UNIVERSITY OF AGDER

From Space Technologies to Everyday Technologies

Kristoffer Liland

Elisabet S. Hauge
Elisabet S. Hauge

This master's thesis is carried out as a part of the education at the University of Agder and is therefore approved as a part of this education. However, this does not imply that the University answers for the methods that are used or the conclusions that are drawn.

University of Agder, 2015
School of Business and Law
Department of Working Life and Innovation

From Space Technologies to Everyday Technologies

"It is difficult to say what is possible, for the dream of yesterday is the hope of today, and the reality of tomorrow" - Robert H. Goddard, founding father of modern rocketry.

Investing in Space - An Introduction

NASA has closely organised the results of the Spinoff program all the way back to 1973 and has shown that the agency has generated and detailed almost 2000 spinoff innovations into the private market (NASA, 2015A; NASA 2015B) Estimates say that anywhere from 7 to 14 dollars of return on investment (ROI) from every single dollar invested into NASA(Great Business Schools, 2014). NASA's Technology Transfer Program purposes to make sure the technology developed for missions in exploration and discovery become available to the public at large and thereby maximizing the potential benefit to the people of the United States (NASA, 2015C).

Problem & Research Questions

Coming from a position of understanding of how the space industry operates during the last three years in the milieu, and the last two years professionally, I've learned a lot and made many assumptions. In this master thesis, I seek to explore my understanding of NASA's influence in people's daily lives. I will argue and discuss how NASA's spinoff program has been incredibly successful, and that investing in the agency has benefitted the public at large. What I would like to better understand is how this happens, how does NASA generate such spinoff innovation, and what are some specific innovations that have become everyday technologies?

Therefore this master thesis posits the following two research questions:

How do NASA investments in space technologies contribute to spinoff innovations in private industries?

and

What innovation model do NASA spinoffs prefer when developing new technology?

The study will present several cases that explores spinoffs innovation model preferences and highlights how the NASA Technology Transfer Program realizes innovations that come into into everyday, public life.

Contextual Background

NASA - the National Aeronautics and Space Administration -

NASA (the National Aeronautics and Space Administration) is the principal government organisation with dedication to space and aeronautics in the United States of America. It's vision statement is *"We reach for new heights and reveal the unknown for the benefit of humankind."* NASA influences a whole range of industries both directly and indirectly, and has for decades contributed to realize many important high-tech innovations that have been introduced for home and everyday use. To understand how NASA contributes to the influence of people's daily life, it is important to describe the background of the organisation NASA. This chapter attempts to highlight NASA's background and organisation (NASA, 2015D).

The Organisation

NASA headquarters is located in Washington D.C. From here NASA is managed under current administrator Charles Bolden. NASA spans ten field centres, but overall encompasses more than 22 work centres across the US, which cover the range of conduct that NASA works with, such as laboratories, airfields, wind tunnels, launch ramps and control rooms (NASA, 2015D).

NASA has four mission directorates, which are four specific directions of work for NASA. The four missions are as following (NASA, 2015D):

- **Aeronautics**: Researches air mobility in manners that are more environmentally friendly and sustainable, while also finding and bringing in technology from outside aviation that helps its pursuits.
- **Human Exploration and Operations**: Main work in the operations of the International Space Station (ISS) as well as the development of commercial spaceflight and human

exploration beyond the ISS, which is stationed in low-Earth orbit (LEO). This includes future human exploration of the Moon, Mars and other bodies in the solar system.

- **Science**: NASA also explores the Earth, the solar system and the greater universe. By this NASA attempts to define the best path to discovery and how to pass the benefits of this research onto society.
- **Space Technology**: Develops, innovates and demonstrates radical technologies that enable NASA's missions into space, while simultaneously providing many of these innovations to the public that they may contribute to economic growth.

The History of NASA

NASA was established in 1958 by U.S. President Dwight D. Eisenhower. The organisation was founded partially as a result of the Soviet Union having launched its first artificial satellite, Sputnik (Russian: satellite/fellow traveller), the previous year (NASA, 2015D).

