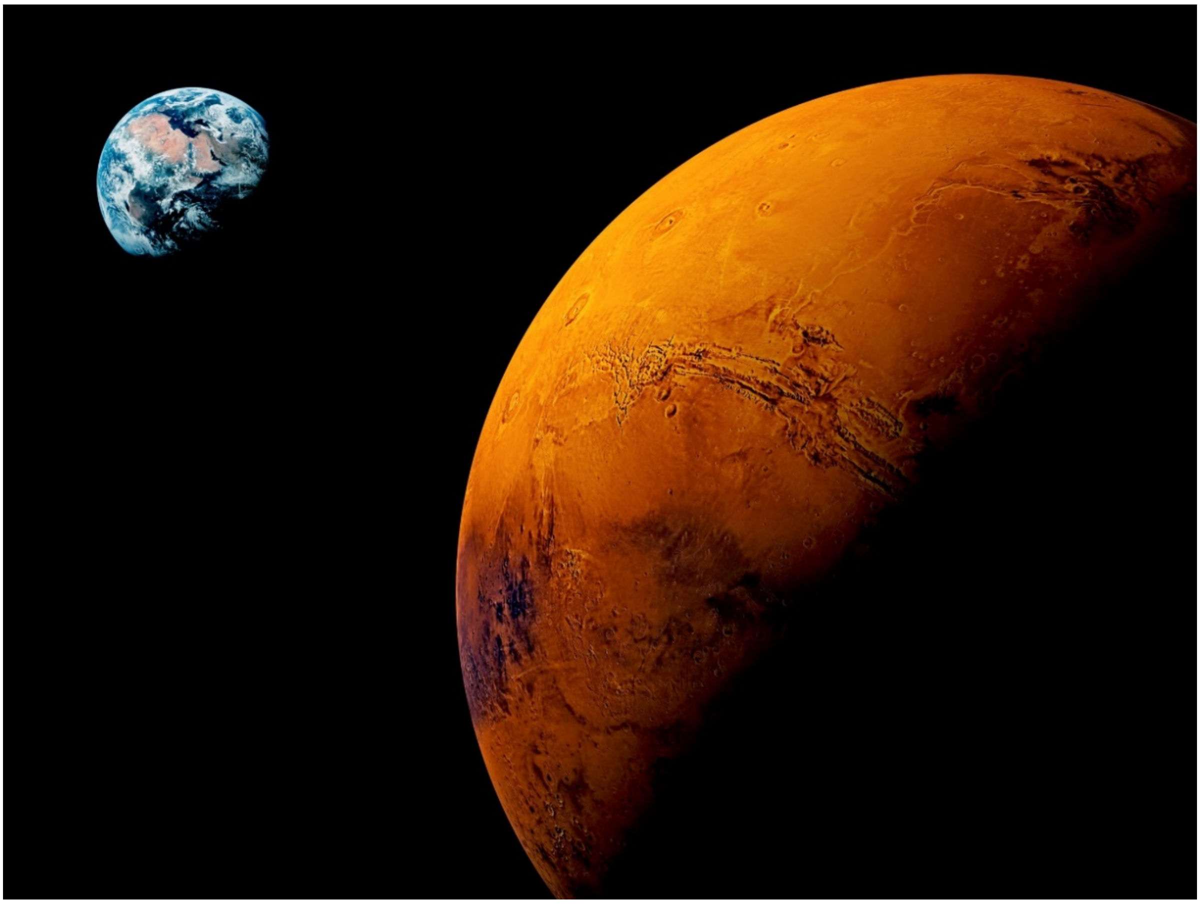
Future Fibres.... Taking us to Mars & beyond



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ARC Research Hub for FUTURE FIBRES

Executive Summary

Fibres are an important class of material which finds application across a broad range of industries: from the clothes we wear to carbon fibre planes, carpet, insulation, biomaterials and general textiles. The ARC Research Hub for Future Fibres undertook a strategic planning and brainstorming event with a broader group of researchers from Deakin University, CSIRO and industry to consider the future for fibre use and research. This document captures the outcomes from that event and focuses them around a mission to Mars and colonisation of the red planet. This thought-provoking and educational framework is used to demonstrate the broad application of fibres, and how technology developed for highly advanced applications such as space travel can also benefit the general public.

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Introduction

Imagine you are in the year 2040…. The first manned missions to Mars are underway, and humans are working towards establishing a colony on the red planet. On close inspection the number of different fibre materials involved in the expedition and subsequent colonisation of Mars is enormous – fibres are crucial to the success of the mission! From the clothes an astronaut wears, to the spaceship itself, and the habitat required to survive on Mars, fibres play an integral role. The limited resources on Mars means the methods to process the fibres, manufacture a material, and to recycle or reuse fibres are also critical.

It's not just the direct application of any developed fibre technologies in a mission to Mars, but the spin-off technologies that can be used by everyday people on Earth. Since 1976 NASA has profiled more than 2,000 technologies in their annual Spinoff publication.[1] These are technologies developed during their bid to understand space which are now routinely used in day-to-day living. Examples include: CAT scanner, cordless tools, freeze-dried food, insulation, memory foam, scratch resistant lenses, smoke detector, world's fastest swimsuit, water filter.

This document discusses various phases of a manned mission to Mars. It examines the challenges, and investigates the role fibres could play. It also discusses how these technologies could be used on Earth.

Context

There is growing momentum in the race to send humans to Mars. As of 2019:

- NASA has the goal to send humans to orbit Mars in the 2030s.[2] In fact, in 2017 NASA was issued a mandate to get people to Mars by 2033. Note the current plan is to only send people into orbit of Mars by 2033. No timeline for landing people on Mars has been released yet.
- The European Space Agency (ESA) and Russia's space agency (Roscosmos) are jointly conducting the ExoMars program which consists of the previously launched (2016) trace gas orbiter and doomed Schiaparelli landing module, and the planned 2020 launch of a rover.[3]
- Roscosmos also announced in 2017 that it will begin work in 2019 to prepare for a manned flight to Mars.[4]
- The China National Space Administration (CNSA) announced a deep space exploration program commencing in 2006. It later announced a robotic probe mission to land on Mars in 2020,[5] with manned missions proposed between 2040 and 2060.
- The Japanese Aerospace Exploration Agency (JAXA) propose to explore the moons of Mars, launching in the 2020s,[6] and the Indian Space Research Organisation (ISRO) has started planning a mission to put a lander on Mars in 2022.[7]
- SpaceX, a private company, has an ambitious plan to send a manned mission to land on Mars in 2024, following an unmanned mission to land supplies in 2022.[8] The long term goal of SpaceX is to build a thriving city and eventually a self-sustaining civilisation on Mars.

