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Innovations from Space Having A Real impact on Earth

A Benefits and Limitations Analysis Perspective

APS 1012

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Executive Summary

NASA's aerospace research has created feasible benefits back to Earth in the form of commercial products and services in the fields of medicine, environmental and energy resources, transportation, computer technology and consumer goods. The benefits have spread throughout the economy and around the globe. However, the research shows that although benefits are notable, the benefits could have been larger if NASA had undertaken a more holistic approach to managing its diverse programs and projects. The objective of this report is to analyse the role NASA plays in innovation, examine how space exploration impacts our daily life, and identify solutions on how NASA should change to make their innovations more valuable. This is accomplished through review of the many innovations which were developed for space exploration projects, and their effect on our life on Earth. The transfer of developed technologies for public benefit in various areas was analysed. Benefits and limitations were identified, lessons learned synthesized and proper recommendations made. The following are the key findings.

Institutional Role of NASA in Innovation

NASA as a US national institution is in a special role in its ability to influence innovation. As the organization tasked with the responsibility for advancing aerospace science, it is intimately involved with many of the technological developments necessary to further travel into space. In addition, it is able to affect how we travel in our own airspace on earth more effectively, in economic, technological, and environmental terms. The advancements of these technological innovations implies the US and the world will benefit advantageously in the realm of social, political, military, and economic domains as a result of its development in science, technology, engineering, and mathematical technical disciplines, through which NASA is assisting to improve in. To facilitate these technological advances, NASA runs several funding programs targeted to outside organizations for scientific advancements beyond NASA's core competencies, with an office established to manage technology development with small businesses. All improvements done under NASA's funding agreements must be reported to NASA, some of which may find its way into NASA's patent portfolio easily searchable and accessible online through its Technology Transfer Portal. NASA aims to encourage innovation, and enable it to further carry out its mission and vision as stated in its strategic plan of 2014.

Medicine and Healthcare

NASA's innovations in space exploration have greatly changed the medical industry as we know it. NASA research developed robotic and teleoperator technology which led to the voice controlled wheelchair, allowing quadriplegics freedom they never had before. NASA research at its Jet Propulsion Laboratory developed the cool laser, which opened the door to laser angioplasty, a procedure which clears human arteries of dangerous plaque in a less invasive ways than other methods. Finally, NASA research on the Hubble Telescope created the charged coupled device which led to increased clarity in breast imaging, ultimately leading to stereotactic breast biopsies, which allow doctors to test for breast cancer with increased efficiency and reduced cost.

Environment in Energy

NASA's programs have cultivated numerous inventions and partnerships were formed to transfer developed technologies for public benefit in the Environmental and Energy sector. In the environmental sector, the collaboration between NASA and Google resulted in the Google Earth Engine, a project designed to use the Landsat Earth observation database to facilitate global change monitoring. In the energy sector, the dividends are brought by the Redox flow battery technology initially developed during the Apollo project. NASA's partnership with Deeya Energy developed the initial Redox flow battery into a hybrid flow battery technology that delivers higher charge efficiency than standard rechargeable batteries. The research identifies that to a large extent NASA's research and development in this field is revolutionary, developing innovative technologies. However, the complex regulations, intellectual property challenges, inadequate funding, inconsistencies in the technology transfer programs and lack of collaboration with private sector often reduce the successful launching and implementation of technology into the commercial sector, resulting in less than optimal benefits. There is a shift change from the approach that operations have been managed a few years ago to the approach that they must be operated today. The challenges today pertain not only to the technology and its management, but also to human-centric factors such as communication, processes and planning, and cultural aspects as well. The question then arises as to whether the agency has the ability to operate in a new environment that requires ongoing change? Given the importance of innovation, NASA shall be oriented toward being an organization that promotes a tomorrow that is tuned to the future, an external environment that addresses the needs of all stakeholders and a culture of innovation that encourages individuals who initiate change.

Transportation

NASA's Space Shuttle program originally developed to transport astronauts and science experiment payloads to the International Space Station (ISS) has also brought about benefits to transportation on Earth. Collaborative efforts with The Boeing Company lead to the introduction of the Boeing 777 aircraft, a wide body twin-engine aircraft designed entirely using a computer. NASA's applied research facilities also contributed to the success of the Boeing 777, however Boeing reimbursed NASA for the use of these facilities, and therefore this contribution is treated more like a supplier than a partner. Greater technological advances in airplane design and travel can be accomplished if NASA is more open-minded to working with other space agencies. Space Act Agreements allowed NASCAR racers access to materials used to shield the Shuttle during its re-entry. These materials now shield the drivers from intense heat and make racing far less dangerous. However these agreements are difficult to enter into due to IP and US government legislature, in addition private sector companies require their own financial backing to enter into these agreements making it only available to the elite. Greater progress can be made if NASA takes the role of an agent and negotiator to develop partnerships between private sector companies and government agencies in order to help these companies overcome financing difficulties.

Computer Technologies

Throughout NASA's developments, the agency created numerous technologies for its internal use. One such technology is a power converter to be used in harsh environments; this technology is created in conjunction with a small company call VPT and can operate in the harsh environments of space. It has since been adapted for use in harsh environments on earth. However, one drawback is that VPT is a relatively small company and is the only collaborator with NASA regarding this technology. If VPT experiences any setback, then the means to manufacture the power converter is lost. In NASA's telescopes, advanced image processing software were developed to properly analysis the images of stars and earth. The software and the platform it operates on are hugely powerful and can cross reference data from different satellite and images to produce a detailed analysis of results. NASA has made the analysis platform public and allows anyone to adopt it for personal use. However, the barrier to entry is still very high as it requires individuals or companies to have the means to acquire raw unprocessed satellite images and therefore difficult to obtain. NASA also only provided the platform without the processing algorithm which needs highly specialized individuals to develop. It is therefore recommended to NASA that they collaborate with more companies on its technology development process to ensure that setbacks on one company will not affect the overall objective. The public would also benefit from NASA releasing more of its algorithms, software, and raw satellite data to reduce the barrier of entry.

Consumer Products

A consumer product has many attributes that make it suitable for a particular purpose. In the case of NASA, this has largely been accomplished via the NASA Innovative Partnerships program, which has helped transfer NASA technology to the private sector. One shining example would be the development of a water filtration system using acoustic nanotube technology, which provided a cheap and scalable method of filtering water in areas that couldn't afford it. The 360○ FFL cameras used in the Mastcam system on Curiosity were jointly developed with Malin Space Systems, and gave birth to panoramic photography products such as the Bublcam and GIROPTIC. Although economical, issues related to biological accumulation, sizes and safe disposal still exist that impede the speedy adoption of the same. It is recommended that NASA work in concert with its partners and industry to overcome these challenges and thereby enable the public to appreciate the significant benefits of the research leading to the development of these products.

Concluding Remarks

The complicated and lengthy federal government procedures, lack of collaboration, some intellectual property difficulties, and various inconsistencies in the technology transfer programs often inhibit or delay the successful launching and implementation of technology, resulting in less than optimal benefits, and sometimes substantially delaying the transfer of new technologies into the private sector. Solving these issues facing the space agency require a more collaborative attitude that forms upon teamwork and knowledge of all stakeholders. Furthermore, it should be asserted that innovation gets achieved through lessons learned and through transformation.

Moving forward, NASA should:

- Be oriented toward being an organization that promotes a tomorrow that is tuned to the future demands, an external environment that addresses the needs of all stakeholders and a culture of innovation that encourages individuals who initiate change.
- Make effort toward developing programs and policies that inspire a degree of trust between businesses and government.
- Consider a more proactive collaboration with other space agencies as it is in everyone's interest to explore space, the agencies should find ways to work together and share rather than compete and work in secrecy.
- Act as an agent and negotiator to develop partnerships between private sector companies and government agencies in order to help these companies overcome financing difficulties.
- Work in concert with its partners and industry to overcome challenges and thereby enable the public to appreciate the significant benefits of the research leading to the development of novel products.
- Release more data, algorithm, and software to the public to reduce the barrier of entry into the field thereby receiving more collaboration with the public.
- Check the progress and the impact on the economy of transferred technologies continuously.
- Improve the knowledge management system by sharing knowledge, integrating distributed knowledge, capturing knowledge and modeling expert knowledge more efficiently.

Finally, it should be emphasized that these issues are challenges to both NASA management and personnel. Since innovation is accomplished through people in organizations, this report encourages NASA management and personnel to challenge these issues and make their innovations even more valuable to society.

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1. INTRODUCTION

As a species, mankind has triumphed over all others due to its superior intellect. This has been used to facilitate our day-to-day living via the creation of various products, which enable us to lead better lives. NASA Programs have cultivated numerous inventions and partnerships were formed to transfer developed technologies for public benefit in various sectors. However, it can be argued that while benefits are significant, the benefits could have been greater if NASA had operated its programs and projects in a different manner. The objective of this report is to review research work completed on innovations NASA championed for space exploration and their effect on our life on Earth in five sectors in order to (1) identify the innovation trends (2) understand how to manage limitations and promote organizational innovation more effectively (3) synthesize lessons learned.

We begin by analysing the institutional role of NASA in innovation and then describe 2 case studies and illustrate the technology used therein, along with their application to everyday life. These case studies are drawn from the following five sectors: Medicine and Healthcare, Environment and Energy, Transportation, Computer Technology and Consumer Products.

The methodology used for the research is to first review the history of NASA innovation in the above areas based on readily available literature, and formulate an understanding of the current state (the "As Is" state) of the each of these five sub-sectors. Innovations and the driving factor behind the mission or project that created the technology were analysed and technology transfer in the aforementioned sub-sectors was evaluated. Attempts were also made to identify the issues and limitations in the promulgation of these innovations, and suggestions were put forth on how better policies, marketing practices, management frameworks and cross-institutional collaboration could be adopted to further foster innovation.

The major objective here is to illustrate the application of the Management of Innovation concepts to identify the benefits and recognize the cause for limitations in respect to NASA's Innovations and Technology Transfer activity and to determine how related Management of Innovation concepts can be employed to cope with limitations and increase benefits in the future.

2. Institutional Role of NASA in Innovation

2.1 Background

NASA is a federal entity involved in the advancement of space science and the exploration of outer space for the US. NASA's continuous exposure in the advanced industry sector, and its role as the national space agency, puts it at an advantageous position to influence and impact the development of new research and technologies. This section attempts to provide a high-level summary of some of NASA's involvement in the processes of innovation and its level of engagement within it in the present.

2.2 Strategic Role, Goals, and Objectives of NASA, and Mission Purpose in the Present

In its strategic plan of 2014, the space exploration agency laid out its future-state vision, as well as its reason-to-be in its mission outline. NASA's vision, or its aspiration and most important goal, is to strive for new heights and reveal the unknown for the benefit of humankind [1]. NASA's purpose as an institution, mentioned in its mission statement, is to drive advances in science and technology related to aeronautics and astronautics, so as to enhance knowledge, education, innovation, economic health, and stewardship of the Earth [1][2]. To do this, NASA adopted three strategic goals, and objectives within each strategic goal to achieve it [1]. The first strategic goal is to expand knowledge, capability, and opportunity in space. The second strategic goal is to enhance the understanding of Earth and to develop technologies to better the quality of life on Earth. The third strategic goal is to ensure competency in management skills and technical capabilities of its workforce. It encompasses multitude of innovation in many fields, and it is apparent innovation and a superior future state is something that NASA is putting lots of effort into.

NASA's vision, mission, strategic goals, and strategic objectives, are aligned to enable pre-eminence in science and technology for the US, while enhancing the quality of life and a better understanding of Earth [1] [2]. Its strategic direction is designed to accomplish priorities of national origin in civil aviation, astronautic exploration, and scientific research and development [1]. This is seen in objective 1.3, 1.7, objective 2.1, 2.3, 2.4, and the whole of strategic goal 3, which are organized to serve the American public, empower US industry, and advance national capabilities. It focuses on gaining tangible benefits of cross-cutting technological developments [1]. In other words, NASA aims to discover, invent, and demonstrate new technologies, tools, and techniques for the betterment of the US, and a greater understanding of Earth, as part of its efforts to explore space.

