Innovative Technologies from Science Fiction (ITSF) - Executive summary

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Introduction

Any space exploration endeavour that one can think of started just as an idea in someone's mind – and very often a very unusual one. And that is also what Science Fiction is about. In SF imaginative ideas are used to enable the story progress or to put the characters in a given situation that could not take place without it. Creative concepts are therefore used as an enabling tool in SF, in a similar way as innovative technology concepts are often needed to accomplish increasingly ambitious objectives in the exploration of the universe.

Science Fiction prepares us to accept new ways of using technologies. In addition it gives us the urge and the motivation to master them. There probably wouldn't be a space program without Science Fiction as the genre made several generations dream about space flights and moon landings and prepared the public to spend millions on these achievements.

These are among the reasons that make an assessment of the concepts described in SF literature worthwhile. In consequence, the Innovative Technologies from Science Fiction (ITSF) ESA study was initiated with the following objectives:

- To review the past and present Science Fiction literature, artwork and films in order to identify and assess innovative technologies and concepts described therein which could be possibly developed further for space applications.
- To obtain imaginative ideas, potentially viable for long-term development by the European space sector, which could predict the course of future space technologies and their impact.

The vast variety of the topics and the breadth of some of them make it necessary to proceed stepwise on this study. This document intends to be a first analysis of the outcome of the survey and it points out some areas that could be interesting to investigate in more detail.

Preliminary Results

Both the ITSF Factsheets and Technology Dossiers have been subject to an initial assessment. The Factsheets are grouped in a number of categories and include a brief description of the concepts discussed in the dossiers. Some of these concepts and technologies require a more specific discussion due to their potential interest, and they are discussed below.

1. Terraforming

Rationale

Terraforming -in particular Mars terraforming- is not a new concept. The term "terraforming" itself was first coined by the SF writer Jack Williamson in his story "Seetee Ship" (1951) and can be defined as the process by which a planetary environment is altered in order to make it more suitable for life. Other early appearances of the concept in SF literature where in Edgar Rice Burroghs novels (starting with "A Princess of Mars" in 1917) that portrayed an arid Mars made habitable by an "atmosphere factory".

Over the last years it has become clear that mankind has developed a remarkable capability to affect and modify the global environmental conditions on our planet. Unfortunately, this potential has not been used in a positive way until now. One of the ways to put this power to a better use would be to improve the habitability of another planet, and Mars is probably the best target that is available.

The ecological, scientific, economical and even socio-political consequences of the successful terraforming of Mars would be of an enormous magnitude. Also important would be the ethical considerations and the planetary protection aspects to take into account. But the technological challenges and the required investment would also be huge.

Therefore, at this stage it is interesting –and feasible- to assess the viability of small-scale demonstrations and their potential spin-offs e.g. deployment of large structures in space, Closed Ecological Life Support Systems (CELSS), In Situ Resource Utilisation (ISRU), etc. In the future some of these technologies could also turn out to be useful even to contribute correcting the damage we have already caused to the Earth's biosphere.

Technology

The proposed concepts for an initial Mars human settlement in SF literature include:

- Use of Martian regolith to protect human settlements against the effects of radiation.
- Set up of a Mars orbital supporting infrastructure fulfilling some of the needs of the settlers (in particular solar space power production and wireless power transmission from orbit to ground assets)
- Deployment of mirrors ("solettas") in areostationary orbit in order to increase the temperature of selected regions and to extend the duration of the day.
- Construction of a space elevator (dubbed "Skyhook") anchored on an asteroid in areostationary orbit.

This stage would be followed (in some cases almost immediately, in others in a more distant future) by the actual terraforming process, which would involve, always according to SF narrative:

- Utilisation of genetically engineered algae and bacteria for oxygen production and soil fertilisation
- Utilisation of self-replicating machines (for distribution of the algae and bacteria in the suitable conditions)
- Reduction of Mars albedo by distribution of dark organic matter over the surface.
- Cometary bombardment (maybe somehow changing the orbit of the comets in the Oort cloud) to increase the content of water vapour in Martian atmosphere and enhance the greenhouse effect.

These scenarios suggest some areas for further studies and development:

- In Situ Resource Prospection & Utilisation
- In Situ Manufacturing
- Solar Space Power
- Large Space Structures
- Nanotechnology
- Materials
- Robotics and Automation
- Genetical Engineering

2. Space Elevators

Rationale

A "space elevator" would consist of a structure extending from the surface of the Earth to at least Geostationary Earth Orbit. Its centre of mass should be at GEO so that the entire structure orbited the Earth in synchrony with the Earth's rotation, maintaining a stationary position over its base attachment at the equator. Russian engineer Yuri Artsutanov first raised the idea of the space elevator in 1960. The concept was further investigated by other authors in the following years [Isaacs, 1966; Pearson, 1975] but went largely unnoticed until 1979, when Arthur C. Clarke used it as the centrepiece for his novel The Fountains of Paradise.