Alongside these government and private industry plans for Mars, the not-for-profit Mars Society[9] is an advocacy organisation dedicated to promoting human exploration and settlement of Mars and aims to educate on the benefits of exploring Mars and the need to create a permanent human presence. It was established in 1998 by Dr Robert Zubrin, a strong advocate for manned exploration of Mars, and now has chapters in 19 countries. The Society also provides support for government and privately funded Mars research and exploration projects.

Finally, Australia has recently joined the space race, with the establishment of the Australian Space Agency in 2018.[10]

Background

Travelling to Mars with existing technology, when the planet is closest to Earth, will take approximately 260 days, with this launch window opening every 2 years. Proposed round trip duration for a mission to Mars is 2 to 3 years. Table 1 outlines some fundamental properties for Earth and Mars.

Table 1: Fundamental properties of Earth and Mars

	Earth	Mars
Average distance from Sun	150,000,000 km	229,000,000 km
Temperature range	-88 to 58 °C	-140 to 30 °C
Atmospheric composition	78% N_2, 21% O_2, 1% other	96% CO_2, <2% Ar, <2% N_2, <1% other
Atmospheric pressure	101.3 kilopascals	0.6 kilopascals (0.6% of Earth)
Force of gravity	100 kg on Earth	38 kg on Mars (62.5% less gravity)
Day length	24 hrs	24 hrs, 40 mins

Key challenges

The key challenges that have been identified in humans travelling to Mars and establishing a colony are summarised below.

- Protection against radiation – current spaceship materials do not provide enough protection for a Mars mission or for establishing a colony.
- Clothing – can't easily be washed in space/on Mars, needs to integrate comfort, functionality, and reusability.
- Sustainable food/water/energy supplies – necessary for the long voyage and colonization.
- Sustainability and use of resources – closed-loop system, everything needs to be re-used.
- Advanced manufacturing technologies – that can be used in flight or on Mars.
- Oxygen – the need to develop an oxygen rich environment.

Note

NASA has made much of their research and plans available to the public, while SpaceX has released plans for its BFR rocket, but no details on what astronauts will wear, or how they will establish a colony on Mars. Other space agencies have also released little information as their plans to send manned missions to Mars have not yet progressed as far. Therefore much of the information in this report comes from NASA or associated research.

Getting to Mars

Introduction

The development and construction of spaceships capable of transporting humans to Mars is already underway. NASA has been constructing the Space Launch System (SLS) rocket with Boeing since 2014, with the first mission into space proposed for late 2019. NASA is also developing the Orion Multi-Purpose Crew Vehicle (Orion MPCV) – the spaceship designed to launch on top of the SLS and facilitate missions to Mars. Meanwhile, privately owned company SpaceX has announced ambitious plans to colonise Mars and in September 2017 released details of their proposed Starship and Super Heavy Rocket (previously known as BFR) to undertake the voyage. This rocket is intended to be the successor to previously developed SpaceX launch vehicles – Falcon 9 and Falcon Heavy (first successful launch in Feb 2018).

NASA Mars Mission

An international consortium, led by NASA, proposes to construct the Lunar Orbital Platform-Gateway (LOP-G) – a crew-tended space station in a highly elliptical orbit around the moon. While the initial aim of the LOP-G is to facilitate manned missions to the moon, it is also proposed to be the staging point for NASA's proposed Deep Space Transport (DST) – a reusable vehicle that uses electric and chemical propulsion for missions such as to Mars. Therefore, there are various vehicles required for this proposal – the rocket to launch ships from Earth, a ship to transport people and supplies to LOP-G, the space station itself (LOP-G), and the DST to take people and supplies onwards to Mars.

SpaceX Mars Mission

SpaceX is proposing for one reusable spaceship to take people and cargo all the way from Earth to Mars. They propose to refuel the ship in Earth's orbit before departing to Mars, and also to build a propellant plant on Mars to provide fuel for the return voyage (fuel is CH_4/Liq O_2). The Super Heavy Rocket and Starship is designed to not only take humans to Mars but also to replace all existing SpaceX vehicles. It will thereby also target the Earth-orbit market for satellites, and missions to the International Space Station.

Mars Direct

Mars Direct is a plan developed by American aerospace engineer and Mars Society founder Dr Robert Zubrin.[11] It is designed to be a cost-effective, minimalist mission, utilising Mars resources to generate rocket fuel (methane/oxygen), extra water and to supply minerals for construction. The plan consists of an initial launch of a single Earth Return Vehicle (ERV) containing nuclear reactors capable of generating fuel for the return trip. During the next launch window 26 months later two more ships would be sent: a second ERV as back-up, and a manned ship with a Mars Habitat Unit (MHU). After 18 months the crew would return to Earth using an ERV, and a second set of two ships would be sent. This cycle is proposed to continue every two years so that eventually a series of habitats would be established on Mars, and a permanent human settlement could begin.

The plan received significant interest when first announced, however it has not been adopted by any space agencies. It has undergone regular review and further development since it was first conceived, and some aspects such as the habitat unit and propellant generator have undergone some testing. It is still heavily promoted by the Mars Society and Zubrin himself.

Radiation Protection

Protecting astronauts from deep-space radiation is a major problem. Cosmic radiation is extremely high energy and very penetrating. The levels of exposure on current shorter missions, or in low Earth orbit (i.e. on board the ISS) is acceptable, but technology used in current space ships is not believed to be sufficient for longer distances/time, outside of the Earth's protective magnetosphere.[12]

> "The Agency cannot support human missions greater than approximately 90 to 100 days beyond low Earth orbit (LEO) without developing shielding and/or biological countermeasures to remain below Permissible Exposure Limits." Sheila Thibeault, leading research on materials at the NASA/Langley Research Center.[13]

A 2013 study suggested that a return trip to Mars would expose astronauts to a lifetime's dose of radiation in one go, not including any time actually spent on Mars.[14]

Aluminium

Aluminium is typically the material of choice for spacecraft as it is strong, light and relatively cheap; however, the thin layers usually used for constructing a spaceship offer virtually no protection against radiation. Exposure to high energy cosmic radiation can also produce secondary radiation by knocking protons or neutrons out of the nuclei. This secondary radiation can have a severe effect on biological tissue, and also disrupt electronic systems.