In accordance with this future-state vision in mind, the long-term goal for NASA is to land humans on Mars in the decade of the 2030s [1] [2]. As a stepping stone towards this achievement, and an intermediary milestone to such a target, astronauts will explore an asteroid that will be captured and towed to the Moon by 2025 [1] [2]. The asteroid operation will serve as a demonstration to further test and develop new technologies for mechanisms of human operations in space, for example travel onto Mars. Other focuses include the emphasis on using

US private industry to commercialize space transportation, research through the International Space Station, and progression in the manufacturing of the James Webb Space Telescope [1].

2.2.1 Implications of NASA's Advancements in Science and Innovation

The importance of science and innovation to NASA as an organization was detailed in its strategic plan [1]. The successful implementation of it would imply certain ramifications in the military, social, economic, and political context, mainly for the US. The implications are that new technologies developed by NASA through its purpose and strategic drive could be repurposed for use with military intent, or in other words enable the creation of a more advanced and capable military [3]. A form this could take may be the creation and deployment of military vehicles which can travel faster, or better withstand environmental stresses, and is potentially one of the benefits of NASA's endeavours to advance science. Socially, the adoption of new discoveries, such as lighter materials that are more environmentally sustainable and help to produce less pollution, allows a better quality of life to come about, first for the people in the US, and eventually the rest of the world through diffusion of technology. In addition, the advancement of state-of-the-art technologies at the forefront of science may attract ambitious and bright-minded scientists from around the world to further the US's developments in high technology, and enable it to maintain its pre-eminence in the world's knowledge economy. It is explicitly stated that a stronger American economy is one of the goals of NASA's project, and many who drafted the plan are confident a better American economy will increase the livelihood of the American public [1][2]. Being able to say that the US is the first nation to land on Mars is may possibly be considered a political achievement by some, and can translate into greater national prestige and a first-time historical achievement for the US and the world as a whole. NASA's goals as an organization will ultimately enhance the understanding and quality of life on Earth for all, regardless of national origin.

2.3 Framework in Encouraging and Perpetuating Innovation

NASA makes an overt effort to transfer technologies to American commercial businesses. This is done through the Technology Transfer Program (T2P), with its own dedicated website set-up to collate appropriate software and technologies for viewing by the potential licensee [4]. The website gathers the technological innovations from the ten separate research centers of NASA, and centralizes the patents in a public database for all to see [4]. In addition, the website is in a simple and easy to read format.

Under the heading "Patent Portfolio", the patents are separated by field of subject, such as manufacturing, aeronautics, and materials. Within each patent includes an informative and concise introduction to the invention, details about the patent, and the point of contact for further inquiries. A search reveals new materials and technologies that the public may not have known, including high efficiency tantalum-based ceramic composite structures, new polyaniline/carbon nanotube sheet nanocomposites, an obscure heat treatment process for making cast aluminum with improved impact toughness, a novel method for joining metallic and composite components together, or a new nanoengineered thermal material based on carbon nanotube array composites. The technology readiness level is included in graphical format as well, so that the prospective firm may quickly understand if the risk of the development is worth it for the business. There exists a separate database for software organized by functional categories similar to the patent portfolio, and another entry for time-expedited technology licensing called QuickLaunch, which is a group of inventions based on its ease of licensing process [4].

In making these inventions publicly available for adoption by American companies, the visibility of the patent, and the potential for commercialization of the technology, in bettering the technology of the product, or the process for making these products, are improved. It raises the competitiveness of the American companies, and places them at an advantageous position relative to its competitors in the marketplace. Especially for the US, it benefits the economy, creates jobs, and improves the quality of life [1]. Small businesses play an important role in innovation, and thus NASA is inclined to help develop small high-tech businesses through its small business innovation research/small business technology transfer (SBIR/STTR) funding program and its website [5]. Any research work done under any NASA funding agreements that constitutes improvements of any kind must be reported to NASA [6], which then could potentially be included within the patent portfolio found on the website [7] [8].

Companies who apply for these technologies and fundings are likely to be listed in the spin-off magazine issued annually by NASA, an article which publicizes the work NASA has done to commercialize technology and improve the economic health of the country [9]. In addition, the metrics for measurement of the statistics related to technology invention and transfer is online and viewable by anyone who wish to be informed on the quantity and degree of success in technology commercialization by NASA under the title “T2 Analytics” within the additional resources section of the main webpage [4].

2.4 Conclusion

NASA aims to contribute highly to further advance innovative developments in the field of aeronautics and astronautics, and has a stake and capability to facilitate it. It has taken steps to aid in the smooth running of the innovation process by reducing barriers to technology transfer so as to enable commercialization of technology. This is seen in its various support resources in the form of navigable websites, concise reporting information, and listing of their point of contacts. In addition, a stringent demand to report any improvements in any technological aspect assists in identifying and cataloguing of new capabilities, which may then be patented and shown on its public database of technologies for licensing. Going forward, this will have beneficial implications for the US and the world at large in regards to its military, social, economic, and political domain, as well as in the disciplines of science, technology, engineering, and math.

3. Innovations in Medicine and Healthcare

3.1 The voice-controlled wheelchair

NASA's various breakthroughs and innovations have been crucial to the development of modern medicine as we know it. Even within the medical field, NASA's contributions have been widespread and immeasurable. NASA's developments have greatly benefitted the physically disabled, and in particular quadriplegics.

Patients with quadriparesis suffer from at least partial loss of all four limbs and torso [10], which may be caused by an injury to the brain or spinal cord, or illness at birth or later in life [11]. Most patients with quadriparesis use an electric wheelchair to move, which is controlled by simple hand movement [12]. In extreme cases, however, a patient may suffer from total loss of all four limbs, rendering them unable to control an electric wheelchair.

Research by NASA during space-related programs have greatly developed robotic and teleoperator technologies [11]. These technological advances have allowed NASA to develop a voice-controlled wheelchair as an aid to completely-paralyzed quadriplegics. Inside the system, a minicomputer converts the audio from the patient's voice and converts them into electric signals, allowing people whom are wheelchair bound to move using simple commands such as "go", "stop", "left", "right", and 31 other commands [13]. The system can additionally "pick up objects, open doors, turn knobs, and perform a variety of other functions" [11].

Fig.3.1.1: A voice controlled wheelchair

As a result, formerly bed-ridden patients can move around their homes, allowing them a level of freedom they previously did not have. In addition, NASA research during space exploration missions has developed aerospace composite materials which allow construction of objects to be made equally as strong as before but much lighter [14]. These technologies have allowed for the creation of lighter and stronger wheelchairs which are collapsible [15].

The improvement and numerous innovations of the wheelchair provide further evidence of the benefits of NASA's space exploration program which benefit humans right here on Earth.

3.2 Laser Angioplasty

Heart disease is the leading cause of death in Canada [16], which is mainly caused by the buildup of plaque in the arteries [17]. Plaque buildup in the arteries, referred to as atherosclerosis, can restrict blood flow throughout the body and can cause damage to the artery walls. Plaque buildup can result in heart arrhythmia and cardiac arrest, a frequently fatal outcome [18].

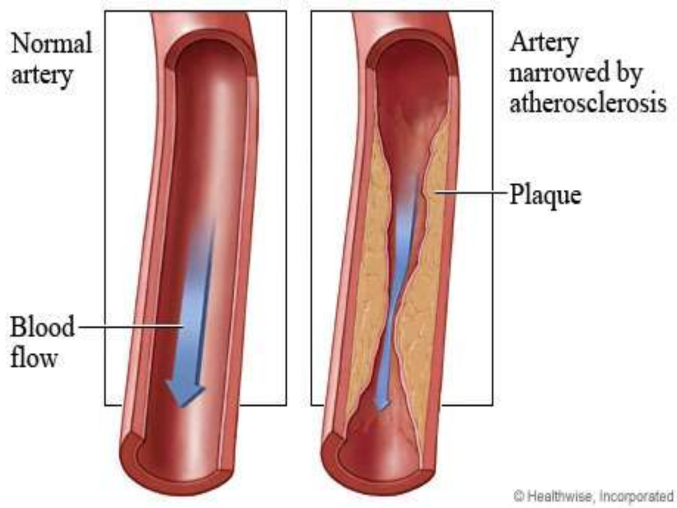


Fig. 3.2.1: A healthy artery (left) and an artery with plaque buildup (right) [19]

Plaque buildup in the arteries can be prevented and reduced through proper diet, exercise, and by taking various medications, however in cases of significant artery blockage, surgery is the most effective course of action to prevent heart damage or failure [20]. There are numerous surgical procedures which can reduce or eliminate plaque buildup in the arteries.

3.3 Invasive Heart Surgery

Patients hoping to increase blood flow through a clogged artery may opt for bypass surgery, where blood is rerouted around a blocked artery through grafted arteries taken from elsewhere in the patient's body [21]. Bypass surgery can be effective at increasing blood flow at the site of the blocked artery, however normal blood flow needs to be completely interrupted for a short amount of time, which can lead to numerous medical complications including death. Kidney disease is often found to be a side effect of bypass surgery [22].

Patients may instead opt to have the blocked segment of artery completely removed and replaced with an artificial one. The risks and drawbacks of artificial heart valve surgery are numerous and similar to the risks of bypass surgery [23]. Those weary of the risks of these invasive surgeries instead opt for angioplasty instead.

3.4 Angioplasty

Angioplasty, or Percutaneous Coronary Intervention (PCI), is a non-surgical procedure where a small tube in inserted into the effected artery. The small tube, or catheter, is equipped with a deflated balloon on the top of it and is threaded through the arteries. Upon reaching plaque buildup, the balloon is inflated to expand the artery and pass the plaque buildup. A stent is left in place in order to hold the artery open wider than before [24]. Angioplasty can be effective in increasing blood flow and circulation in previously blocked arteries and is generally has fewer risks and side effects than bypass surgery [22]. However, bypass surgery may be recommended for severely blocked arteries where angioplasty may not be sufficient [24].

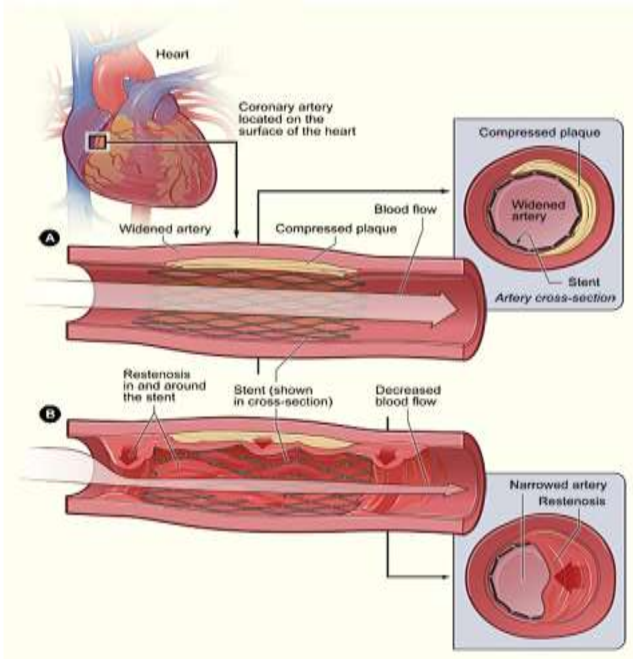


Fig. 3.4.1: Balloon angioplasty [25]

Balloon angioplasty offers a risk of blood vessel damage from the catheter, internal bleeding, and blood clot in the stent [25].

3.5 Laser Angioplasty

A procedure which is heavily based on NASA technology, laser angioplasty offers effective blood flow increase around blocked arteries while resulting is less risk, pain, recovery time and wider utility to the patient than traditional balloon angioplasty [26]. The technology was initially developed for NASA's satellite-based atmospheric studies at NASA's Jet Propulsion Laboratory. NASA's research there allowed for the development of a "cool" laser, which uses ultraviolet energy to operate at 65° C, a temperature human tissue can tolerate [15]. The laser angioplasty innovation was previously inaccessible, as the only known lasers operated at temperatures that would damage the artery walls.