The same year, NASA grew out of the National Advisory Committee on Aeronautics (NACA). This organisation had been operating for over 40 years researching aviation and avionics technology. NASA continued the aeronautics research carried out by NACA (National Advisory Committee on Aeronautics). At at the same time, the new organisation also committed to conducting pure scientific research in addition to the development of space technologies (NASA, 2015D).

President John F. Kennedy's contribution was to stimulate NASA to refine the focus and mission in the direction of putting astronauts on the moon by the end of the 1960s. The Mercury (1961-1963 - 6 flights)(NASA, 2008) and Gemini programmes (1965-1966 - 10 flights)(NASA, 2011) developed many of the technologies and skills that the organisation needed to achieve this goal, which was followed through by the overarching Apollo program. Neil Armstrong and Buzz Aldrin, on July 20th, 1969, became the first two persons out of the 12 who walked on the moon, rising to the challenge set forth by Kennedy (NASA, 2015D).

Further on, NASA developed the first weather and communication satellites. Several satellites such as the Terra, Aqua and Aura Earth Observing System are orbiting the planet Earth; they help us understand how our own planet is changing. NASA also has aeronautics teams that work on improving aviation in order to meet the growth in the global demand for air travel (NASA, 2015D).

The Apollo program was followed by the Space Shuttle, and this spaceship would provide regular access to space. It was first launched in 1981 and flew more than 130 successful missions before it was grounded in 2011. With the Space Shuttle, the United States and Russia realized a permanent human presence in space. Since the year 2000 the International Space Station (the ISS), has become a multinational project spanning 15 nations (NASA, 2015D).

NASA continued its scientific research and in 1997 the Mars Pathfinder became the first of many spacecraft and rovers with the goal to explore the planet Mars. In the last decades NASA and its partners have tried to determine whether life has existed on Mars, and if so whether it still does (NASA, 2015D).

Hence, throughout the NASA history, the organisation has conducted, stimulated and enhanced research that resulted in a multitude of benefits to the life on our planet. How NASA contributes and affects people's daily lives constitutes the contextual background of my study. My study on spinoff innovations will use NASA as a starting point for a case study, and will delve into how these innovations move into everyday life (NASA, 2015D).

NASA Spinoff

Due to congressional mandate in 1962, NASA created the Technology Utilization Program, a program designed to transfer aerospace technology to the private sector (NASA, 2002). From the 60s to the 80s the number of Technology Utilization Offices grew from four to ten units. NASA published the Tech Briefs, a publication dedicated to inform the scientific community about NASA technologies available to the public. The many requests that were received for more information showed there was a strong need in the private sector for new technologies that would aid in a generation of new commercial products and services (NASA, 2015B)

In 1973 NASA published the first Technology Utilization Program Report, followed by a second report in 1974 (NASA, 2015B). These were a direct result of spinoff products emerging from space technologies, and the publications generated a lot of interest in technology transfer as a concept, its successes, and as a tool for public awareness. For these reasons, NASA made them into a yearly publication named Spinoff. Spinoff was published for the first time in 1976 this was followed by a new issue every year. Spinoff has a special focus on technology transfer from NASA to the private sector. Spinoff is read by lawmakers, economic decision makers, business leaders, academicians, technology transfer professionals, the media and the general public(ibid.)

Spinoff fulfills several NASA goals. It shows that NASA funding generates economic growth and is a tool to educate the media, as well as a tool to dispel myths of wasted taxpayer dollars The journal Spinoff also contributes to maintain and reinforce interest in space exploration. It shows the highlights of American inventions and inventors, entrepreneurs and engineers, as well as showing government willingness to assist in innovation. Since 1976 almost 1,800 stories have been showcased, which does not include the roughly 100 stories of spinoff innovations from the '73 and '74 reports (NASA, 2015B; NASA, 2010).

Examples of Spinoff Innovation At NASA

This chapter presents examples of NASA spinoff innovations. I will use these examples to show the scope of work that NASA influences. Some of the cases will be utilized in the study as empirical contributions to answer the research question;

How has NASA investments in space technologies contributed to spinoff innovations in private industries?

