedded (in which case they have a grey surround) and others are YouTube links (no surrounding – needs an internet link for them to play).

Ask students what they may have heard about Elon Musk in the news.

Give them some basic information about *SpaceX* (using the PowerPoint) and show them the YouTube clip (which is on slide 6): https://www.youtube.com/watch?v=A0FZIwabctw&t=22s (1 min 52s), which covers the maiden launch of the rocket *Falcon Heavy* developed by *SpaceX* (February 2018). The rocket comprises a central core, external boosters and a second stage and currently the most powerful operational launch system in the world.

SpaceX aims to reduce the cost of space flight by designing rockets that can be re-used on further flights. The clip shows the external boosters separating and then landing under power back near the launch pad, which is a tremendous technical advance. The central core of the rocket should have landed at sea on a specially prepared barge[1] but, on this occasion, it crashed just short. Later missions have successfully landed all three of the re-usable stages.

The video is atmospheric and shows the enthusiasm and joy associated with working as a team to develop new technologies. The number of women involved in the project is clear and should be emphasised to the class.

As this was a test, the rocket payload was Musk's own *Tesla Roadster* car, which had a mannequin placed in the driver's seat. On-board cameras showed views of the car and the mannequin, named *Starman*. Also visible is the display 'DON'T PANIC' on the car's navigation screen. This is a reference to Douglas Adam's *Hitchhiker's Guide to the Galaxy*.

The intention was to place the upper stage and car onto a Mars transfer orbit, similar to the path that would be used by a manned expedition. However, the correct transfer was not achieved, and the payload went into a Sun-centred orbit crossing that of Mars. To date, it has completed one orbit. Full details regarding the orbit and the path of the upper stage can be found on the *Wikipedia* page: https://en.wikipedia.org/wiki/Elon_Musk%27s_Tesla_Roadster.

SpaceX makes money by launching satellites for other organisations. It sends supplies to the *International Space Station* (ISS) on behalf of NASA and has successfully developed a manned capsule, *Dragon* and space suits. *Dragon* has been used to deploy two crews to the ISS (slide 4): https://www.spacex.com/vehicles/dragon/.

Alongside this work, *SpaceX* has started development of the next generation of even more powerful rockets known as *Super Heavy*. The upper stage, *Starship*, will have a payload capacity of up to 150,000 kg (slide 12). *Starship* is currently under development and slide 9 contains a video showing the prototype *SN8* doing a short flight. This is significant, as the design calls for *Starship* to land vertically under power. On Mars, the atmosphere is too thin to allow a glide landing (which is how the Space Shuttle landed), hence the need to develop this landing mode. This is a point that can be discussed with the students, who may note that the ship has small fins at the nose, which can be adjusted in-flight. While the *SN8* mission ended with a catastrophic explosion on landing, the overall mission was classed as a great success. The value of this clip is that it shows the phases of the landing, which can be seen without annotation in other clips. Emphasise to the class that the purpose of test flights is to isolate issues, fix them and move on. Hence *SN8* demonstrated many aspects that worked perfectly, allowing them to focus on the single issue (albeit a major consequence) that needed work. Slide 10 shows the successful flight and landing of *SN10*. In truth, SN10 exploded a few moments after landing (Musk refers to such events as 'rapid unscheduled disassembly'). An alternative is to show the flight of SN15, which can be found at: https://www.youtube.com/watch?v=z9eoubnO-pE, in which case you may want to start the video at the actual launch, which is at 6 min 20 s into the video. The in-flight quality is not as good as for SN10, due in part to low-lying cloud. However, the flight was completely successful and SN15 has now been dismantled. There is also a video at https://www.youtube.com/watch?v=K5Vw2ZDe-G0 ,which shows the development phases of the Starship design and their test flights.

The last slides in the PowerPoint discuss the plan to send *Starship* to the Moon with paying passengers in 2023 and then the sequence of flights scheduled for Mars exploration. Also included is a collection of quotes from Musk and from the *SpaceX* website. It is worth spending some time focusing on these and gathering the views and reactions of the students.

Once the initial information has been presented, emphasise that *SpaceX's* plans are in progress and, given the remarkable advances that the company has made since its founding, we should not be too sceptical regarding the team's ambitious aims.