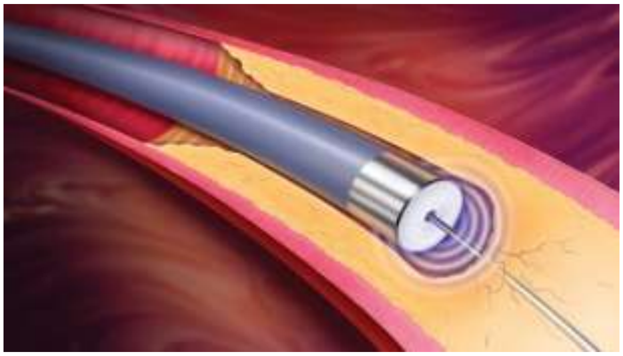


Fig. 3.5.1: Laser angioplasty dramatization [25]

With NASA's technological developments, laser angioplasty has become widely accessible in the treatment of blocked arteries. The result in a safe, effective, and inexpensive (relevant to invasive surgeries) procedure. Laser angioplasty has contributed to the 75% decrease in cardiovascular death rate in Canada since 1952 [24].

The laser angioplasty innovation is another example of how NASA's technological developments have contributed to a safer and more advanced society.

3.6 Stereotactic Breast Biopsy Technology

Breast cancer is the most common type of cancer in women, with an average of approximately 1.7 million new diagnoses per year worldwide [27]. Breast cancer is an epidemic of the modern age, and even with a wealth of awareness, the cause is still unknown and a cure does not exist [28]. Given the wide range of people it affects, any innovation which improves the ability to prevent, diagnose, or treat breast cancer is invaluable to our society.

3.6.1 Breast Biopsy

To maximize chances of surviving breast cancer, detecting the cancer as early as possible is crucial. In fact, all women should regularly be screened for breast cancer (go for tests even without a lump or symptoms) to try to catch cancerous cells as soon as possible [29]. However, many instances of breast cancer are preceded by the patient feeling a lump on their breast, prompting them to visit a doctor.

Abnormalities or lumps in the breast can very possibly be benign. Initially the doctor will usually gain information on the lump using a diagnostic mammogram or ultrasound of the breast. Many times, these tests are sufficient in concluding that the lump is benign. In situations where these tests return positive for cancerous activity, or where these tests are inconclusive, a breast biopsy follows. A breast biopsy requires the removal of some of the tissue in the lump in order to test more thoroughly for cancerous cells in a laboratory, which provides the most conclusive evidence as to whether or a lump is cancerous [30]. There are several different types of breast biopsy, including fine-needle aspiration biopsy, core biopsy, and surgical biopsy, each varying in effectiveness in diagnosis and invasiveness. While each method varies in its ability to accurately diagnose different types of cancer cells, each method is quite painful to the patient and is expensive to perform [30].

3.6.2 Stereotactic Breast Biopsy

Starting in 1997, stereotactic breast biopsies became a viable option to diagnose breast lumps. The technology originated from NASA technology which was originally developed to increase the Hubble Telescope's ability to see faint objects in high resolution [31]. NASA, in a joint effort with Scientific Imaging Technologies Inc. (SITe) creates a new charged coupled device which completed the goal of increasing the Hubble Telescope's range and clarity. It was not long after that this new innovation was applied to improving breast biopsies. Both the Hubble Telescope and an effective breast biopsy require extremely high resolution to decipher fine details. The innovation additionally shortened exposure time in breast imaging [31].

Fig. 3.6.2.1: A stereotactic breast biopsy table and imaging system

With this new innovation, image-guided biopsy became a reality. Improved resolution from NASA and SITe's charged coupled device allow the radiologist's instrument to be guided by x-rays, leading to more efficient and direct path to the cells which need to be tested. The cells in question are then frequently pulled out using a vacuum-assisted device (VAD) and then sent to a laboratory for testing [32].

The result of stereotactic breast biopsy is more a clear and efficient biopsy process, saving patients time, money, pain, radiation exposure, and scarring which would result from more invasive biopsy techniques [31]. The increase in efficiency is also reflected in annual health care costs, as this innovation makes biopsy less expensive for more than 500,000 women who undergo the process annually. It has been predicted that this technique will eventually reduce American national health care costs by more than $1 billion per year [31], which is a very secondary benefit to the increased diagnosis ability and the ease of procedure which stereotactic breast biopsy offers.

4. Innovations in Environment and Energy

4.1 Background

Given the importance of innovation, change and organizational renewal shall be a paradigm and a continuous process explored by NASA. It can be argued that change is challenging, yet paramount due to the fact that the space era launched a number of projects of such scale and magnitude that another type of management needs to be shaped to guarantee successful results [33]. There is a shift change from the approach that operations have been managed a few years ago to the approach that they must be managed today. The challenges today pertain not only to the technology and its management, but also to human-centric factors such as communication, processes and planning, and cultural aspects as well [34]. Thus, NASA needs to undertake a holistic approach to managing its various programs and projects to facilitate and capitalise on change and innovation.

The following case studies provide context for the impact of NASA innovations in the Environmental and Energy sector, identify issues and limitations and find solutions on how NASA can change in order to make their innovations more beneficial for the society.

Case study 1, named Landsat Program Data Enhances Google Earth, presents an analysis of NASA originating technology and its transfer to Google and discusses the success and limitations of the Landsat program, the effect of Landsat data becoming free for innovation and the outcome from the Google Earth Engine joint project between NASA and Google.

Case study 2, named Battery Technology Stores Clean Energy, focuses on NASA's Redox project and provides an analysis and evaluation of Redox Storage System technology development. Furthermore, it reflects on the collaboration between NASA and Deeya Energy and discusses the L-Cell Energy Storage Platform, which is based on the redox battery design invented for NASA.

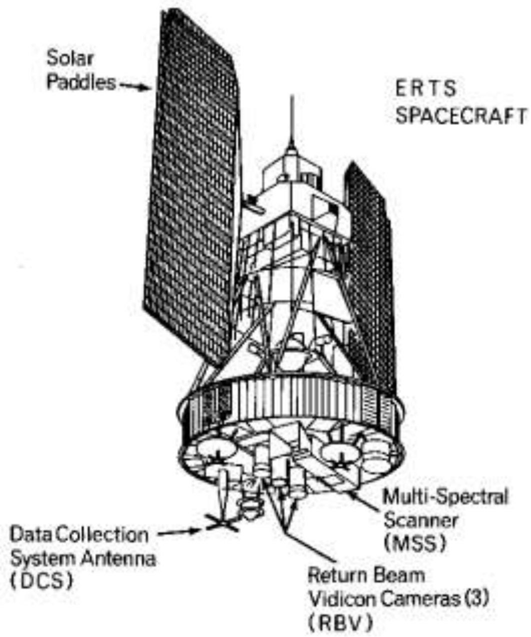
Is NASA management and personnel up to the challenge?

4.2 Case study 1: Landsat Program Data Enhances Google Earth

4.2.1 Landsat Program: Successes and Limitations

The event started on July of 1972, when NASA initiated the Earth Resources Technology Satellite known as Landsat, which was the first spacecraft designated to monitor Earth's surface. Landsat consisted of a camera and an experimental multispectral scanner (MMS) dedicated to record data in green and red spectral bands and two infrared bands (Figure 4.2.1.1). [35] Although there were concerns that the moving parts may not work well in space and the scanner could not create high quality digital imagery, the result was a huge sensation and the people at NASA were surprised at the high reliability of the data that was sent back by the chattering imager. The Landsat program proved to be an achievement as the MSS provided 300,000 images and helped researches to move towards remote sensing and adding dimension of time to studies of Earth's resources [35].

Figure 4.2.1.1 Landsat 1[35]



The MSS was a valuable tool for enhancing crop forecast and monitoring clear cutting of forest. Landsat information was useful to observe water levels of Lake Okeechobee and get a comprehensive picture of the ecology in Miami area [36]. It also facilitated the analyses of flood dynamics near the Cooper's Creek in Australia [37]. As a result, Dr. John E. Clark, representing NASA, and Daniel J. Fink, representing General Electric, received a Collier Trophy for the Landsat program in 1974 for proving the value of U.S. space technology in the management of the Earth's resources and environment for the benefit of all mankind [38]. It took more than two generations, eight satellites and millions of pictures that NASA has gathered to build a remarkable database of images that can make a slide show of our swiftly altering Earth. Refer to Table 4.2.1.1 for a timeline of the Landsat missions. [35]

Table 4.2.1.2 History of Landsat Missions USGS database [35]

Landsat 1	Launched July 23, 1972 and terminated operations in 1978
Landsat 2	Launched January 22, 1975 and terminated operations in 1981
Landsat 3	Launched March 5, 1978 and terminated operations in 1983
Landsat 4	Launched July 16, 1982 and terminated operations in 1993
Landsat 5	Launched March 1, 1984 and decommissioned by the USGS in 2012
Landsat 6	Launched October 5, 1993 but failed to reach orbit
Landsat 7	Launched April 15, 1999 and still active
Landsat 8	Launched February 11, 2013 and active

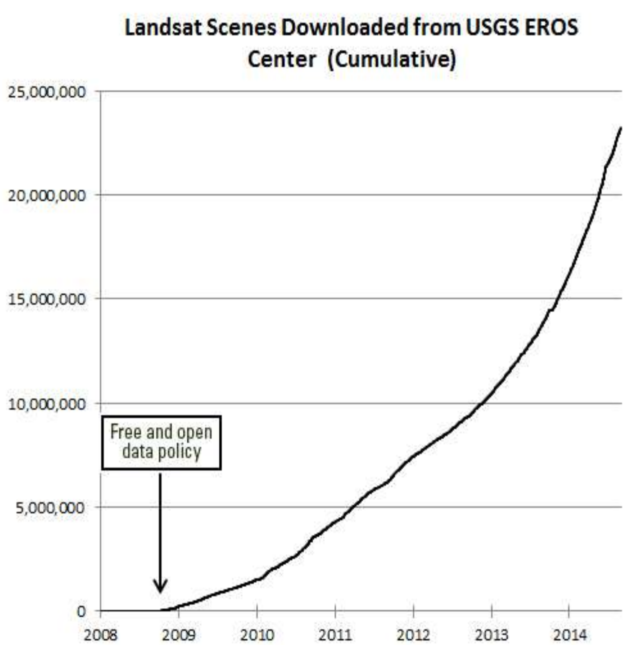
Regardless of the fact that the program had great recognition in the first years from its launch, NASA had a difficult task to demonstrate the value of the Landsat to prospective users and Congress. Even though Landsat was a small program, it obtained public interest as people aspired that the space program would provide more evident benefits on Earth. NASA management wanted to respond to such interest from Congress and the general public by trying to convey the idea that Earth resources satellites could have good impact for the public and that there may be interest for technology commercialization as well. However, there was not enough determination from NASA's side as their leadership had the tendency to see space exploration as the main mission of the agency and wanted to continue with research and development. As a result, Landsat turned out to be a project that started to present political capital to NASA and its supporters, which complicated even more the issue of balancing the needs of scientists and of possible operational users [39]. Moreover the program was exposed to some difficult political ambiguity and was sometimes considered a "technology in search of an application." Thomas S. Kuhn's recommendation for scientific innovations and revolutions was calling for caution on these developmental stages by foreseeing a period of scientific vagueness, if not complete denial, by entire sectors of the science and technology community [40].

There were multiple attempts at privatization and the responsibilities for data diffusion were transferred from NASA to the United States Geological Survey (USGS) Data Center. The idea was that NASA will further develop sensors and platforms while USGA will act as the supplier of Landsat products. Beside NASA and USGS, other agencies were involved in this transition process such as The National Oceanic and Atmospheric Administration (NOAA), The Department of Defense (DOD) and the United States Department of Agriculture (USDA). Although the intention was good, the differences in responsibilities and management of the above agencies inhibited the Landsat program. In order to solve this issue, administration after administration reviewed the military and civilian space policies, made changes to the policies with the attempt to make the civilian program operational, administered by NOAA, and ultimately delegate them to the private sector [41]. However, Government policies which intended to transfer the Landsat program from the public to the private sector were ambiguous. These policies did not result in market growth, were more costly to the Federal Government and significantly inhibited applications of the data [42]. The program was also criticized that its database had limited commercial freedom. However, James Irons, Landsat Data Continuity Mission Project scientist at Goddard Space Flight Centre and his colleagues never stopped to pursue the idea to make the global data publically available for free and in 2008 a decision to distribute the data at no cost was adopted. The USGS and NASA policy of unrestricted access and free sharing of Landsat data was intended to encourage scientists all around the world to develop practical applications of the data and use it for future innovations. Complete access to imposing Landsat pictures offers a reliable record of Earth situation that improves the common understanding of environmental issues worldwide by public, scientists, and decision makers [43].