It is possible to use thicker aluminium plates to increase the shielding capability, however this dramatically increases the cost of constructing the spaceship, as well as increasing the weight and thereby fuel requirements.

Polyethylene

Research has suggested that materials that have a high hydrogen content can reduce primary and secondary radiation to a greater extent than metals.[12] For example, polyethylene provides 50% better shielding from solar flares than aluminium and 15% better protection against cosmic rays.[15] Ultra high molecular weight polyethylene (UHMWPE) is already used on the International Space Station, particularly for the sleeping quarters, where panels several centimetres thick provide protection for the crew members against radiation.

Polyethylene has been used by a research team at the Marshall Space Flight Center to make bricks. They layered 200-300 fabric pieces in a mould and used a vacuum pump to remove air before annealing in an autoclave.[16] The resulting brick weighed half as much as a similar piece of aluminium. In 2003 the same group also reported a polyethylene fibre reinforced epoxy matrix composite (1-5 cm thick), termed RXF1, which has 3 times the tensile strength of aluminium, is 2.6 times lighter, and is better at shielding against cosmic rays and solar particles.[17]

However, polyethylene is very flammable and so presents a flame and temperature risk if used on-board a spaceship. More work is needed to address this risk before polyethylene can be safely adopted as a construction material in space.

Cella Shield

More recently English company Cella Energy, a spin-out of the Rutherford Appleton Laboratory, was awarded a patent for a spaceship material made by combining solid hydrogen compounds with plastic fibres.[18] The team uses electrospinning to attach solid hydrogen compounds (hydrides) to polymer fibres and claim a higher hydrogen weight content than polyethylene. While the primary focus of Cella Energy is the stable storage of hydrogen in a solid state, they are also investigating application of their technology as a radiation shield.

Other

The NASA Langley Research Centre, Jefferson National Lab and National Institute of Aerospace have recently synthesized long, highly crystalline boron nitride nanotubes (BNNT) as a potential space radiation barrier.[19] They have extraordinary strength and high temperature stability and can potentially by hydrogenated and theoretically used for load bearing structures.

SpaceX has suggested they might use a large internal water layer to help shield occupants from radiation.[20] This could be strategic storage of the water needed to supply the crew.

Other Spaceship Materials

The weight of a spaceship is critically important, as the cost of launching from Earth to low Earth orbit averaged $18,500 per kilogram from 1970 to 2000.[21] A major decrease in cost occurred in 2010 when SpaceX launched Falcon 9 with a cost of $2,700 per kilogram, and has decreased even further for Falcon Heavy – to $1,400/kg.[21] SpaceX announced in 2016 that they intend to make most of their spaceship out of carbon fibre composites.[22] Not only is this material lightweight, but it also has high tensile strength, design flexibility and low density. SpaceX have already constructed and tested a 12 metre diameter fuel tank, which must withstand extreme conditions of temperature and pressure.[23] NASA and Boeing have also developed a 5 m diameter carbon fibre fuel tank.[24]

Case study: Curving carbon fibre

Putting a curve in ballistic materials presented a challenge to scientists. The stiffness of ballistic fibres made it seemingly impossible to bend without wrinkling the material. This meant curves were generally obtained by splicing or cutting the material, and then usually putting together by hand – resulting in a product with reduced strength and performance and a labour intensive process.

Researchers at Deakin were part of a team which developed a unique process to curve and harden the ballistic fibres into the correct shape. The process, Double Diaphragm Deep Drawing (D4), uses thermal forming to shear the fibres and can achieve perfectly shaped combat helmets which are 20-30% lighter than previous helmets.* The process avoids intensive manual lay-up and can be used with a range of fibre systems including carbon fibre composites, and Kevlar.

The D4 technology has numerous non-military potential applications, including aerospace, automotive, construction and furniture.

* www.deakin.edu.au/research/research-news/articles/researchers-conquer-ballistics-armour

Clothing

The clothing worn by astronauts has many requirements. It needs to protect humans from radiation, extreme temperatures, and the lack of atmosphere and breathable air when outside the spaceship or habitat. Inside the ship or habitat the requirements are less, however there are still technological challenges for a Mars mission and colonisation.

Spacesuit

Outer Space Suits

In Earth orbit temperatures can range from -250 °C to +250 °C, often from one side of the suit to the other depending on whether it is facing the sun. The suit also needs to supply oxygen, water to drink, and protect astronauts from being injured from small bits of space dust and radiation. The current NASA spacesuit – the Extravehicular Mobility Unit (EMU) weighs about 125kg on Earth and consists of many components which fit together in a modular fashion.[25]

A wide range of different fibre materials play a critical role in spacesuit performance. The flexible parts of the EMU, such as the arms, are made from several layers which perform different functions (14 layers for the arm). The innermost three layers are the liquid cooling and ventilation garment which contains tubes woven into a tight-fitting mesh one-piece suit made of nylon tricot and spandex that covers the whole body. Next is the bladder layer which creates pressure and holds in the oxygen. Following this are support layers, tear-resistant layers, seven layers of Mylar insulation and the outer layer which consists of a blend of three fabrics: a woven blend of Kevlar (impact resistant) and Nomex (fire-resistant) which is coated with Teflon (water resistant).[26] Overall the suit contains a wide range of fibre materials including: spandex, urethane coated nylon, Dacron, neoprene, aluminized Mylar, Goretex, Kevlar and Nomex.[27]

The hard upper torso segment is made from fibreglass, and the helmet shell is polycarbonate. The lower torso assembly (pants, boots, knee and ankle joints, and the waist connection) also contains multiple layers. The innermost layer is a pressure bladder of urethane-coated nylon, then there is a restraining layer of Dacron and an outer thermal garment composed of Neoprene-coated nylon. It also has five layers of aluminized Mylar and a fabric surface layer composed of Teflon, Kevlar, and Nomex.

The astronaut also has to wear a communications carrier assembly: a fabric cap which contains microphones and speakers for hands-free communication. The cap is made of nylon/lycra and Teflon. The gloves contain multiple layers of fabric, similar to the arms, but also include rubberized fingertips for improved grip and heaters in each fingertip to protect from the extreme cold. These space suits contain both hard and soft components, and also include features such as pleats and rotational bearings to allow for mobility.