Space Technology

Prominently NASA's innovations are connected to technologies related to the organisation's core mission, aeronautics and astronautics with related science and technology goals. For this master it makes sense to show how NASA creates and generates spinoffs that cannot be used for its own purpose or which they do not have the funds to work on themselves.

Bigelow Aerospace's B330 module, which is currently under development, comes from the NASA Transhab technology that was developed in the late 90s, originally for the International Space Station (Bigelow Aerospace, 2015; Lieberman, 2015). Its original intent was to be a much larger space station module that could inflate itself from a contracted position. The space station module could also serve as a dual-purpose module by being a transport habitat for deep-space flights, hence the name Transhab. Bigelow Aerospace revived this technology through NASA's Technology Transfer Program, and named it B330, Bigelow's first live test module, the BEAM, will go to the ISS on the 6th of January, 2016 (Lieberman, 2015).

Outside Aerospace & Aeronautics

The rotary drill is among the cordless power tools invented in cooperation with Black & Decker as an important example of how aeronautics and astronautics tools get usage outside of space. Black & Decker had invented cordless power-tools, but with the help of Martin Marietta and NASA, Black & Decker expanded on this technology as a result of a lack of power-plugs in space. One challenge they had to solve was how to use a drill in space by not rotating the astronaut, and to use software to utilize less electrical power and to be more efficient and compact at the same time. The rotary drill is an example of the rigorous demands of space pushing new technology or vast improvement of technology (NASA, 1981).

To illustrate just some of the scope of the NASA spinoffs the following section presents a short list of several technologies that are being used widely on Earth in everyday lives (Space Foundation, 2015).

- DeBakey blood pump (based on the design for liquid propellant turbine pumps for rocket engines, to pump blood around without damaging blood cells)
- Improved firefighter's breathing system (Developed from Apollo astronaut life support systems)
- Seismic damper technology (Allows for earthquake-secure buildings)
- Cochlear implants
- Tempur foam (used in beds)

- Micro-Algae Nutritional Supplements (for generation of essential fatty acids, used among others in formula for children)
- LED for medical applications (curing cancer, speeding up growth of tissue)

NASA Today

Today NASA is involved in a multitude of projects. NASA has attempted to expand the focus for humanity in its next big mission; "NASA's Journey to Mars". NASA is developing the capabilities to send human missions to asteroids and to Mars. Mars is already studied for its climate which once had conditions suitable for life (NASA, 2014). NASA just recently announced they had found liquid water on Mars, a discovery that makes it promising for finding existing life beyond the confines of our planet (Redd, 2015).

The "Journey to Mars" begins with The ISS. Astronauts are permanently living and working in space. Researchers conduct research that helps to uncover how humans will live and work off Earth over extended periods. U.S. commercial companies like SpaceX and Orbital ATK are supplying cargo to the ISS and will within a few years' time launch astronauts again from American soil (NASA, 2014). This way NASA breaks ground and develops a private industry that aims to increase access in general for more companies, organisations and people to space. Additionally a part of the ISS is a U.S. national laboratory where NASA conducts a wide array of scientific research such as technology, biology, human research, biotechnology, Earth science, physical sciences and educational activities (NASA, 2015E).

For its journey beyond the moon and into the solar system the organisation is developing a highly advanced rocket and spacecraft, which is called the Space Launch System. The spacecraft Orion will carry four astronauts to missions beyond lunar orbit. This spacecraft will be launched from the Kennedy Space Center in Florida. The Space Launch System will be able to return a capability of launching that was not seen since the Apollo program (NASA 2012).

NASA is working on a mission named the Asteroid Redirect Mission, which will be the first mission that ever has been made to identify, capture and direct an asteroid near earth to a stable orbit around the moon. Further, it will be explored by astronauts, whom will return samples. This mission is designed to test for what spaceflight capabilities are needed to go to Mars (NASA, 2015D).

NASA is continually studying the Earth, and will through current and coming spacecraft contribute to answer many of the questions we have regarding climate change, sea levels, freshwater and other weather events that impact human lives (NASA, 2015D).