4.2.2 Landsat Data Free for Innovation

As of late 2008 Landsat data became available to all users at no cost. Since then over 22 million Landsat images have been downloaded through the USGS-EROS website and the rate of downloads has been increasing exponentially (refer to Figure 4.2.2.1) [44]. The diffusion of innovation model can be applied to analyze the rate of adoption of this innovation. The diffusion of innovations model was initially expressed by Everett Rogers (1995) and examined in diverse succeeding research studies. This theory suggests that the rate of adoption of an innovation follows an equation similar to that of the spreading of an epidemic disease [45]. The collective number of adopters of an innovative technology follows a logistic (S-shaped) curve, and as a result the number of adopters over time follows a normal distribution. Rogers acknowledged five categories of technology adopters:

Fig 4.2.2.1 Landsat Downloads USGA Database [46]



1. *innovators*, the first 2.5% of the people in a system to adopt an innovation;
2. *early adopters*, next 13.5% of individuals that are a more integrated part of the local system than are innovators;
3. *early majority*, 34% people that adopt new ideas just before the average member of a system;
4. *late majority*, next 34% who adopt new ideas just after the average members;
5. *laggards*, 16% of individuals who are the last to adopt innovation. [45]

Applying Rogers's diffusion of innovation model to spatial information technology download rate, the curve in Figure 4.2.2.1 indicates that the maturity level and the curve is in the *early adopters* stage. [46] Early adopters are in general described as curious and exploratory users who exploit first, talk fast and spread the word to others about the pros and cons of what they have utilized or consumed. [45]

The benefits of Landsat Earth data are acknowledged and adopted quickly all around the world as it is essential to science, resource management, agriculture, medicine and military. The Landsat Advisory Group tried to measure the benefits that the Landsat program achieved in terms of estimated annual efficiency savings in monetary terms. They took in consideration costs of substitutes to Landsat for existing uses of the information. The group of experts summarized sixteen processes that could be considerably more costly without an operational Landsat database shown in Table 4.2.2.2 [46].

Table 4.2.2.2 Summary Table: Estimated Productivity Savings from Uses of Landsat [46]

Landsat Application	Estimated Annual Efficiency Savings
1. USDA Risk Management Agency	over $100 million
2. U.S. Government Mapping	over $100 million
3. Monitoring Consumptive Agric. Water Use	$20 – $80 million
4. Monitoring Global Security	$70 million
5. Landsat Support for Fire Management	$28 – $30 million
6. Forest Fragmentation Detection	over $5 million
7. Forest Change Detection	over $5 million
8. World Agriculture Supply and Demand Estimates	over $3 – $5 million
9. Vineyard Management and Water Conservation	$3-5 million/year
10. Flood Mitigation Mapping	over $4.5 million
11. National Agricultural Commodities Mapping	$1.9 million/year
12. Waterfowl Habitat Mapping and Monitoring	$1.9 million/year
13. Coastal Change Analysis Program	$1.5 million
14. Forest Health Monitoring	$1.9 million/year
15. NGA Global Shoreline	over $90 million (one time)
16. Wildfire Risk Assessment	$25-50 million (one time)

According to the Advisory Group measurement study, these sixteen Landsat applications generate savings of $350 million to over $436 million per year for Federal and State governments, NGO's, and the private sector [46].

4.2.3 Technology Transfer - Google Earth Engine

Once Landsat data became accessible to all users for free, Google took advantage of the new opportunity. The Google Earth Engine joint project between NASA and Google took place in 2010 and it allows any person access to a 30 year time interval of the Earth's surface. Due to this invention, Google Earth Engine allows researchers, scientists and the public to explore and analyse this rich planetary information (Figure 4.2.3.1). The Engine includes applications such as identifying deforestation, categorizing land cover, assessing forest biomass and carbon, and mapping the world's road less areas. The images, and predominantly the movies, that derived from this meticulous work are astonishing. They reveal reach stories about how the Earth has changed environmentally with lakes and rivers that diminish, mountaintops deteriorated by mining companies and glaciers that retreat or disappear. On the other hand, there are good facts that come from examining the Google Earth Engine such as the oil sands fields of Canada that surface and in result free North American and other countries from dependence on petro rulers. In addition, irrigation systems can be noticed on the Engine turning deserts into green spaces. [35]

Figure 4.2.3.1 Google Earth Engine allows researchers, scientists and the public to explore and analyze planetary information [35]

The benefits from this collaboration are vast and visible and the public-private partnership between NASA and Google is bringing environmental dividends already. For instance, eager to cope with and manage the situation of its forests, the government of Mexico got in touch with Google in regards to creating a broad map that could show how much of the forest territory is still unharmed and how much has been lost. For governmental agencies and environmental researches, there is a lot of profound and captivating data to take out from the maps and movies. For the general public, there is something puzzling but just as significant called the future perspective. People like to watch over their own petite plots on Earth, their houses, yards and gardens and are able to see how they are changing the planet and start thinking how they can make changes to make it a better place. [35]

There is no doubt that the benefits from the Landsat program and NASA's activity are visible and valuable, but the question arises as to whether the agency has the ability to operate in a new environment that requires ongoing change? Stephen Armstrong suggests that a while ago organizations had time to be concerned about "the next wave of change", however "in the new millennium that wave of change has become perpetual white water" [47]. What steps can NASA management and personnel take to ensure that their programs and projects remain on the cutting edge of innovation? Space exploration management is a completely "new ball game", requiring creative and holistic approaches to managing problems and averting conflict. NASA needs to take steps today in order to challenge the "unique management problems" that may arise in the future [48]. Furthermore, detailed conclusions and recommendations of the above findings are elucidated in sub-section 4.4

4.3 Case study 2: Battery Technology Stores Clean Energy - NASA Partnership with Deeya Energy Inc.

4.3.1 Redox Project: Originating Technology Successes and Limitations

Presented in NASA Spinoff of 1985 and initiated in 1970s by Lawrence Thaller at NASA's Lewis Research Center as a possible equivalent energy source for long-term space flight, iron-chromium redox energy storage systems represent a hybrid technology that provides the extensive support of fuel cells with the flexibility of batteries (Figure 4.3.1.1). The technology is low cost, robust, abundant and safe, and may hold immense promise for substituting gas fired peaking power plants, and for offering critically required grid stabilization services [49].

Figure 4.3.1.1 Load-leveling liquid redox systems originated as potential energy storage for long-term space flight. [49]

In 1975, the Energy Research and Development Agency (ERDA) began support of the NASA Redox project. Later, the Department of Energy, first under DOE/NASA Agreement EC-77-A-31-1002 and subsequently under Interagency Agreement PE-AI04-80AL12726 continued this support through 1982. The work at Lewis continued until early 1984, using previously authorized but uncommitted DOE funds [50]. By 1981, the system level effort was immobilized in order to concentrate on challenges and limitations with the basic electrochemical performance of the iron-chromium single cell. Some of the major architectural limitations that still required investigation were: low volumetric energy densities; "shunt" described as bypass or leakage current, reactant back mixing and compensation for ionic migration [51]. This afterwards pointed out to an identification of the source of the challenges and limitations and allowed to make the changes for their prevention. [52]

The changes to the main operating concept concluded in a large increase in the operating current density and an improvement in electrochemical energy efficiency. Consequently, these changes required an increase in projected system cost [52]. Initial system analyses pointed out that at this level of performance combined with the mass production of system components would conclude in an efficient and cost-effective Redox system. At that time the accomplishment of these high levels of cell performance had significantly increased the belief that the Redox system, at a cost of about $7S/kWh, could be a legitimate contestant for storage applications. Redox flow batteries have exclusive characteristics that make them particularly desirable when compared with conventional batteries, such as their capacity to decouple rated maximum power from rated energy capacity, as well as their operation flexibility along with features such as reasonable cost, modularity and transportability [53] [54].

Despite the fact that the technology was initiated in the 1970s, the road to commercialization was difficult and lengthy due to the above mentioned product limitations and high costs required for the innovation to happen. At last, in 1984 the Redox system was considered to be ready for the commercial market. Standard Oil of Ohio (Soho) has undertaken such an assessment of the technology, to be followed by further development. The transfer of the technology to Soho was backed by the agency and an exclusive license for patents owned by NASA was transferred to Soho [55].

It can be argued that implementing renewable energy projects is a difficult process that requires careful planning, which incorporates factors such as determining goals, building teams, establishing site feasibility, and choosing the correct project funding instrument. Moreover, large funds requirements combined with restrictions on federal agency energy contracts make it difficult to finance energy projects.

4.3.2 NASA Collaboration with Deeya Energy

Established in 2004 with sites in California and India, Deeya Energy Inc. is a clean-tech company devoted to developing and manufacturing electrical energy storage systems [56]. Deeya Energy's innovation, the L-Cell, was created based on the original flow battery technology initially developed by Lawrence Thaller for NASA. Thaller assisted Deeya by providing development support for the company‘s proprietary liquid-cells (L-cells), which have higher power capability than NASA’s original design. In 2008, the Space Foundation approved the L-cells as a Certified Space Technology, a designation for products realizable by space research and development [57].

According to Deeya Energy, the company has developed its L-Cell Energy Storage Platform technology into an Energy Storage Platform (ESP™) and the initial product in this category is the ESP 24K. (Figure 4.3.2.1).

Figure 4.3.2.1The ESP Energy Storage Platform Deeya Energy Inc. [57]

The ESP 24K accomplishes a new level of reduced cost and improved performance in offering vital infrastructure support for low availability service areas, and optimizing mass renewable energy diffusion within the energy industry. Deeya’s technology is beneficial for cell phone providers in India and other rural areas in the developing world, which require smaller backup systems for the cell towers and with L-cell battery systems they get improved reliability of services. Future plans include the use of L-cells as backup systems for traffic lights and cash machines. [57]

In spite of the fact that energy storage has immense future promise, companies activating in this industry are not always aware of the challenges such as a very competitive market and tough regulations. Moreover, a significant problem faced by the industry is the implementation of new and innovative knowledge into its processes and products. The challenges derived from lack of good knowledge management are multiple and include: duplicate effort, absence of new knowledge and as a result low productivity and efficiency. As Michael Porter claims knowledge and innovation are the pillars of sustainable competitive advantage, and consequently are a resource for sustainable development and growth for enterprises. [58] In this regard, NASA is not keeping adequate connection with their alumni companies, sharing knowledge and offering enough guidance, advice and support.

4.4 Conclusions and Recommendations

On the basis of the above findings it can be concluded that although benefits are significant, there are many reasons for a constant need for change in NASA's organization. The complex regulations, intellectual property challenges, inadequate funding, inconsistencies in the technology transfer programs and lack of collaboration with private sector often reduce the successful launching and implementation of technology into the commercial sector, resulting in less than optimal benefits.

Once NASA thoroughly understands what they currently do and how they do it, they can start to plan for the future. Two critical questions to ask are: what inefficiencies can be found within organization's structures and processes, and how can they be more effective as an agency that tends to be the nucleus of innovation and ideas? The common NASA undertake to technology transfer is to establish prospective commercially advantageous technologies from research and development in progress and use a number of different techniques to promote these technologies into commercial use. This is achieved using various channels through the contractor or supplier that developed the technology, through obtained patents, or through publication and effort is made to promote some sort of commercial initiative. The approach is to future commercialization, however the reality is that most of commercial achievement today is based on the research and development completed many years ago. There are many companies selling products and services that partially or in whole are built on NASA's inventions. These companies frequently have no existing NASA funding or any official relationship with the agency. However, these are companies that are NASA's principal illustration of successful transferred technologies and offer a good representation for those companies that may commercialize current technologies and be successful in the future. [59]

NASA should consider being more proactive with companies selling products and services which are built on NASA's inventions. This will allow for an improved way of recording the spinoff connections available to NASA for public relations use and also could provide benefits for both NASA and those companies. NASA can institute a connection with the companies by offering possibilities to show their technologies at open houses and exhibitions, and be available for continuous technical assistance. In addition, if there is a spinoff technology that is utilized by NASA which is also a prospective commercial product that requires some sort of government involvement, NASA can act as a representative for the company. For instance, if the issue is one of getting an agency's endorsement for the purchase of a technology, NASA can support the company's needs and possibly accelerate the process. If the technology has cost-saving and other social benefits, the government will take advantage as well as the company from an earlier implementation and use of the technology. [59] Greater results can be achieved if NASA revises their capacity to:

- *Foresee Change* by understanding instability and trends.
- *Create Confidence* through commitment and collaboration.
- *Run Initiative* with techniques that facilitate proactive behavior.
- *Unshackle Thinking* with an environment that promotes and mentors innovation.
- *Assess Outcome* by managing knowledge and improving processes.