NASA are currently developing next generation suit technologies. The Prototype Exploration Suit (PXS) is a technology demonstrator with improved fit and performance and incorporates sizing features which could be 3D printed, allowing for easier adaption to different people.[28]

Planetary Suits

The EMU, at 125kg, is too heavy to wear on Mars, therefore work is being done to develop new suits which would be suitable. NASA have developed the Z-2 prototype which is designed for use on a planetary surface.[29] It features enhanced mobility for exploring, collecting samples and getting in and out of habitats/rovers. The Z-2 uses advanced composite materials to achieve a light-weight durable suit weighing approximately 65kg.[30] The upper torso is a non-autoclave hard composite.

The Z-2 is designed to be entered via a back hatch, more like a spaceship than clothing – this is to allow people to enter the suit easily from a mobility vehicle. It has adjustable shoulders and waist to fit different crew members.[31]

Other researchers have proposed the development of a bio-suit system, or space activity suit (SAS), based on the concept of a "second skin", in a radical departure from traditional space suits.[32] By using mechanical counter pressure (MCP), where pressure is applied to the entire body through a tight-fitting suit with a helmet for the head, the spacesuit would theoretically require a greatly simplified life support system, could tolerate a small tear, and could be considerably less bulky and heavy than the current spacesuits. The suit would also enable much greater mobility, and would be quick to put on and take off. MCP suits could incorporate wearable electronics, conductive fibres, and could be constructed from a range of possible materials including nylon-spandex, elastic, urethane-painted foam and responsive polymers.

Other space clothing
Apart from spacesuits, the astronauts also currently wear a specialised orange Advanced Crew Escape Suit (ACES) on launch and re-entry into the Earth's atmosphere. This one-piece suit provides full positive air pressure if there is a pressure leak and also has a parachute, life raft, drinking water and signals in case of emergency. The 12.7kg suit has a Nomex cover layer, while underneath astronauts wear thermal underwear and maximum absorbency garments. The Orion missions are planning to use a modified ACES suit (MACES) with increased mobility and a closed-loop system to preserve resources.

Regular clothing

Currently astronauts on the International Space Station wear the same types of clothing as on Earth, albeit with more pockets and Velcro, selected from either Russian or US clothing supplies. Cotton is the fibre of choice due to its low flammability and comfort. Clothes are not washed, rather new clothes are sent up on resupply missions. They don't change clothes very often - outer clothing is changed every 10 days, underwear and socks every second day, and exercise clothes every 3 days. After use clothes are packed into a bag for disposal. Most is then put in a departing resupply vehicle and burnt up on re-entry to Earth's atmosphere.[33]

In 2015 NASA undertook a study on clothing systems.[34] The study evaluated several clothing options, including antimicrobial clothing (silver/ion impregnated) and natural wool. It also evaluated several cleaning/sanitation technologies (water-based laundry and sanitation by ozone or vacuum) for their resource cost and ability for longer wear times.[34] They found that for ISS missions disposable clothing has a lower launch mass than any cleaning/reuse options. It's only for missions longer than 8 months for sanitation methods, or 14 months for water-based laundry methods, that cleaning options become more economically viable than disposable clothing. This means these options will need to be further investigated for missions to Mars.

It has been suggested a Mars mission needs to have 95% water recyclability, an improvement over the current 85% recyclability on ISS. This will pose further restrictions on what laundering options are possible. Traditional methods are not possible due to water requirements and the need for gravity. One possibility is a micro-gravity washing machine which has extremely low water consumption. Dirty clothing is placed into a plastic bag and washed using jets of water (no air). The jets bend the clothes back and forth to work the soap solution through. After washing the clothes are dried by a microwave generator.[35]

Other ideas have been proposed to clean clothes in space including sanitizing with ozone (generated by ultraviolet lamps) or steam, however these techniques can only be used a few times, not dozens or hundreds of times like water washing can.[34] There are also some toxicity concerns with ozone, and its use in an enclosed spaceship cabin. Vacuum sanitation has also been considered – by use of a special chamber which can be exposed to the vacuum of space. It is a simple, low-power technique, however some microbes can survive space vacuum.[34]

Lint from cotton garments can clog up ISS machinery.[36] Stored dirty clothing awaiting disposal can also become smelly. NASA textile engineers undertook a study in 2015 which aimed to evaluate and optimise indoor astronaut clothing for the ISS. Their experiments identified Merino wool shirts and polyester shorts as the most promising garments to reduce odour and lint. The team are currently investigating options for Mars-bound astronauts and have put the call out for industry partners to work with them on developing these innovative textiles.[37] These findings could also be applied to clothing on Earth.

Case study: Keeping a tie on those loose fibres

Pilling and abrasion of fabrics are the result of fibres coming loose from the fabric and either entangling or coming off. Pilling and abrasion are a major consumer problem, but can also account for a proportion of microfibre pollution worldwide. Reducing the likelihood of losing fibres from a fabric has clear consumer and environmental benefits. However, it usually comes with degraded fabric feel and lower consumer comfort.

HeiQ Australia, HeiQ Materials AG and Deakin University have recently developed novel, low-impact treatments aimed at markedly increasing the lifetime of a garment, and at the same time limiting microfibre-related pollution.*

HeiQ No Fuzz uses novel polymer structures to reinforce the yarns within fabrics, preventing the loosening of fibres from the surface, the formation of unsightly pills, and the fall-out abrasion and wear effects. This is achieved with minimal impact on the comfort of the garment.

The technology has shown improved abrasion and pilling performance in synthetic, natural-fibre based and blend fabrics. Industrial-scale testing of the technology was undertaken by HeiQ Materials AG in its Headquarters in Zurich, Switzerland.

It is foreseen the product could make its way to Mars, enabling a more comfortable and less wasteful journey for the astronauts.

* www.deakin.edu.au/about-deakin/media-releases/articles/no-fuzz-new-deakin-treatment-does-away-with-fabric-pilling

Mars Missions

Clothing will have to be cleaned and maintained with careful management of resources – water, energy, raw materials – for a Mars mission (duration at least 2-3 years). For extended stays on Mars the manufacture and recyclability of clothing also needs to be considered.