Such a structure would be used as a mass transportation system between Earth and space. Once in place, it would allow cheap access to space, as the cost of putting payloads into orbit could be of a few Euro per kg, compared with tens of kEuro per kg on a conventional chemical rocket. This reduction together with not so stringent physical fitness requirements for the people travelling to space would also make space tourism economically viable.

Two independent teams -one at NASA/Marshall's Advanced Projects Office and the other at Eureka Scientific, with NASA's Institute for Advanced Concepts funds- have carried out preliminary studies on the elevator's technological requirements. Though their initial assumptions and approaches are very different, both studies have concluded that this structure could be feasible provided that certain technologies become available, as it will be discussed below.

Nevertheless, the most solid reason to start some short and medium-term development –maybe with experimental demonstration of some of the required technologies- would be the potential spin-offs in material science, tether technology, robotics, in-situ resource utilisation and Near Earth Object characterisation.

Technology

In order to accomplish such an ambitious feat, many innovative technologies would be required, and multiple strategies can be considered in order to carry out its practical implementation. Both aspects could be the target of follow-on system studies and, in some cases, ground testing, prototyping and short-term demonstration flights. This can be illustrated with some specific examples.

Some of the most demanding requirements are placed on the material used to make the tether. For the cable to have practical dimensions, NASA's estimates suggest that the material should have a tensile strength of at least 62.5 gigapascals, 30 times stronger than steel and 17 times stronger than kevlar. The only material that could meet this requirement would be the carbon nanotubes, which are microscopic hollow cylinders made from sheets of hexagonally arranged carbon atoms. They exceed the tensile strength of steel by at least a factor of 100. Even conservative estimates place their strength at 130 gigapascals, which exceeds the required limit by a wide margin. One of the problems, though, is that they are extremely expensive (about 600 Euro per gram). On the other hand, at present even the best synthesis methods yields tubes no longer than a few micrometres, while the estimated length that the nanotubes would need to form a viable composite material is about 4 millimetres. This is, therefore, one of the aspects that should be tackled for the elevator to become a reality.

Some ground research and testing on this material are envisioned as part of the NIAC's phase II study, particularly on its resistance to space environment conditions. Actually the deterioration of the cable once it is in place could be the main showstopper. Testing on radiation, atomic oxygen and hypervelocity impact endurance of the material could be justified as this material will find much other space applications even if the space elevator never becomes a reality. However, the main issue would still be making the carbon nanotubes manufacturing process cheaper and more efficient.

Once the enabling materials are readily available, the construction strategy can be considered. Many SF authors propose similar approaches to initiate the fabrication of the tether: an asteroid is placed in geostationary orbit (or areostationary orbit if about Mars), where the centre of mass would be. Autonomous robots - maybe even self-replicating machines in the most optimistic versions- would then automatically manufacture the structure of the tether using the materials extracted from the asteroid. The cable would then be deployed to its full extension, eventually being attached to the top of a tower situated on the Earth's equator.

This strategy however implies the non-trivial problem of having to move a huge mass "all at once", including materials that might not be used at all. The advantage is that the processing of the raw materials would take place in a much more accessible orbit, comparably simpler to reach –at least with the technology that is currently available - than that of a NEO; and indeed, much more accessible than the main belt asteroid objects.

An alternative approach could also be suggested. This would consist in the in-situ processing of carbonaceous asteroids, which could be used to manufacture separate tether segments also by means autonomous robotic devices. These already processed segments could be towed separately, avoiding wasting energy in the rest of the materials that would not be used.

Segmentation could even be carried out in a way such that the generated filaments where joined to form the supporting structure of a solar sail. This structure could then be covered with a reflective foil carried "ad-hoc" to the asteroid vicinity, or maybe manufactured in-situ if the required materials were available. However, this approach might not be feasible -among other reasons- because such a structure would probably be too heavy to be used in an effective solar sail, and also because different segments might have to be manufactured in different asteroids far away from one another.

Finally, the approach used in the NIAC study by the Eureka Scientific does not assume that a large mass will be needed to make the centre of mass be at GEO. Instead, it proposes to double the length of the cable so that it extends out for 72000 km. It also tackles many of the problems in a different way (e.g. it does not use electromagnetic propelled vehicles, the cable would be attached to a floating platform rather than to a fixed structure (e.g. a tower) on solid ground.

In conclusion, the space elevator is a daring but interesting concept that demands some further definition, as there are several alternative approaches that could be assessed in more detailed studies. Some preliminary experimentation and development could be started in the short term, as this effort would already be justified by the benefits derived from the spin-offs on some key technology areas.

3. High Isp Propulsion Systems

Rationale

Power production and its utilisation to produce propulsive thrust seems to be pivotal to SF, in the same way as it is for real exploration of space. Some of the proposed concepts, particularly Nuclear Fusion Power Systems, are also seriously considered world-wide for their potential benefits. There are obvious reasons why the ongoing research efforts will be continued: Some countries with the required technological capability but having limited natural resources -e.g. Japan- will always invest a significant amount of money in studying the feasibility of these type of power sources. Europe has also identified this as a research priority area, funding activities such as the Joint European Torus (JET) and pursuing the construction of an International Thermonuclear Experimental Reactor (ITER). A budget of 700 Me has been proposed for Thermonuclear Fusion research during the 2002-2006 period as part of the Euratom programme. To some extent this makes the mid-term development of these technologies more probable.