In addition, NASA and the government are expected to make effort toward developing programs and policies that inspire a degree of trust between businesses and government personnel. As NASA improves its collaboration with enterprises, and benefits are revealed for companies as well as for the government and the economy, confidence will grow and additional companies will be willing to work with the agency for the prosperity of all [59].

Moving forward, NASA should be oriented toward being an organization that promotes a tomorrow that is tuned to the future demands, an external environment that addresses the needs of all stakeholders and a culture of innovation that encourages individuals who initiate change.

5. Innovations in Transportation

Through partnerships with industry and the NASA Space Act Agreements many substantial contributions were made and formed to transfer developed technologies in the field of transportation for public benefit. NASA's research in avionics and the Shuttle Program not only allowed astronauts to travel to the International Space Station (ISS) but also had had an economic impact and positive effect on how we travel here on Earth. Two case studies are used to illustrate the positive impact of NASA's contributions in the field of transportation and a brief discussion of the limitations is also included.

5.1 Transportation Case Study 1 – The Boeing 777

5.1.1 Background

Transporting astronauts to Space required many new materials and testing capabilities to be developed. The harsh conditions from launch to successful return needed to be researched, understood and tested prior to putting lives on the line. As a direct result of the Space Shuttle program many new materials, design and testing capabilities were made available to The Boeing Company through partnership agreements.

5.1.2 Bringing the Technology Home

We've all heard of a paper airplane, but did you know the Boeing 777 was the first paperless airplane? It was the first commercial aircraft to be designed completely using computer aided technology; no drawings were ever produced so no trees were harmed in the making of it. The entire design was made in the computer, which allowed the engineering team to produce a virtual aircraft, visualizing how some of the 3 million components would connect and potentially interfere with one another. Manipulating the plane within the computer was much less costly and more practical than building all of the components. It allowed for design alterations to be made quickly and effectively.

Spending more time in the software rather than in costly production of hardware allowed for cost avoidance later in the manufacturing environment. Ensuring parts fit together correctly would significantly reduce the number of engineering change orders required later.

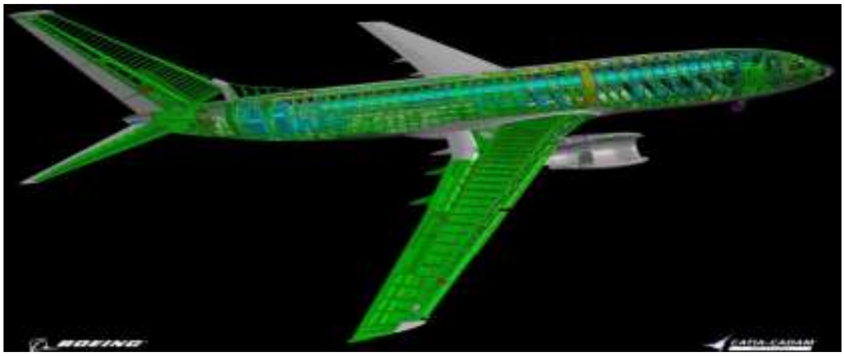


Fig. 5.1.2.1: CATIA (Computer Aided Three-Dimensional Interactive Application) software used to design the Boeing 777. Picture from Boeing.

The largest twin engine long range wide body commercial airliner, the 777 was made possible by collaboration between NASA and Boeing. Table 5.1 summarizes some of NASA's largest contributions to the design, test and build of the 777 utilizing applied research and innovative technology.

NASAs contributions coupled with The Boeing Company's lean manufacturing techniques lead to an innovative, first of its kind aircraft capable of being designed tested and manufactured cost effectively.

Fig. 5.1.2.2.: Testing the Structural Integrity of the Airframe in NASA wind tunnel at Langley Research Center. Picture from NASA

Fig. 5.1.2.3: Boeing 777 cockpit simulator. Picture from NASA

Not only did Boeing utilize the innovative resources at NASA they also tapped into the voice of their customer (VOC). For the first time in history airplane passengers played an integral part in the design of an aircraft. Boeing refers to it as their "Working Together" philosophy and it not only included the customer's input, it included teams of people working together with one goal in mind, "Working Together to produce the preferred new airplane". [60]

Using the "Working Together" philosophy Boeing acquired input from major airline carriers and designed the interior with the passenger in mind; natural lighting, larger windows, larger storage bins, and higher humidity resulting in more comfort during flights.

As a direct result of NASA's collaboration the Boeing 777 was lighter and more fuel efficient. Fuel efficiency and savings lead to a direct reduction in emissions from the aircraft which is positive for the economics as well as the environment.

As a direct result of listening to their customer they created a commercial airliner that major Carriers and passengers wanted to be a part of and set the new standard for what their customers expected and valued.

Table 5.1 A Summary of Major Contributions Made by NASA in the Design and Testing of the Boeing 777 [61] [62] [63] [64] [65]

Research/Technology Developed by NASA	The Boeing Company in Collaboration With	How it was used on Boeing 777
Mathematical computer-based design techniques to simulate airflow patterns.	NASA (Langley Research Centre)	Computer based aerodynamic analysis allowed the Boeing 777 design to be completely paperless, no drawings existed. Engineers manipulated the airplane in the computer and verified no part interferences before having to build expensive physical prototypes.
Wind tunnel testing facility		Wind tunnel testing is performed on all aircraft and rockets prior to flight. It essentially allows for "flight" on the ground. The structural integrity of the 777's wing-airframe was tested and verified by NASA. NASA was fully reimbursed by Boeing for this testing – deal with as a customer/supplier relationship rather than partner.
Aircraft Landing Dynamics Testing facility		Tires on the landing gear of the 777 underwent testing to confirm adequate strength and durability.
lightweight aerospace composite structures		The floor beams, flaps and tail are made from lightweight composite materials. This lead to fuel savings and the ability to fly farther. Resins and adhesives.
Research in cockpit technology lead to an automated, fully integrated glass cockpit.		Used to ensure the pilots had all of the information they needed in a user-friendly format that wasn't distracting and allowed them to maintain eyes on the horizon during flight.
Research and testing aimed at improving the performance of NASA's Space Shuttle engines led to improvements in the Boeing 777's new jet engines designed by Pratt & Whitney	NASA (Marshall Space Flight Center)	NASA engineers conducted evaluations of wake patterns flowing through the plane's turbine engine airfoils. Data taken proved useful in obtaining better turbine efficiency, as well as realizing substantial fuel saving. Glenn Research Center has long-standing partnerships with the General Electric Aircraft Engines and Pratt & Whitney in long-term research projects, such as the Energy Efficient Engine. These have resulted in technologies that increase engine efficiency, reduce engine noise and reduce harmful emissions. The technology base has been applied in the GE90 and PW4084 turbofan engines that power the new twin-engine Boeing 777.
Advanced Flexible Reusable Surface Insulation (AFRSI) used on the Space Shuttle [66]	NASA (Ames Research Center)	Blankets on the plane's inlet, hinge and strut were quilted and made from with either stainless steel or ceramic thread. These blankets protect areas of the plane that have the potential to be exposed to high temperatures and/or fire.
Fly-by-wire system based on the original Apollo guidance and control hardware		Electrical subsystems known as "Fly-by-wire" are used to control the ailerons, elevator, and rudder. This replaced the typical pulley and cable systems used on previous Boeing aircrafts, leading to a weight and cost savings.

The collaboration between NASA and Boeing doesn't end here. Today they are working together to build a spacecraft that will replace the Shuttle and be able to transport astronauts to and from the International Space Station (ISS), with Boeing looking to take the lead in this endeavor it frees NASA up to focus its sights on sending humans to Mars [67]. As the Shuttle Program contributed so much to the success of the Boeing 777, it seems quite fitting Boeing now contributes to its replacement.

5.1.3 Limitations with Transportation Case Study 1 – The Boeing 777

The collaboration between government (NASA) and industry (Boeing) contributed substantially to the success of the Boeing 777 aircraft, but is it enough?

The technology that NASA develops is not open-source and not available to all aircraft manufacturers. Does this collaboration give Boeing an unfair advantage in the commercial airliner business; will it make it impossible for other aircraft manufacturers to compete?

Collaborating with other Space faring nations is made more difficult by the laws and regulations of the United States. The International Traffic and Arms (ITAR) regulation makes it very difficult to share technology outside the United States [68]. As the United States continues to isolate itself from the rest of the world the rest of the world is successfully finding innovative ways to collaborate.

The countries of Brazil, Russia, India and China (BRIC) have joined economic forces to work together openly and help support each other as they grow and prosper [69].

Although the Boeing 777 is more fuel efficient than its predecessors there is still much more that can be done to reduce the impact on the environment. Commercial aircrafts have a significant impact on the environment due to the amount of fuel they use. Now armed with a common purpose to reduce this impact Boeing has started to collaborate with Airbus in the United Kingdom and Embraer Air in Brazil to develop sustainable and affordable biofuels [70]. This is a very strategic move as this allows Boeing access to the BRIC technologies. Brazil has an advantage here as they have been using sugarcane to produce ethanol as a replacement to fossil fuels since 2000, but economic challenges may make this difficult to sustain on their own [71]. Working with the major aircraft manufacturers to generate a sustainable biofuel for air travel could give Brazil the economic boost they need.

NASA has the history, the heritage and the name, but if they don't find more innovative ways to partner with other industries, space agencies and countries in general they may find themselves out of the race they once lead.

5.2 Transportation Case Study 2 – NASCAR, Racing toward Earth

5.2.1 Background

If you've ever watched a Space Shuttle land you've no doubt seen the extreme heat generated from friction with the atmosphere. The Shuttle's surface reaches temperatures up to 1477 ° C, this heat is generated when the kinetic and potential energy that exists due to the speed and altitude of the Shuttle upon entry. Since the Shuttle was designed to provide astronauts with a reusable transportation to and from the ISS it had to be designed to be able to withstand this heat [72] [73].

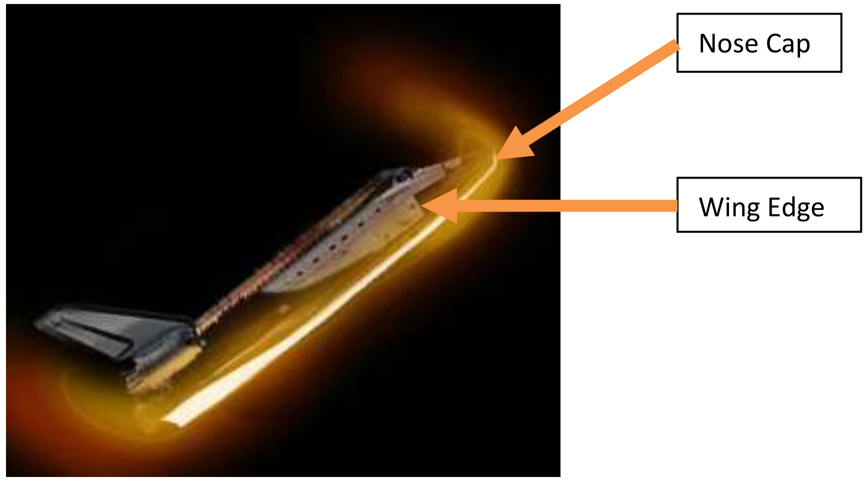


Fig. 2.2.1.1: Space Shuttle upon Entry. Picture from NASA Website

The underside of the Space Shuttle requires thermal protection to protect it from the intense heat experienced during re-entry into the earth atmosphere. This is referred to as a Thermal Protection System (TPS). The TPS on the Space Shuttle combined materials with high temperature resistance with insulating materials designed to prevent conduction of heat into the interior of the aircraft, ultimately protecting both the vehicle and the crew. Different materials were used in different location of the Shuttle depending on the temperature it was predicted to see and the materials thermal survivability, durability and thermal shock capability. For example the nose cap and the wing tips were exposed t to the highest temperatures [72] [73].