Requirements for space wear garments for long duration missions include durability, cleanability, comfort, flame-resistance and aesthetics.[38] Alongside cotton, wool is being revisited for flame resistance and odour control, and synthetic fibres are also being looked at. Polyester has been used on the ISS in small quantities and under strict conditions due to flammability concerns. Astronauts currently use some polyester clothing for exercise and then stow them away in flame-retardant bags. Researchers have looked at high-tech new fabrics consisting of existing materials mixed with polyester microfibres. They have also looked at applying finishes to wool and modacrylic garments for odour control, cleanability and flame resistance.

The ambient atmosphere on the ISS means clothing has similar requirements as on Earth and cotton is the fibre of choice. However, the atmosphere on a deep space mission will likely have higher oxygen levels; up to 40% oxygen (by vol) at 10.2 psi. This is more reminiscent of the earlier Apollo (1963-1972) and Skylab (1973-1979) missions. Clothing for these missions was mostly made of fibres that do not ignite easily, or melt, such as glass, fluoropolymer, polybenimidazole (PBI) and Durette – a chemically treated flame-retardant aramid material. PBI has physical and mechanical properties suitable for replacing cotton, and is still manufactured and used in protective clothing (such as firefighter's gear) on Earth. PBI is being considered for future Orion missions.[38]

Case study: Protective clothing

Lightweight, comfortable clothing that also provides the wearer protection against the environment can be crucial in many applications. The development of such protective clothing requires careful consideration of the type of fibres to include, and how to best incorporate them for optimal performance in the target application. It also requires an understanding of the failure mechanism.

Deakin researchers, in conjunction with Australian jeans manufacturer Draggin Jeans, have developed denim jeans which incorporate Kevlar, the same material used in bullet-proof clothing.*

Developing a strong understanding of the effect of the Kevlar structure on its protective abilities, the researchers were then able to knit the Kevlar in such a way that the resultant jeans have shown superior resistance to abrasion, protecting the rider when they slide during an accident.

The jeans have recently received AAA rating against the CN EN 17092 standards – a level usually only achieved by traditional leather race suits, which have thermal, ergonomic and weight penalties. The jeans achieve this high rating while still looking like standard fashionable denim jeans, which are comfortable, breathable and lightweight.

A similar research philosophy could be applied to the development of protective clothing for astronauts in space, or living on Mars where protection against the harsh, rocky environment is vital.

*www.deakin.edu.au/research/research-news/articles/a-safer-ride2

Wearable Technology

Spacesuits/clothing and tools have changed very little since the 1960's, despite the huge advances in technology since that time. Astronauts still use laminated plastic checklists or notebooks taped to their wrist instead of other electronic technologies.[39] LCD screens and current electronics don't operate well in the cold of space, and the high density of the smaller electronic components makes them more susceptible to damage from cosmic rays. This is a major constraint to introducing advanced technologies to space clothing.

NASA has undertaken some work on integrating wearable technologies into crew clothing, primarily through their Wearable Electronics Application and Research (WEAR) Lab. They have faced similar difficulties with the radiation problem described above. However, they do recognise that a better, smarter, more high-tech uniform is needed to send humans to Mars.

Examples of some potential future wearable technologies include a uniform embedded with circuitry to power and manage an array of changeable electronic modules, and integrated textiles used to monitor the health of astronauts and the environment they are exposed to (e.g. radiation, O_2).

Case study: Textiles that make sense

Strain sensing textiles that can track a wearer's movements, without the need for bulky or invasive supports, is a step towards intelligent, multi-functional clothing.

Researchers at Deakin have engineered a knitted strain-sensing textile which relies on conductive elastic fibres that stretch and relax during movement.* As the resistance levels change, this information is sent to a computer using a wireless transmitter chip, where it can be recorded and analysed. These textiles can be worn directly, without the need for a supporting frame, substrate or other clothing item, giving them an advantage over previous technology in the field.

These textiles could one day find application monitoring the movement and health of astronauts as they move about in space or on Mars. On Earth, the textiles could monitor the performance of athletes and rehabilitation patients, enhancing exercise efficiency, preventing injury and improving rehabilitation.

*www.deakin.edu.au/about-deakin/media-releases/articles/deakin-researchers-create-strain-sensing-clothes-to-monitor-your-movements

Survival on Mars

Habitat

At the time of writing, there are virtually no confirmed plans available regarding establishing a colony on Mars. NASA do not currently have a timeline for landing on Mars, and certainly not for establishing a colony. However, they have undertaken some initial conceptual discussions and are in the process of holding a 3D printed habitat challenge designed to advance construction technology that can be used on the Moon, Mars or on Earth to create sustainable housing solutions.[40] SpaceX have an ambitious plan to establish a colony on Mars from 2024, however they have not made any detailed plans available.[41] Other external groups or people have prepared conceptual designs, and engaged in discussion regarding living on Mars.

It is known that housing enclosures need to be self-sustaining, sealed against the thin atmosphere and repairable. If they are above surface they have to deal with almost no oxygen, extremely cold conditions, low pressure and high radiation. Below-ground habitats, i.e. excavating a space, or using an existing lava tube, are one possibility to overcome some of these difficulties, however they also introduce new problems.

Habitats for short-term visits have smaller space requirements, and could potentially be transported aboard space shuttles. However, longer term or permanent habitats require much more space for inhabitants. This type of habitat is likely to be too large and heavy to be sent to Mars, and would need to be constructed making use of some local resources. This would also allow for on-site expansion of the colony.

The construction material needs to be carefully considered. Shipping materials from Earth has a very high cost. It's estimated that one brick would cost US$2 million.[42] Instead, bricks could be made from Martian soil, which could be further reinforced with polymers/fibres. Ice, sourced from Mars, is another possible building material. A habitat could also be covered with ice or soil to provide extra protection. It's been estimated that 5m of regolith would provide equivalent radiation protection as Earth's atmosphere.[43]

If the housing structure is pressurized to Earth's atmosphere, then the force of air on the inside walls needs to be considered. This has been estimated to be over 96 kPa for a pressurized habitat on the surface of Mars.[42] In comparison, manned aircraft, must withstand forces of 53-67 kPa when at altitude. The atmospheric pressure starts to be equivalent to the surface of Mars at an altitude of about 45 km above Earth.