The aeronautics team is working with government organisations, universities and industry to make air transportation better, and to maintain the competitiveness of American aeronautics (NASA, 2015D).

A series of robotic explorers is both in Mars orbit and on its surface, working ceaselessly to provide NASA with potentially important knowledge that creates a better understanding of the planet for future human explorers (NASA, 2015D).

New Horizons passed by Pluto on July 14th, 2015 and was the first spacecraft to do a close up photo of the dwarf planet (Chang, 2015). The Juno spacecraft is set to reach Jupiter next year. Additionally multiple NASA missions are studying the sun, the solar system and attempt to unravel the questions we have about their origins. By being able to understand the sun's variations we are better at understanding and characterizing space weather, which may impact exploration of space and technology on our planet (NASA, 2015D).

NASA also operates a number of telescopes looking into the further reaches of our galaxy and the universe. The Hubble Space Telescope has been in used space to take pictures of faraway places for 25 years. The telescope will be replaced by its successor the James Webb Space Telescope within a few years. In addition there is the Kepler telescope which helps us discover planets in other star systems than our own (NASA, 2015D; NASA, 2013).

Regulatory Context

I will use this chapter to show how the Aerospace industry in general is tightly regulated for national security reasons for the United States of America, and more specifically the International Trade of Arms Regulations (ITAR).

ITAR - International Trade of Arms Regulations

ITAR is an american regulatory system to prevent other undesirable nations getting ahold of weapon systems and military grade technology that constitutes a national safety concern. The Arms Export Control Act gives the President of the United States the power to designate the articles and services that are considered defense related. This role is currently delegated to the Secretary of State who places these articles and services on the U.S. Munitions List. All defense articles and services on this list are under permanent or temporary import control under the authority of the Attorney General and the Secretary of State. Articles and services are chosen in cooperation with the Department of State and the Department of Defense (Arms Export Control Act, 1993).

Civilian rocket technology and space grade technologies are also largely regulated by this system of laws as shown on the list below. These laws enforce special rules regarding citizenship of labour, licensing, sharing of information and technical data across companies and borders and determines which countries may export and import defense articles and services, with a clear beneficial exemption to NATO countries and close trade partners of the United States (Arms Export Control Act, 1993).

Category IV—Launch Vehicles, Guided Missiles, Ballistic Missiles, Rockets, Torpedoes, Bombs, and Mines

*(a) Rockets, space launch vehicles (SLVs), missiles, bombs, torpedoes, depth charges, mines, and grenades, as follows:

(1) Rockets, SLVs, and missiles capable of delivering at least a 500-kg payload to a range of at least 300 km (MT);

(2) Rockets, SLVs, and missiles capable of delivering less than a 500-kg payload to a range of at least 300 km (MT);

(3) Man-portable air defense systems (MANPADS);

(4) Anti-tank missiles and rockets;

(5) Rockets, SLVs, and missiles not meeting the criteria of paragraphs (a)(1) through (a)(4) of this category;

SOURCE: UNITED STATES MUNITIONS LIST, INTERNATIONAL TRADE OF ARMS REGULATIONS §121

Sample from the US. Munitions List showing how Launch Vehicles (spacecraft that send cargo or humans) to space are considered to be defense articles and therefore regulated as such (Arms Export Control Act, 1993).

Method & Methodology

Here I will highlight my methods for conducting this study and thesis, as well as my methodology as a researcher.

Methods

Methods are the specific data-collection and analysis choices made by the researcher (Halvorsen, 2008). Specific methods garner specific datasets, and the main separation between methods are quantitative and qualitative methods.

This thesis will be a qualitative case study of selected cases of spinoff innovations from NASA technologies. A case study is research conducted on just one or few research units, such as a family, a company or a community (Halvorsen, 2008). In this this study these research units comes down to specific spinoffs from NASA. The selection of cases is not made to generalise, but for analytical purposes. Cases can be selected based on what one considers unique occurrences or phenomena, or phenomena that are considered typical (ibid.). These kinds of studies may be focused on processes, that is, how something occurs or develops, and often this means using qualitative methods (ibid.). This could also mean to use a case to cast a critical light on the selected theory (Repstad, 2007). Organisational studies are often case studies which are pragmatically segmented (ibid.). The case studies in this paper seeks to illustrate the pathways chosen by NASA and spinoff capitalisers to generate innovation, and particularly those innovations that spinoff into everyday use.