NASA is smart enough to know what they don't know and that's why they partner and work with other organizations. They do this by entering into Space Act Agreements. These agreements allow NASA to engage and work with other organizations and share core competencies, this is beneficial to both organizations and the American Tax Payers because it means NASA does not have to develop all core competencies. It's through these agreements that a lot of dual-use (Space and earth) technologies are created. Sometimes they take technology developed for space and put it to use on earth and other times it's earth made materials finding a purpose in Space [74][75].

5.2.2 Bringing the Technology Home

Gentlemen start your engines. One Space Act Agreement NASA entered into was with Rockwell Space Systems and BSR Products, Inc., of Mooresville, North Carolina. There isn't a lot of room in a NASCAR stock car, but there is a lot of heat and this is a perfect earth based application for TPS materials. The Stock Car driver can be exposed temperatures as high as 160C and they can get badly burned or blistered from this exposure. The heat generated by the engine and transmission are radiated to the driver.

Fig. 5.2.2.1: NASCAR Automotive Magazine; Feb 2013

The Flight Director at the Kennedy Space Center was a fan of NASCAR racing and recommended the TPS material to shield the driver from excessive heat.

NASA worked with Rockwell to create and cut patterns that fit around various components of the car to insulate and conduct heat away from the driver.

With the help of NASA BSR Products went on to create and manufacture TPS insulation blankets that are used today on NASCAR Stock Cars. The materials used reduced the temperature by almost 50C and added only 4 lbs. of extra weight to the car; this trade-off was considered acceptable [76] [77].

Fig. 5.2.2.2: BSR Products, floor panels, oil tank blankets, filters, transmission tunnel blankets, and exhaust crossover shields. The insulation lowers race car temperatures and keeps drivers cooler. Courtesy of NASA Spinoff Website

5.2.3 Limitations with Transportation Case Study 2 – NASCAR, Racing toward Earth

There are three types of Space Act Agreements that NASA can enter into with private industry; Commercial Orbital Transportation Services (COTS), Commercial Crew Development (CCDev), and Commercial Space Transportation Capabilities (CSTC). Each of these were created for the development, engineering and testing for design concepts, however the CSTC is different as it only commits NASA to increase their support to the private industries but not financial commitment. This means that although NASA is helping the private sector the companies that wish to enter into a Space Act Agreement will need the financial backing to do so [78].

6. Innovations in Computer Technology

6.1 Case Study 1: Power Converters

6.1.1 Introduction

In electronics, power is everything. Power supplies are the energy centers of electronics. A power supply receives an energy source and then converts said energy to a more useable form of energy for the purposes of ease of usability and stability for electronic components to use. One may wonder then to the feasibility of power converters as compared to just feeding power from the main energy source. There are two reasons why this is necessary.

- Efficiency: In electronics, electrical components mainly use low voltage and high current; power sources however, are generally high voltage and high current. If electrical components are directly tied to a higher voltage power source, then there is a high probability of the component being damaged as it is provided too much power. Even if the component can handle a high voltage source, a lot of power would be wasted through the process. For space applications, power is essential as there is only a finite supply and it would be nearly impossible change existing power structures of an already deployed spacecraft.

- Stability: Power converters also provide stability. The main power source is generally very unstable as it fluctuates in voltage and current due to its nature of needing to power the entire machine. One key feature of power converters is to isolate the electronics from the power source. A power converter ensures that the electronics receive a stable voltage as the converter itself stabilizes the power it provides to the various electronics.

6.1.2 Background

Electronics that are built to work on earth generally have an ambient temperature tolerance of -40 C to 85 C. Majority of electronic components are designed to operate at these temperatures, such components will generally breakdown if the temperature becomes more extreme. Space however is very different. Temperatures in space widely fluctuate. Studies have shown that satellites in space will reach a temperature of -129 C when it's out of sunlight and +120 C when in sunlight. Therefore, due to the harsh conditions of space, electronics needs to be much more reliable and resilient compared to electrical circuits used on earth [79].

For NASA, power converters for space applications are very difficult to implement due to the extreme environments of space. NASA performed a study in 2003 that shows the effect temperature have on power converters and as the graph from the study shows, the extreme coldness of space impacts the stability and efficiency of the power converters greatly.

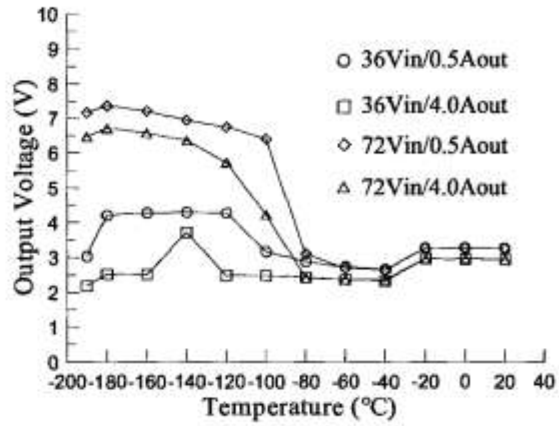


Figure 2- Output Voltage of a DC/DC Converter Module

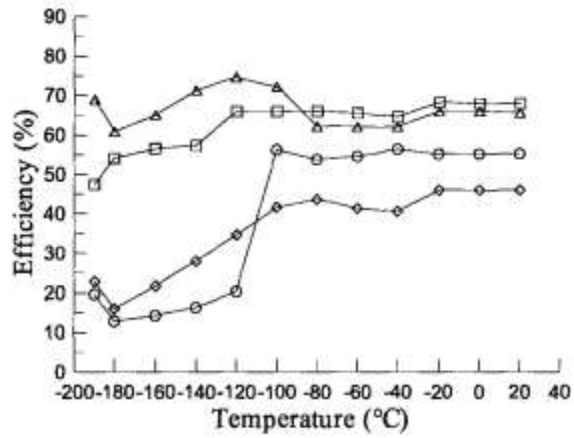


Figure 3 - Efficiency of a DC/DC Converter Module [80]

In addition to the temperatures, cosmic radiation is also a big concern. Cosmic radiations are high energy particles that travel throughout space. While we don't experience cosmic radiations on earth as earth's atmosphere filters them out, in space, the radiations are ever present. Cosmic radiations are dangerous to electronics as it slowly degrades the performance of electronics and eventually, the electronics will not function anymore. This is particularly a concern as modern day electronics keeps on getting smaller and smaller and thereby allowing cosmic radiation to cause more damage.

6.1.3 VPT DC-DC Power Converter

Due to all these concerns, in order for power converters to be reliable in space, NASA has to create a power converter that will be able to withstand the harshness of space as well as maintain basic functions of stability and efficiency.

In 2004, NASA partnered with VPT to design a DC-DC power converter that will meet all of the requirements of working in space. NASA and VPT working together designed a power converter that not only met the requirements but exceeded it. The converter that was designed can withstand harsh temperatures and radiations. In addition to that, the power converter is designed to be a standard package that is usable for all future spacecrafts. This power converter is currently used in New Horizon mission to Pluto, the Messenger mission to Mars, and the lunar orbital reconnaissance. [81]

In addition to uses in space, the power converter also has various uses on earth. Due to its ability to withstand harsh conditions, these converters are used in numerous civilian and military applications. These applications are highly specialized and require the hardware to withstand rapid temperature changes, extreme g-forces, and heavy radiations. In this instance, NASA's innovations in space electronics clearly have a large impact on earth and helped advance the technologies on earth.

6.1.4 Limitations

This technology does have some limitations. One such limitation is that VPT, the company that NASA coordinated, with is a relatively small company and therefore may not be equipped with such a large scale production. In most industrial practices, companies generally dual source their design to ensure that two separate companies are capable of doing production, then in the case of unexpected emergencies happening to one company such as assembly line breakdown or natural disasters, the other company can take over and pick up the slack. In this instance, NASA single sourced the design with VPT without having a second source and therefore can have potential consequences if VPT production line fails.

Another limitation is that this design is not public, for the public to obtain the converter, they have to go through VPT to purchase it. This further illustrates the previous limitation as NASA's demand for the power converter is in low quantities for spacecrafts it only plan on building once, however, the public demand requires continuous supplies for the products and thus having VPT as the only company is a limitation.

6.2 Case Study 2: Image Processing Software

6.2.1 Introduction

NASA not only has hardware achievements, its software achievements are equally impressive. Through NASA's history, various telescopes were pointed at various objects in our universe, however, these objects are very far away and thus a sophisticated image processing software is needed to be able to process all of the data acquired.

6.2.2 IMAGELAB FFT

NASA has a few notable image processing software. In 1990, NASA's Ames research center created a software called IMAGELAB FFT. IMAGELAB FFT first takes a long exposure image, it then digitizes the image and transfers the image onto a supercomputer to calculate the two dimensional Fourier spectrum of the image. By using this method, the software can take a long exposure shot of a star over several months and use the blurred lines of the star and its Fourier spectrum to determine the velocity of an object. This technology is very useful to NASA as it can calculate the velocity of movement of stars and other objects observed by NASA telescopes. As computing technology becomes more advanced, a supercomputer is no longer needed and this software becomes commercially available. Adaptations of this software are now used by law enforcement and other organizations to analyze security footage for banks and other related enterprises. [82]

6.2.3 Web Coverage Processing Service

To continue on the image processing work, in 2000, NASA launched the Earth Observing 1 Satellite. This satellite is used to map the topology of the earth. In order to process the data properly, NASA created an image processing framework called Web Coverage Processing Service (WCPS) that allows dynamic upload of processing algorithms and data from satellite and airplanes. This platform is very beneficial to image processing as it allows data to be cross checked and calculated to produce a more meaningful result. The flowchart below shows an example.