Protection against Mars dust and possible microbial contamination (both ways) is also needed. Mars is covered with vast expanses of sand and dust and littered with rocks and boulders. It is known to occasionally have planet-wide dust storms, though they probably only move slowly. This very fine dust, some of which remains suspended in the atmosphere giving the sky its distinctive reddish colour, could be a health hazard as it contains fine-grained silicate materials which can be harmful if breathed in.[44] As these dust particles are very fine grained, and are suggested to potentially be sticky due to a significant static charge, they are expected to stick persistently to things, such as spacesuits, and thereby work their way into the living quarters.[44] This dust then presents a problem not only to the health of humans breathing it in, but can also clog up air filters, water purifiers and other critical instruments.

Case study: A breath of fresh air

Air can contain many small pollutants, particles, irritants and viruses which if inhaled can cause respiratory issues, or have a negative impact on any equipment operating in that environment.

A pilot electrospinning machine at Deakin University has produced a thin layer of electrospun nanofibres which can be incorporated into a haze mask, or an air filter.* The nanofibre layer allows effective capture of tiny oil and solid particles from the air stream. It also has some ability to absorb small molecular odours.

The ability to provide more effective filtering of the air will allow people to breathe more easily and equipment to operate more efficiently on Mars and on Earth.

* www.deakin.edu.au/research/research-news/articles/researchers-put-a-new-spin-on-nanofibre

Food & Water

Food on Space Flight

It is theoretically possible to take enough food supplies to last for the duration of a round-trip mission to Mars. However, for a 3 year, 4 person round trip this has been estimated to equate to ~10,900 kg of food.[45] Given the high cost of launching supplies into space this amount of food has been estimated to cost $300 million, becoming economically challenging. Thus alternative options of producing some food during the mission become necessary. One suggestion is to use a self-contained system which uses plants to provide food and also to produce oxygen, remove CO_2, and possibly purify water.[46] Suitable plants would need to produce little waste, be hardy and compact, easy to grow, and ideally multi-functional. NASA have identified 10 candidate crops: lettuce, spinach, carrots, tomatoes, green onions, radishes, capsicum, strawberries, herbs and cabbage. In 2015 NASA astronauts on board the ISS ate lettuce grown in space using the Veggie plant growth system, which consists of small "pillows" containing seeds, soil and fertilizers which are activated by crew members when ready to grow.[47,48]

Food for Mars Colony

For the establishment of a colony, sustainable food supplies need to be developed and maintained on Mars. Mars has a thin atmosphere and reduced sunlight; the ability to grow plants under these conditions is not yet fully understood. However, scientists have previously researched growing plants on the Moon and found that they can grow in regolith (layer of unconsolidated solid material on extra-terrestrial bodies), as long as they have air, water, light and fertilizer. Mars is covered with vast expanses of regolith littered with rocks and boulders. The soil is known to contain minerals, but not the organic material required for plant growth. It also contains toxic chemicals such as perchlorates.[44] These would have to be removed before plants could be grown. Mars has a CO_2 rich atmosphere which could be of benefit to the growth of plants.

The use of fibres to reinforce soil, similar to the effect of vegetation roots on Earth could be one method to enhance the stability of Mars soil.[49] Previous research has suggested that synthetic fibres have an advantage over natural fibres in that they can be produced with the required size and properties, and they don't usually degrade. There has already been some research conducted in this area using fibres to reinforce soil under construction projects.[50]

Consideration needs to be given to what plants could/should be grown on Mars. As well as providing food, plants can be an important source of fibres and other materials needed for human habitation of Mars.

There are many other possible areas of research in growing plants on Mars, including:

- The use of polymers or fibres to assist with providing water and nutrients to growing vegetation.
- The possibility of using plants to provide oxygen within the habitats. Also, if it is possible to grow plants at a reduced air pressure then this would help to ease requirements for high pressure buildings.
- A process to make fertilizer from waste (human, organic from plants etc).
- The possibility of making edible fibres for humans either on a voyage, or on Mars.
- Growing food/fibre dual-purpose plants. A Martian fibre variety may have unique properties that are also useful on Earth.

Water

In late 2017 scientists found layers of water ice buried just 1-2 m below the surface of Mars.[51] Previous research had found a buried ice sheet that holds about as much water as Lake Superior (12,000 km^3), but this new discovery has investigated eight different sites and found deposits of water ice that could be >100m thick. This finding is very significant for future missions to Mars. Water could be extracted by either baking it out of hydrated minerals, or mining it from ice deposits. It could then be drunk, or broken down to hydrogen and oxygen to use for fuel or breathable air. If it is to be drinkable it will need to be purified – possibly using a membrane filtration system. A purification system would also be needed to enable recycling of water within the habitat. As with all infrastructure on Mars this system would need to be easily maintained and able to be repaired or replaced using materials already present.

Waste Management/Sustainability

Waste materials will need to be reused, recycled or adequately disposed of. This is particularly true for a colony on Mars where resources will be extremely valuable and therefore a closed-loop system would need to apply. For example:

- Air inside the habitat areas would need to be scrubbed to remove CO_2.
- Water would need to be purified and re-used.
- Organic waste/human waste would need to be treated and re-used, i.e. for fertilizer.
- Clothing would need to be recyclable.
- All other materials would need to be reusable or recyclable.

Therefore, a key factor when designing systems for Mars is considering the end-of-life of a product and how it can be repurposed. Can the product be easily broken down into component materials? Can these materials then be isolated and used to produce new products? How long can this cycle be maintained (i.e. can an item of clothing be recycled 5 times or 500 times before it is no longer viable). For example, carbon fibre is a key component in space infrastructure due to its light weight and strength, however it is currently difficult to recycle carbon fibre.

A further consideration is the potential use of waste products. For example, can waste plant matter be turned into fibres and then used in clothing, habitats, healthcare.

Case study: Recycling textiles

Using your old pair of jeans to help make your new pair could be possible in the future. An innovative textile recycling project being undertaken at Deakin has developed technology to pulverise your old pair of jeans, and use this powder to provide colour to your new jeans.* Given that on average, the life cycle of a pair of denim jeans produces more than 30 kg of CO_2, uses around 3,500 litres of water, and the jeans are usually dumped in landfill at the end of their life, this new technology could have significant environmental impact.

Deakin researchers have also developed a method to dissolve denim, and manipulate the remains into an aerogel – a low density material with a range of uses including water filtration, artificial cartilage, and as a separator in advanced battery technology.‡

Recycling technologies such as these will have an important impact on sustainability of resources, both on Mars and Earth.