The method employed in the study is a qualitative case analysis that utilises text-analysis as its sole research method. The case is constituted by the use of information directly from NASA, and other case based agents and actors, from documents and publications, as well as documents directly detailing spinoff innovators and producers.

Qualitative methods deals in characterisation of studied phenomena (Repstad, 2007) They are used when the researcher wants a deeper insight in a defined or observed phenomenon. While it is said that quanta and numbers are not important to qualitative methods, these methods still use terms such as "most seem to think", "by and large this is the case". It is human to count, so when we say that counting is subordinated in qualitative methods as opposed to quantitative methods it means that the systematic use of numbers as an aid to the analysis is mainly absent in the use of qualitative methods (Repstad, 2007).

Qualitative methods are flourishing, though the four common ones are observation, field-work, interviews and text-analysis (ibid.). I will use the last one, text-analysis, because data on NASA spinoffs are well documented and accessible. Qualitative methods don't normally go in width, depth in its research. This means that few or just a single point of analysis with all its concrete nuances are studied (ibid.). This thesis can be called a phenomenological study. Rudestam (2007, p. 106) defines phenomenology as "[...] *a phenomenological study usually involves identifying and locating participants who have experienced or are experiencing the phenomenon that is being explored.*" Phenomenological research uses idiographic sampling, meaning it's focused on the individual or case studies in order to understand the total and complex experience (Bailey, 1992, in Rudestam, 2007).

Important data sources in this master thesis is documentation produced by NASA. As previously shown; NASA has documented spinoff technologies since 1973, and actively published the *Spinoff* magazine since 1976. Other than that spinoff capitalisers have provided part of the information through their websites, or information has been provided through space advocacy organisations. All of this is available online.

The cases that I have selected have all been featured in *Spinoff*, NASA's magazine detailing successful spinoffs. The reason for their choice have been to cover a varied range of industries, that is the typical cases, but also some due to their initial surprising distance from aerospace technology in addition to being somewhat relatable technologies for everyday use or that affect something in our everyday use, meaning they can also be exemplary cases. Through analysing their documented history, the actors, agents and networks that may have taken part in its development either as the original generator or the capitaliser of the spinoff opportunity. I am looking into their initial spark in order to understand some of the how, especially regarding innovation models and their evolution in the spinoff path.

Methodology

Arbnor & Bjerke (2009, p. 3) denotes methodology as "[...] *a mode of thinking*" but also "[...] *a mode of acting*". Within methodology we find a series of concepts that attempt to describe the steps and relationships in the process of generation and search for new knowledge. Different methodological views make their own ultimate presumptions; presumptions which present different modes of understanding, explaining and improving. These ultimate presumptions are made about reality, and they are of a philosophical nature. The assumptions made become a guide for the researcher in their effort to research reality. The views we use are made for our reflection (Arbnor & Bjerke, 2009).

A methodological view has a double function by encompassing some ultimate presumptions while also providing the prerequisites for the design of practical tools, that is, the development of an operative paradigm for working in a study area. While our paradigms, our theory of science, consist of our conception of reality, our conception of science, our scientific ideals as well as ethics and aesthetics and these may be somewhat fixed and slow changing (evolutionary), methodology and our operative paradigm consist of methodical procedures and methodics (ibid.). Arbnor & Bjerke (2009, p. 17) mention that "[...] *methodology is the understanding of how methods are constructed*" in other words it is how we develop an operative paradigm.

Innovation Systems are by nature ascribed to General Systems Theory (Fagerberg et al 2005). As a researcher I look for systemic connections between components, agents and networks forming a systematic series of synergies. The whole of a system is more than the sum of its parts. (Arbnor & Bjerke, 2009)

The systems view is comprised of three overlapping philosophies; systems theory, holism and structuralism.