Fusion power space systems are unlikely to be possible if the research on ground systems does not succeed first. However, the technology requirements for the applicability of nuclear fusion to propulsion systems are not the same. The research efforts on this field are currently much more modest, though its potential – with theoretical Isp's of more than 100000 s, that would enable routine human travel across the Solar System- is still immense. Some of this also applies to propulsion systems based on matter–antimatter annihilation, or to combined systems. It is therefore worthwhile to investigate the feasibility of such concepts.

Technology

A large number of the propulsion systems described in SF literature are actually based in well-know phenomena that ordinarily takes place in nature e.g. nuclear fusion and matter–antimatter pair production and annihilation. These processes are however difficult to reproduce –at least in a controlled fashion- with our current technology. Up to now, in spite of ongoing efforts self-maintained (i.e. without external power supply) controlled nuclear fusion reactions have never been attained. Antimatter can also be generated in very small quantities, but normally at an energetic cost of more than 2000 times the energy produced in the annihilation reaction.
Currently both the magnetic confinement fusion (MCF) and inertial confinement fusion (ICF) concepts tend to be very heavy and large. They also present a high complexity in issues such as power conditioning, materials, radiation shielding, EMC, thermal design, etc
Alternative concepts have also been proposed to tackle some of these problems, including Fusion/ Antimatter hybrid systems and Magnetically Insulated inertial Confinement Fusion (MICF). It has been

suggested that small quantities of antimatter could be used to initiate or enhance nuclear fusion reactions. One of the concepts that is suggested in SF ("The Nightdawn trilogy", by Peter F. Hamilton) is that of an orbiting anti-matter generation facility. Though in this story solar power is used, other power sources can be suggested (harnessing the energy of the Galactic Cosmic Rays...?). The space environment might also facilitate the storage of the produced antiparticles.

Even these proposed solutions will probably encompass new engineering feats, sometimes more complex than the problems they intend to sort out. Therefore it would be good to assess their technical feasibility and their potential benefits in further studies.

Conclusions

The results of the study are promising. Some of the concepts that are genuinely related to space exploration and could be worth looking into in more detail include:

- Mars terraforming enabling techniques, such as:
  - In Situ Manufacturing
  - Solar Space Power
  - Deployment Large Space Structures, esp, Mirrors and Shades
  - Bio-machines (towards self-replicating machines)

- Space elevator precursor techniques
  - New Materials (esp. Carbon Nanotubes) Space Environment Testing
  - On-Orbit Manufacturing
  - NEO Characterisation

- Advance Propulsion systems based on:
  - Nuclear Fusion
  - Matter-Antimatter Annihilation. Antimatter on-orbit production
  - Hybrid Systems/ Pulsed mode systems

It should be noted that some of the technological areas of interest for the future are common e.g. ISRU and in-situ production, space power and wireless power transmission systems, deployment of large space structures, highly autonomous devices, high Isp propulsion systems, etc.

There are also some technologies that are mentioned in this study that (at least to some extent) are already being looked into by the Agency, in most of the cases through GSP studies, including:

- Study of the authenticity and feasibility of Gravity Control Techniques
- Technological applications of the Casimir Effect
- Micro Magnetosphere Plasma Propulsion (M2P2)
- Nanoarrays applied to Biosensor Instrumentation

Finally, some of the proposed technologies, not being specifically space-related, are already being investigated somewhere else. Most of these are already quite well defined from the scientific point of view, and the main problem consist in carrying out (often expensive) experimental work that eventually could make some of them technically feasible:

- Power Sources based on Nuclear Fusion and Matter-Antimatter Pair Production and Annihilation
- Quantum Entanglement applications to Computing, Cryptography
- Nanotechnology esp. Biomolecular Engineering,

ITSF is indeed an interesting initiative with additional benefits such as its contribution to involving organisations and entities a priori not related to space technology in space exploration studies and activities.

Bibiography / Additional reading

Terraforming

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- *Making Mars Habitable,* C P McKay, O B Toon, J F Kastings, *Nature*, Volume 352, 8 Aug 1991
- A good selection of references of academic papers on terraforming can be found at http://spot.colorado.edu/~marscase/cfm/terrabib.html#A3

Space Elevator

- *The fountains of Paradise.* A C Clarke, Harcourt Brace Jovanovich,1979. ISBN: 0151327734
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- *The Space Elevator.* NIAC Phase I study final report. The PDF file can be found at: http://www.niac.usra.edu/studies/

Nuclear Fusion and Antimatter power / propulsion systems

- *The Nights Dawn series.* P F Hamilton. Including the titles "*The Reality Dysfunction*"(1997); *"The Nutronium Alchemist*"(1997); "*The Naked God*" (1999) "*The Confederation Handbook*" (2000); "*A Second Chance At Eden*" (1998)
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Study details

Study contractors

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David Raitt, Technology Harmonisation and Strategy Division

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