*www.deakin.edu.au/about-deakin/media-releases/articles/denim-goes-green-thanks-to-deakin-innovation

‡www.deakin.edu.au/about-deakin/media-releases/articles/deakin-researchers-discover-how-to-transform-jeans-into-joints

Advanced Manufacturing

Technology is required to enable recycling of materials and also to manufacture new products on Mars. There is limited payload available to take multiple pieces of equipment into space, therefore versatile technologies are needed. Colonists on Mars will need to be able to manufacture replacement parts for equipment, and also manufacture new parts to grow the colony. This includes manufacture of small parts such as screws and pins, and also larger parts such as casings and panels.

3D printing is one possibility which is beginning to demonstrate widespread application with many substrates, and in the printing of a variety of customisable shapes and designs. Objects can be printed out of numerous materials including metal, plastics, and even biomaterials and cells. The latter would be required to enable colonists to treat any medical conditions that arise.

Case study: Printing new body parts

Advanced manufacturing techniques such as 3D printing could one day be used to produce bio-scaffolds for regenerating tissue, print prosthetic body parts, or even use bio-inks to fabricate living tissue or human organs.

Hydrogel scaffolds are great candidates for soft tissue regeneration as they mimic the extracellular matrix, however they often have poor mechanical properties, limiting their use. Researchers at Deakin have made a leap forward in the 3D printing of hydrogels, overcoming the poor mechanical properties through the incorporation of silk particles for reinforcement. The reinforced hydrogel scaffolds not only demonstrate greatly improved mechanical properties, but they also have good cell adhesion and growth, and no cytotoxicity.

Advanced manufacturing technologies will assist astronauts to undertake medical procedures as required. The ability of 3D printing to customise body parts or medical treatments offers great flexibility which could one day be exploited in space and on Earth.

Other Research Areas

As well as the areas outlined above, there are several other areas where fibre technology and innovation can play a key role. These include:

- Energy generating/storage textiles – there is a need for sustainable energy sources on Mars. One possibility is thermoelectric fibres/materials which take advantage of the large temperature difference between day and night. Energy also needs to be stored.
- Healthcare – bandages, sterilisation, anti-microbial materials. These also need to be able to be sterilised and recycled.
- Making optical fibres from raw materials on Mars for communication.

Case study: Energy storing fibres

Energy-storing fibres could one day be used to turn our clothes into chargers for electronic devices. Fibres created by researchers at Deakin represent a new class of fibre supercapacitors, with the potential for creating flexible power sources for electronic gadgets and wearable technologies. These fibres are made by combining sheets of MXene – a nanoscopic material made of carbon and titanium – with a small amount of graphene, resulting in a knittable fibre with "amazing energy properties". These high-tech fibres can be knitted into a fabric, offering a wearable alternative to bulky batteries and portable chargers.

Novel, high-tech materials such as these could one day be used to enable comfortable, flexible health and environmental monitoring for astronauts, or on Earth.

Benefits on Earth

The problems outlined in this document, as well as the potential for fibre solutions, are not only applicable to a space mission to Mars. There is no doubt that many of the technologies that will be developed to solve key issues in sending humans to Mars will also prove immensely, and immediately, beneficial for everyday issues on Earth.

Lightweight materials

Lightweight materials with high structural integrity are not only needed for a spaceship, but also for Earth transport options and civil structures. Light-weighting has become increasingly important in vehicles to enable better fuel efficiency. Carbon fibre is one material used for light-weighting vehicles, alongside application in numerous other fields. Research is being undertaken to develop carbon fibre with different performance specifications and reduced cost, alongside technologies to process carbon fibre into the final product. Developing methods to reuse or recycle carbon fibre materials is also necessary, and would be of great interest to businesses working in the field, such as Carbon Revolution – manufacturer of one-piece carbon fibre wheels,[52] and Quickstep Technologies – manufacturer of carbon fibre parts.[53]

Case study: Self-healing materials

Next generation composite materials that are able to heal themselves when damaged would improve the safety and reliability of structures, as well as reducing maintenance costs and increasing their lifetime. These materials are able to automatically repair or reverse damage or degradation, and restore mechanical properties, without external intervention.

Research is being undertaken to develop new carbon fibre composite materials with controlled structures that are able to automatically detect, and then self-heal, damage.

These materials would be of great benefit in space craft where it would otherwise be difficult to detect and repair damage, and would also overcome durability issues associated with the use of carbon fibre composites on Earth.

Clothing

The development of clothing which needs reduced laundering, and provides sufficient protection against the space and Mars environment could also lead to the development of novel textiles to be used on Earth. Researching alternative textile materials, including possible new fibre sources which can be easily grown or utilised on Mars (i.e. fibres from waste organic materials) could lead to exciting innovations which would be of interest to companies such as HeiQ – an innovative textile company,[54] and Draggin Jeans, producer of protective clothing.[55] Additionally, developing textile technologies that can provide additional functionality, as required for space missions, would also be of benefit to the textile industry.

Case study: Like water off a duck's back

Having water repellent textiles is one of the major ways to keep clean and dry in extreme environments. While fluorine technologies have been reigning king, this chemistry is not sustainable and is quickly being phased out of all markets. Losing fluorine chemistry, though, is proving tough for market leaders, as alternative chemistries are usually not as effective.

HeiQ Australia, HeiQ Materials AG and Deakin University have recently developed novel, breathable, water repellent treatments aimed at markedly increasing the water repellence of a garment, also improving its washability.

HeiQ ECO-Dry uses 3D technology on the surface of the fabric, providing a reinforced water repellent coating which minimises contact with liquid droplets falling on the fabric. The same technology could help enhance soil removal from the fabric, minimising water consumption, as the drops rolling off the fabric may gather dust particles and other dirt.

Industrial-scale testing of the technology is about to start, care of HeiQ Materials in its Headquarters in Zurich, Switzerland.

It is foreseen the product will make its way to Mars soon, enabling a cleaner and less wasteful journey for the astronauts.