Exercises that could be set to the students include:

- Consider *SpaceX's* plans to reduce flight times to other cities (e.g. Hong Kong from 11 hours 50 mins to 34 mins). What would be the advantages from the point of view of passengers, cargo, businesses, etc? Are there any potential disadvantages[2] to a flight that would take so little time? Design a poster advertising this new service flying from one city to another of your choice (e.g. London to New York).
- How would you advertise for people to join the expedition to Mars? Design a poster that calls for applicants. Emphasise that this will be a dangerous mission and will require at least several years' commitment. How will you make the prospect attractive?
- Write a short story about someone responding to the advert for a Mars explorer. What tests might they have to go through? What training? How might they react to setting foot on Mars for the first time?
- Draw or paint a picture (physical or digital) that shows *Starship* landing on the surface of Mars.

Lesson 5: Research Projects

Having established the basic facts about Mars and seen the seriousness of *SpaceX's* plans to land people on the planet, the students can be set research projects to report back to the class on a range of topics. Depending on the time available, two to three lessons of research and discussion could be followed up by one lesson reporting back to the rest of the class, in the form of a presentation. Student Resource 1 provides hints that will get each group started on their research.

Teachers should familiarise themselves with the material on the recommended websites, in order to advise the students better.

A house on Mars: one team looks at how to design and construct a habitat on Mars. The features of the prime landing site should be researched and used to help develop ideas. The major issue of radiation protection is one that they will need guidance to deal with. At the end, the team reports back to the rest of the class showing their design and explaining the ideas that went into it. The likelihood is that *SpaceX* will deploy inflatable structures inside lava tubes, since being underground provides a measure of radiation protection.

Living off the land: this team looks at growing crops on Mars. They will need to remind themselves about the basic needs of vegetation and research the development that has been done on how to grow crops in the Martian environment. Sunlight is not as intense on Mars, but UV is much more so than on the surface of Earth. Students also need to consider the basic nutrient requirements of humans and how to cater for that on their Martian diet (protein needs some thought). It is allowable to partially rely on vitamin supplements shipped from Earth. At the end of their project, they should come up with an outline design for a Martian greenhouse (discussed with the house team) and plan a Martian lunch.

Martian industry: A developing colony will need construction materials. This team should research what minerals are known to exist on Mars and how to extract iron from the rocks. Clay-like minerals are also present in Martian regolith, so pottery and ceramics (potentially a construction material) would be easy to produce. Glass should also be comparatively easy to generate, leading also to fibreglass. These issues should be discussed with the house design team so that they are aware of the construction materials available to them. The industry team can also investigate the proposals to generate rocket fuel (methane) from the CO_2 in the atmosphere and the O_2 needed as an oxidiser. Again, they should report back to the rest of the group.

The Martian village: *SpaceX's* plans for sending crews to Mars have two ships of ~100 people each in 2024. If that comes to pass, there will be a village on Mars of around 200 people from 2024 onwards. With that many people, and the potential for it to grow at the rate of about 200 every two years (at further oppositions), a system of governance needs to be established. There will be people responsible for growing crops (the Living off the Land team), people who make construction materials (Industry team), construction experts (house on Mars) as well as explorers and scientists. This group needs to consider the range of skills that will be required and the balance of people on the ships.

Each team should give a short presentation to the rest of the class to outline their conclusions. It might be appropriate to award a prize to the most successful team. You should consider:

- The quality of the presentation – how well the students speak, any resources that they use.
- The level of their research – have they just taken the material that they were given, or have they done some substantial research of their own?
- Have they shown any level of discernment in their research – evaluating different sources, checking one against the other?
- Have they just used the internet, or have they spoken to other teachers, consulted books from libraries, etc?
- The organisation within the team and the level of commitment from the members.

[1] One of two autonomous barges *SpaceX* uses for these purposes. The one deployed for the *Falcon Heavy* maiden flight was named *Of course I still love you*. The crash happened as the core stage ran out of igniter fluid and was unable to re-fire two of its three engines during the descent.

[2] If the students are stuck, then suggest the following: extra demands on security with the rate of arrivals/departures, extra demands on cargo processing, longer to drive to the terminal than the flight (!) with extra demands on infrastructure (roads, etc.).