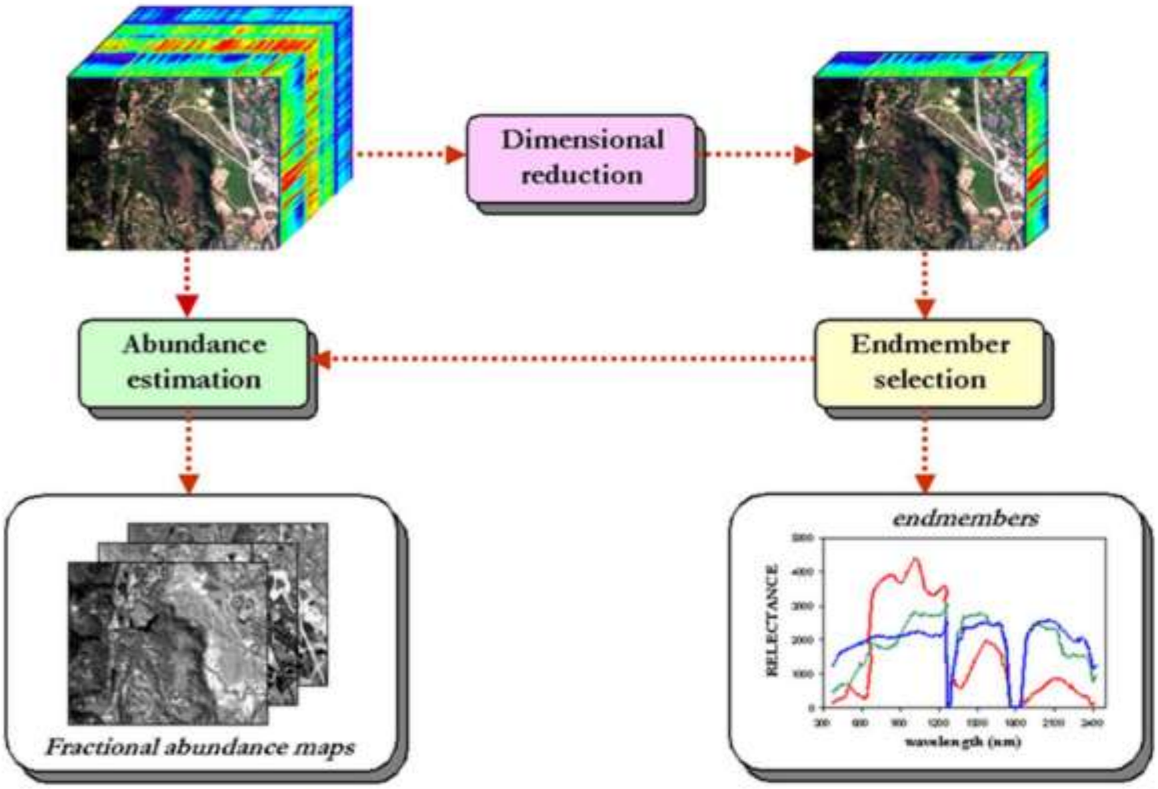
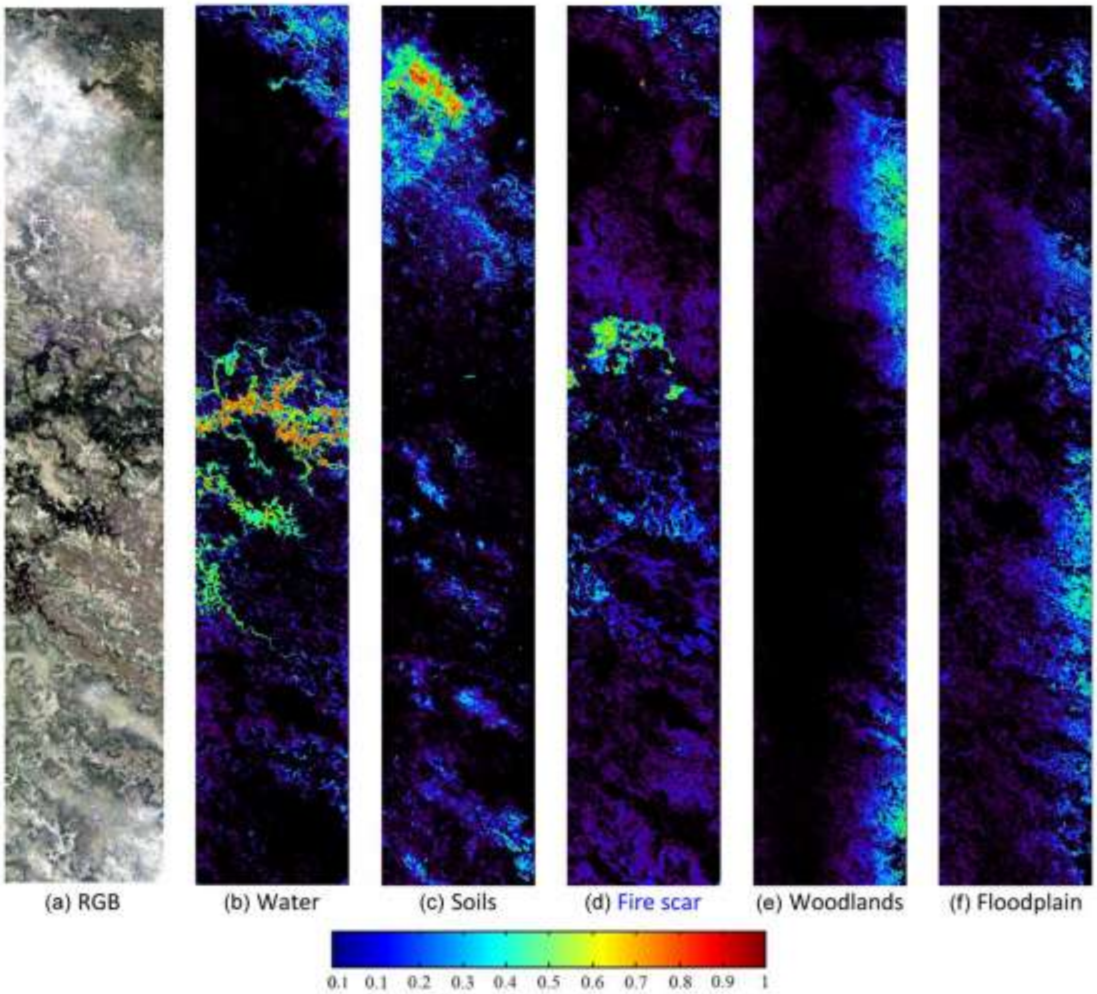


Fig. 6. Spectral unmixing chain implemented in this work in WCPS.

[83]

In this instance, the satellite image is crossed checked with existing satellite images and calculations are performed to determine the abundance of certain landscape features.



(g) Color map used for the representation of abundances

[83]

The features then can be color coded to produce a color map that shows representation of key features. With these features NASA shortens the time and effort of earth image processing and allows for more accurate calculation and analysis. The WCPS software platform is currently available for the public and is very useful by organizations for geography analysis.

6.2.4 Limitations

While the system is hugely successful to NASA, it has a few limitations while made public. First of all, the system is reliant on NASA's array of satellites for images. Since satellite imaging technology has a very high barrier of entry and involves sending satellites up into space, raw satellite images are hard to obtain and therefore the NASA WCPS software platform is only available to a small amount of public companies such as Google that can afford the infrastructure to do so. There may be some security implications on releasing NASA satellite images however; if possible, NASA should consider releasing its earth images for public use.

Another limitation is the fact that the algorithm needed to process these data is highly complex and requires highly skilled individuals that understand satellite imaging, image processing, and earth geography to be able to provide an accurate analysis of the data, these individuals are hard to find and NASA can help the public more by making internal resources and analysis of the data public thereby providing a head start for everyone else.

7. Innovations in Consumer Products

7.1. Background

A consumer product has many attributes that make it suitable for a particular purpose. These attributes arise out of need for the product itself, and may be borrowed from other products from the same field or distinct fields. Some of these even arise as a result of research performed by individuals or organizations. The social and economic considerations for consumer products also vary widely based on external factors such as the availability of raw material, the per capita income, the effect of the product on the environment etc. A successful consumer product can only survive in the market if the company making the product has an excellent understanding of the market's needs and conditions. In the case of NASA, a lot of the technologies that have been developed for space exploration have found themselves embedded in products that consumers use, without the latter even knowing about the origins of the same. This has largely been accomplished via the NASA Innovative Partnerships program, which has helped transfer NASA technology to the private sector. In 1962, as a result of a 1958 congressional mandate, NASA created the Technology Utilization Program, which was supported by Technology Utilization Offices in each of the four field centres and four Industrial Application Centres. Ever since then, NASA has been active in the exploration and development of technologies whose benefits encompass the various fields, including consumer products. The goals of his project are manifold, such as the justification of NASA's expenditure, informing the public about the benefits of the technology, and dispelling the myth of wasted taxpayer dollars. It also serves to highlight the global competitiveness and technological leadership of the United States government.

7.2 Case studies of innovations in consumer products

There are many consumer products that have arisen out of technology that NASA has developed for space exploration purposes, the most notable being the ones listed in [84]. In the following sections, we examine 2 case studies in detail, and their applications to everyday life.

7.2.1 Water filtering using Acoustic Nanotube technology:

Water filtering has often been used to clean water for irrigation, drinking, and swimming. Currently, various filtration techniques exist, such as sieving, adsorption, ion exchanges, and biological metabolite transfer. All of these require energy in some form, and are slow when it comes to filtering. Therefore, there is a pressing need to use filtration techniques that are portable, non-expensive, use minimal amounts of energy and are fast.

NASA has developed a technique for filtering water using ultrasonically vibrating nanotubes [85]. These devices, characterized as acoustically driven molecular sieves, are used for filtering water to remove all biological contaminants and all molecules larger than water molecules. Originally intended for purifying wastewater for reuse aboard spacecraft, these devices could also be attractive for use on Earth in numerous settings in which there are requirements to obtain potable, medical-grade, or otherwise pure water from contaminated water supplies. These devices could also serve as efficient means of removing some or all water from chemical products — for example, they might be useful as adjuncts or substitutes for stills in the removal of water from alcohols and alcoholic beverages. These devices may be constructed using various materials, such as ceramics, metals, or polymers, depending on end-use requirements.

A representative device of this type (see Figure 7.2.1.1) would include a polymeric disk, about 1 mm in diameter and between 1 and 40 µm thick, within which would be embedded single-wall carbon nanotubes aligned along the thickness axis. The polymeric disk would be part of a unitary polymeric ring assembly. An acoustic transducer in the form of a piezoelectric-film-and-electrode subassembly — typically 9 µm thick and made of poly(*vinylidene fluoride*) coated with copper 150 nm thick — would be affixed to the outside of the outer polymeric ring by means of an electrically nonconductive epoxy. The nanotubes would be chosen to have diameters between about 8 and about 13.5 Å because water molecules could fit into the nanotubes, but larger molecules could not. Water to be purified would be placed in contact with one face (typically, the upper face) of the filter disk. The surface tension of water is low enough that water molecules should enter and travel along the nanotubes. The acoustic transducer would be excited by means of an oscillator operating in the frequency range from 50 to 200 MHz. The resulting acoustic waves would be coupled via the polymeric ring and disk to the nanotubes and water molecules. The acoustic energy transferred to the water molecules by the acoustic waves would, conservatively, equal or exceed the specific heat of fusion of ice — sufficient to cause the water molecules to become detached from each other, collectively behaving more like liquid water. Thus, the acoustic excitation would enable water to flow more freely along the nanotubes and to leave the filter disk on the lower face.

Devices of this type would be scalable to larger diameters and power levels and to multiple-filter assemblies. A single-filter device having the dimensions described above could be powered by a 9-volt battery. Larger assemblies could be powered from household and industrial power lines. A diagram of the same is shown on the next page.

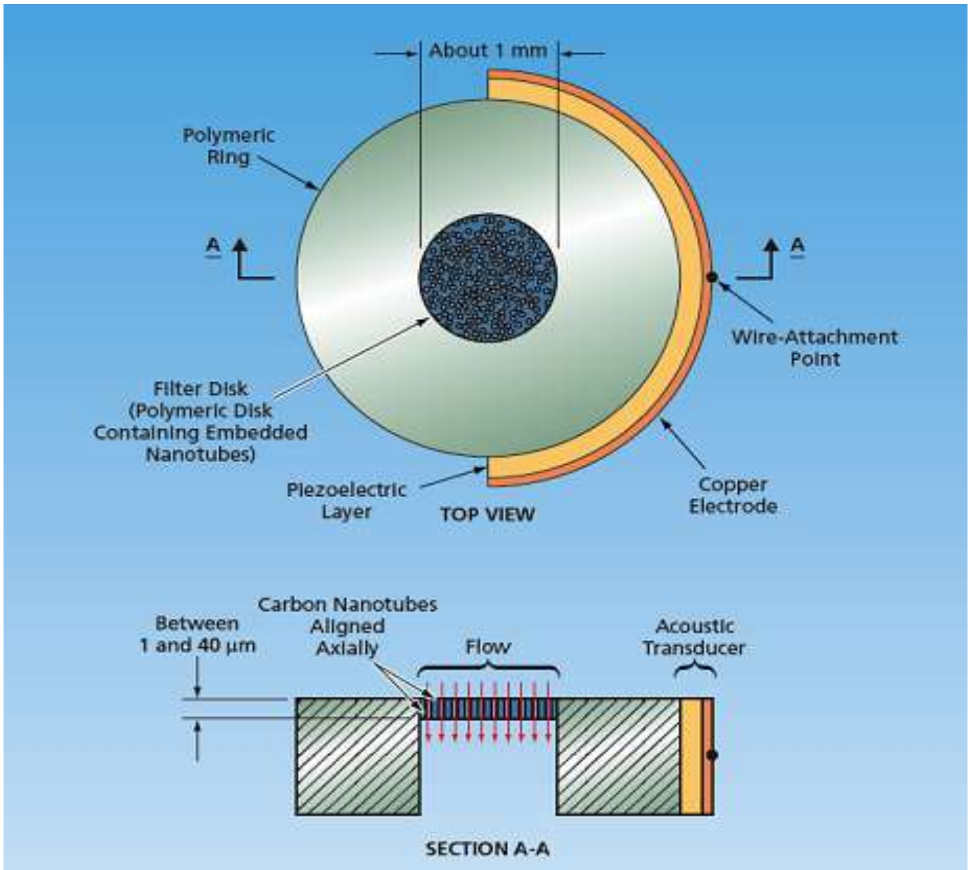


Fig. 7.2.1.1 Water filtering using Acoustic Nanotube Technology.