Quotes courtesy of HeiQ Materials AG

Recyclability and sustainability

A closed loop system is extremely important on Mars and increasingly important on Earth where population growth and consumer demand is placing pressure on resources. Methods to improve the sustainability of fibre materials, and consideration of recyclability and next-use application of these materials, will be of enormous benefit to Earth. For example, Australian's currently dispose of 600 kg of textile waste every minute, or 315 million kg per year.[56] The environmental impact of this waste is starting to be brought into the public spotlight. Additionally, the resources required to make garments are also coming under scrutiny: a single t-shirt can take 2,700 litres of water to make, and a significant amount of energy to grow, manufacture, transport and clean.[57] Research into developing technologies to address sustainability requirements for Mars would be directly relevant to Earth. Solutions would allow for a reduction in resource use and waste, and improve sustainability of the industry.

Wearable technology

While wearable technology is important for monitoring astronaut health and their environmental conditions, it is also important, and in increasing demand, for monitoring the health of everyday humans. On Earth there are also many situations where the use of wearable technology to monitor the environment would be extremely useful. Clothing which monitors the health of the wearer could enable earlier diagnosis of medical conditions and provide real-time on-going monitoring of known health conditions. Wearables which can monitor the environment would be of great benefit to workers in potentially dangerous environments such as miners and chemical industry workers. Also, clothing which can store or generate energy are of interest to not only reduce reliance on other energy systems, but also allow people improved use of their electronic devices, or providing energy for biomedical interventions.

Advanced manufacture

The ability to manufacture materials and parts locally, and on demand will also be increasingly important on Earth. The reduced environmental impact of shipping spare parts and significantly reduced down/lag time by industry, are key factors for the refinement of 3D printing or other advanced manufacturing technologies and would have a significant impact for manufacturing companies. Additionally, the development and refinement of on-demand manufacturing techniques suitable for Mars habitation could also revolutionise the way people live on Earth by offering the ability to print items in the house, or in the local neighbourhood. It can also allow for easier customisation of parts (i.e. 3D print glasses to fit a specific person). In fact, additive manufacturing is already leading to a change in manufacturing processes with Airbus announcing in 2015 that it had 3D printed more than 1000 parts for the A350 XWB jet.[58] This adoption of advanced manufacturing technologies is likely to increase, and research in this field will assist industries in adapting their processes.

It is also likely that 3D printing of biomedical interventions will be needed on Mars, in order to enable the colonists to treat medical conditions that may arise. Companies such as the Ear Science Institute of Australia would also benefit from the development of this technology, as would patients on Earth who could receive customisable printed treatments rapidly.

Food and water

Food and water resources are becoming increasingly stretched on Earth. The world's population is predicted to grow from 7.6 billion people in 2018 to 9.7 billion by 2050.[59] Food demand is predicted to increase by 70% by 2050.[60] A suite of solutions is likely needed to address this challenge. Techniques developed to grow food on Mars could be adapted to grow food on traditionally non-arable land on Earth (i.e. deserts), significantly increasing the usable food production areas. Methods to increase recyclability of water would also ease pressure on our water resources.

Capabilities and Gaps

Worldwide, there has been a surge of new initiatives supporting advanced fibre and textile materials research. Some of the major initiatives are outlined below. While these initiatives are not necessarily focused on future space missions, there are obvious spin-off benefits to the space missions.

AFFOA

Advanced Functional Fabrics of America (AFFOA)[61] is a non-profit public/private partnership, headquartered in Cambridge, Massachusetts. It is the 6th US Department of Defence manufacturing innovation institute and a member of the Manufacturing USA network. In 2016, the Pentagon awarded $75 million for the creation of the institute organized by the Massachusetts Institute of Technology to develop high-tech fibres and textiles. The Revolutionary Fibers and Textiles Manufacturing Innovation Institute is based in Cambridge, Massachusetts, and brings together a consortium of 89 universities, manufacturers and non-profits. In addition to the $75 million, the institute will be funded with nearly $250 million from non-federal sources. By bringing together high-tech firms and textile makers, the institute aims to create fabrics that can "see, hear, sense, communicate, store energy, regulate temperature, monitor health, change color, and more".

AFFRIC

Australian Future Fibres Research and Innovation Centre (AFFRIC)[62] is a major $103 million infrastructure initiative, led by Deakin University and CSIRO and supported by the Australian Federal and Victorian State governments. AFFRIC is based at Deakin University's Waurn Ponds campus in Geelong. An essential facility supported under the AFFRIC initiative is the $34 million Carbon Nexus facility that supports advanced carbon fibre and composites research in Australia. Through the AFFRIC initiative, CSIRO fibre and textile research team and laboratories relocated to Deakin University Waurn Ponds campus. CSIRO and Deakin have also jointly invested in fibre and textile processing facilities, including a state-of-the-art wet spinning/air gap spinning line for making precursor filaments for the carbon fibre line at Carbon Nexus.

ARC Research Hub for Future Fibres

The Australian Research Council (ARC) funded Research Hub for Future Fibres[63] is a $13.2 million initiative which strives to accelerate the transformation of the Australian manufacturing industry to a vibrant, future fibre-oriented sector through collaborative projects with highly innovative small and medium enterprises. Led by Deakin University the Hub brings together two Australian universities and five industry partners: textile innovator HeiQ, carbon fibre companies Carbon Revolution and Quickstep Technologies, protective apparel manufacturer Draggin Jeans, and the not-for-profit Ear Science Institute of Australia. The Hub also draws on expertise from CSIRO and six international institutions to conduct research across three programs: Short fibres and nanofibres, Carbon fibre composites, and High value-added applications.

ETP Fibres Textiles Clothing

The European Technology Platform (ETP) for the Future of Textiles and Clothing[64] is the largest European network of professionals involved in textile and clothing related research and innovation. Its main objectives are to promote collaborative research across national borders, and a rapid translation of results into industry. It currently has about 175 member organisations from industry, research and higher education. They have developed a common strategic industry vision and identified four innovation themes for the next ten years: 1) Smart, high performance materials, 2) Advanced digitised manufacturing, 3) Circular economy and resource efficiency, and 4) High-value added solutions for attractive growth markets.

Conclusion

Humanity is on the cusp of an exciting new wave of space exploration. The goal to send humans to Mars, and potentially establish a colony, is just the first step in what is likely to be an ongoing expansion into space. The technical challenges which need to be overcome in order to successfully send humans to Mars, and to establish a colony there, are immense. The role that fibres play in such a mission is extremely diverse. From natural fibres to synthetic composite materials, fibres are an integral part of spacecraft, astronaut clothing, support systems, habitats, and food/water for survival.

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