7.2.2 360º camera:

Various kinds of photography use different kinds of cameras. Panoramic photography, for example, uses specialized equipment or software to capture images with an elongated field of view. An image showing a field of view approximating, or greater than, that of the human eye – about 160° by 75° – may be termed panoramic. This generally means it has an aspect ratio of 2:1 or larger, the image being at least twice as wide as it is high. Both the aspect ratio and coverage of field are important factors in defining a true panoramic image [86]. In panoramic photography, separate images are taken across different angles and are combined using software to provide a 360 º field of view. An example is illustrated below:

Fig. 7.2.2.1 Three separate images of a house near a beach.

Fig. 7.2.2.2 Panoramic view generated by combining the above images

NASA developed a camera called the '*Mars Gigapixel Camera*' and fitted it onboard the Curiosity rover to capture a 360º panoramic view of Mars. The images for the view were obtained from the two Mast cameras on the rover. One was the '*Narrow Angle Camera'* (NAC) that had a 100 mm focal length, while the other was the '*Medium Angle Camera'* (MAC), which had a 34 mm focal length. The mosaic, which stretched 90000x45000 pixels, included 295 images from NAC taken on Sols 136-149 and 112 images from MAC taken on Sol 137 [87]. Between November 2007 and January 2008, new, fixed-focal length (FFL) Mastcam designs were generated, based on using the MAHLI focus mechanism design; these cameras are described below.

The FFL Mastcams consisted of two cameras with different focal lengths and different science color filters. The stereo baseline of the pair was ~24.5 cm. One camera, referred to as the Mastcam-34 (M-34, also called MAC), had a ~34 mm focal length, f/8 lens that illuminated a 15° square field-of-view (FOV), 1200 × 1200 pixels on the 1600 × 1200 pixel detector. The other camera, the Mastcam-100 (M-100, also called NAC), had a ~100 mm focal length, f/10 lens that illuminated a 5.1° square, 1200 × 1200 pixel FOV. Both cameras could focus between 2.1 m (nearest view to the surface) and infinity. Color thumbnail images of 150 × 150 pixels could be created simultaneously with the acquisition of full scale images, or during processing just prior to downlink. Mastcam hardware and internal processing permitted a wide range of operational flexibility. Each camera was capable of acquiring images at very high frame rates compared to previous missions, including 720p high definition video (1280 × 720 pixels) at ~10 frames per second, and full science frames at somewhat greater than 5 fps. It took between 30 and 45 seconds to rotate the filter wheel a full 360°.

Fig. 7.2.2.3 Mastcam-34 (MAC) and Mastcam-100 (NAC) cameras

Fig. 7.2.2.4 Curiosity self-portrait on Mount Sharp. January 2015 (Panoramic)

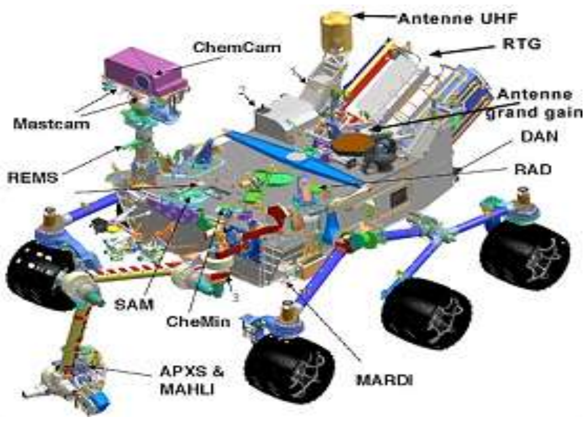


Fig. 7.2.2.5 Location of the MAST camera system on the Curiosity rover **[88]**

Nowadays, the panoramic technology developed for the MAST camera system is used in a variety of applications. Bubl Technology Inc. has developed the Bublcam, which is a camera that is roughly the size of a small baseball, and is capable of capturing 100% of the spherical range through panoramic photos and videos. The patent-pending tetrahedral design allows the 4, 190º lens to overlap, capturing everything within a digital '*bubl*'. A tri-axial accelerometer is used for image stabilization [89].

Fig. 7.2.2.6 Bublcam

Fig. 7.2.2.7 Images from Bublcam

Another 360 camera application is the GIROPTIC 360 cam. It can capture 360 º equirectangular video images at a resolution of 2048 x 1024 at 30 frames per second and 4096 x 2048 sized images as well. Three optics and three sensors are used for capturing these images. A mobile-phone based application allows the user to control the camera via Wi-Fi, and sound can be recorded via three microphones located on the camera. The camera can be fitted to any light-bulb socket, and features a removable and rechargeable battery and a fixture for fitting it on a tripod stand as well [90].

Fig .7.2.2.8 GIROPTIC camera

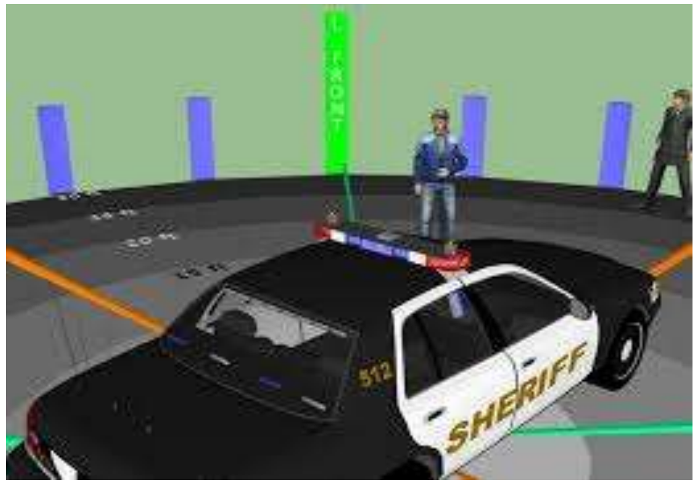


Fig 7.2.2.9 GIROPTIC camera used on a police car

We now turn our attention to the social and economic considerations that drove the creation of these products**.**

7.3 Social and Economic Considerations

With regards to economic considerations on water filtering using carbon nanotubes, we observe that carbon nanotubes require less power than conventional filtration systems, because the only process that requires power is electrolysis. The small amount of power nanotubes require can be provided by energy sources such as solar, wind energy or gravity. These filters are reusable and do not require replacement like common filters. Also, the filters can be cleaned by heating to excess of 121 °C. Since, the nanotube filters do not require a high amount of manpower to maintain they are ideal for implementation in remote areas. Carbon nanotube filters are also much more efficient than its competitors. For example, a study carried out by nSpring, a nanotechnology company, found the cost of filtration per 1000 gallons of compound to be about 70$ compared to: Brita's 273.91$, Everpure's 229$, and Kenmore's 198.99$, and PUR's 299.59$. The huge disparity in cost occurs because, rather than carbon nanotube technology, these companies rely instead on methods of water purification such as reverse osmosis, ultraviolet disinfection, and chloramine disinfection. These numbers indicate, then, that nanotechnology filtration is much more cost efficient than traditional methods of purification [91]. With regards to social and economic considerations when using the 360 º camera, we find that it has widespread applications when it comes to recording lectures for online education, monitoring parking in unreserved areas, as well as sharing information quickly in the digital age.

It could be used by engineers to capture pictures at difficult angles, by weather stations for weather forecasting, and for hobbyist projects as well. It could also be used in automobiles to prevent accidents, as well as by law enforcement for monitoring crimes remotely. It could also be used in sports such as football and ice hockey for goal-line technology as well as in cricket to measure the speed of the ball and for decisions referred to the third umpire. Normal 360 º camera prices range from 200-900 US $, and the Bublcam (700 US $) and the GIROPTIC (220 US $) seem to lie in the same price range but offer more capabilities. Hence, we do see that technology developed by NASA has gone a long way in helping the development of innovative and exciting consumer products.

7.4 Conclusion and Recommendations

The spin-offs resulting from NASA technology have been described in the sections above, with special emphasis being placed on water filtering using nanotube technology and the 360 º camera. The applications of the same were described and the social and economic considerations of these applications were examined. However, there is still room for improvement of these technologies in order to make them more environmentally friendly and feasible for re-use on multiple missions. Though there have not been enough studies done to know the biological effects that would result from the utilization of carbon nanotubes in filtering water, potential side effects have been hypothesized such as: liver damage due to ingestion of nano-particles, DNA and cell mutation due to absorption of nano-particles, and other toxic side-effects. Additional toxicity tests must be carried out in order to justify purification of water by means of nanotechnology as ethically sound. Also, three areas of environmental concern have arisen: toxicity, bioaccumulation, and persistence. These areas of concern would only be pertinent if the carbon nanotubes were to escape into the environment. If the nanotubes were toxic, they could degrade the environment and its organisms. Bioaccumulation would ensue as the result of a buildup of carbon nanotubes in the environment. Such a build-up could pose serious long-term problems such as degradation. The persistence of the nanotubes or the ability to decompose could also cause long-term destruction of the environment. The endangerment of the environment would have adverse effects on human beings as well. Some solutions involve the increase in regulations with regards to nanotechnology, development of biological suppressors that can prevent indiscriminate nano-particle replication and regulate the disposal of the same. In the case of the 360 degree camera, there are issues related to the biological degradation of the materials used for making the camera. The size of the cameras is also a big issue as they require space on the rovers, and the rovers need to be light in order to move fast. A possible solution might be the usage of smaller near-field view cameras surrounded by rubber padding, and a central processor to combine the images generated to form the panoramic view. This could also be alternately accomplished via CubeSats [92] which are miniaturized satellites built using off-the shelf materials and used in space exploration. A number of these could be outfitted with cameras and launched with rover and send their images for final composition on the rover before transmitting back to Earth. It is hoped that the application of these recommendations can improve the usability of these products and make their benefits more accessible to the common man.

8. Conclusions and Recommendations

This report has explored numerous inventions initiated by NASA Programs and analyzed the transfer of developed technologies for public benefit in five areas. The research has identified that space exploration and NASA's inventions have created new technologies that have led to rapid advancements in sectors such as medicine, environment and energy, transportation, computer technologies and consumer products.

This report has identified a number of issues and limitations that are characteristic of the way NASA does business. For instance: complex and slow federal government procedures, intellectual property challenges, contradictions in the technology transfer programs - all of which impede or slow down the successful launching and implementation of technologies. This results in reduced benefits, and at times exhibits substantial delays in the transfer of new technologies into the private sector. Solving these issues facing the space agency require a more collaborative attitude that sits on the pedestal formed through teamwork and knowledge sharing between stakeholders. A change in the system may not occur promptly but it is necessary to foster innovation, as Stephen Armstrong suggests, change management is a very profound process to establish and maintain. Additionally, it should be stressed that innovation gets achieved through lessons learned and transformation, therefore NASA needs to revive its organizational culture and draw a management strategy attuned to long-term future, which could make their innovations more valuable to society. Moving forward, NASA should:

- Be oriented toward being an organization that promotes a tomorrow that is tuned to the future demands, an external environment that addresses the needs of all stakeholders and a culture of innovation that encourages individuals who initiate change.
- Make effort toward developing programs and policies that inspire a degree of trust between businesses and government.
- Consider a more proactive collaboration with other space agencies as it is in everyone's interest to explore space, the agencies should find ways to work together and share rather than compete and work in secrecy.
- Act as an agent and negotiator to develop partnerships between private sector companies and government agencies in order to help these companies overcome financing difficulties.
- Work in concert with its partners and industry to overcome challenges and thereby enable the public to appreciate the significant benefits of the research leading to the development of novel products.
- Release more data, algorithm, and software to the public to reduce the barrier of entry into the field thereby receiving more collaboration with the public.
- Check the progress and the impact on the economy of transferred technologies continuously.
- Improve the knowledge management system by sharing knowledge, integrating distributed knowledge, capturing knowledge and modeling expert knowledge more efficiently.

Finally, it should be emphasized that these issues are challenges to both NASA management and personnel. Since innovation is achieved through people in organizations, this report encourages NASA management and personnel to challenge these issues such that the major objective of the authors is accomplished.

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