Systems theory attempts to serve as a bridge for interdisciplinary dialogue. It is based in two fundamental ideas. First, that all phenomena *"can be regarded as a web of relationships among* *its components, that is, as a system*" (Arbnor & Bjerke, 2009, p. 103), and second; that all systems have "*common patterns, behaviour and properties*" (ibid.), which can be highlighted, detailed or understood to generate greater insight regarding the behaviour of complex phenomena, and perhaps move toward a unity of science.

Structuralism has to do with various theories in the humanities and social sciences that assume that structural or patterned relationships can be studied and exposed (Arbnor & Bjerke, 2009) Relationships between elements of a system can in this way be seen as "*tangible structures, cultural structures and/or structural networks* (Arbnor & Bjerke, 2009, p. 103)."

Holism is the concept that all functions of a system cannot be explained, determined or understood by the sum of its parts, rather the system as a whole determines its behaviour. Scientific holism holds that a system's behaviour *"cannot be perfectly predicted* (Arbnor & Bjerke, 2009, p. 103)", no matter the amount of data available to us (Arbnor & Bjerke, 2009).

Theory

In this chapter I will expand the master thesis by highlighting theory suitable to the research questions asked. As both a regional, national and global promoter of aerospace technology, NASA is a sectoral actor within the aerospace fields. NASA is spread across the entirety of the US, and cooperates with large organisations outside of the US such as Roscosmos (Russian Space Agency) and ESA (European Space Agency)(NASA, 1998). A part of this theory chapter covers spinoffs in general, what they are and in some ways how they are made. Finally the chapter will cover innovation models for greater insight into how innovations are generated, before I ultimately combine these theories into model of analysis for the cases of the next chapter and the following discussion.

For the analysis based in the research questions, I have produced theory on sectoral innovation systems, spinoffs and innovation models in order to attempt to show:

How do NASA investments in space technologies contribute to spinoff innovations in private industries?

and

What innovation model do NASA spinoffs prefer when developing new technology?

Innovation Systems

According to Fagerberg, Mowery & Nelson (2005) Systems of Innovation is defined as *"the determinants of innovation processes"*(p. 182) and *"all important economic, social, political, organizational, institutional"*(ibid.), and other important factors that affect and influence innovation and its development and diffusion. Due to the nature of NASA I will use this section to detail sectoral innovation systems, rather than national and regional systems. As an actor NASA influences regionally, nationally and internationally.

Sectoral Innovation Systems

Franco Malerba (ch. 14, p. 385 in Fagerberg, Mowery & Nelson, 2005,) defines a sector as "*[...] a set of activities that are unified by some linked product groups for a given or emerging demand and which share some common knowledge,*". Companies and organisations in a specific sector are occasionally heterogeneous and have some commonalities. Over time sectors undergo changes and transformation due to the inherent coevolution of its various parts, these being the agents, networks and actors of the sector, the knowledge and technological domains, as well as the institutions comprising a sector, which will be explained in greater detail shortly (Fagerberg et al, 2005).

Sectoral systems are interacting both in a regional context and through a national context, but it is simultaneously delimited from its national constraints, that being that sectoral systems might also have a global context. Sectoral systems may be the formal basis of economic growth in a national system of innovation. Therefore understanding key driving sectors of an economy may help in understanding national growth as well as national patterns of innovative process and activity (ibid.).

What follows are the three main dimensions of a sector (Malerba in Fagerberg et al. 2005)

Knowledge & Technological Domain

The first dimension is the knowledge and technological domain. A sector is clearly characterized by a specific platform or domain of technologies, knowledge base and inputs. Sectors are usually not fixed; they have dynamic boundaries that change over time (Ibid.).

Knowledge is central to innovation. Knowledge pertains to the firm level as it does not diffuse automatically and openly among firms, additionally it has to be absorbed by firms through unique differentiated abilities that are accumulated over time (ibid.).

Dimensions of Knowledge

The first dimension of knowledge is accessibility. Knowledge accessibility may have differing degrees of how accessible it is (Malerba and Orsenigo, 2000, in Fagerberg et al, 2005) Malerba explains as the *" [...]opportunities of gaining knowledge external to firms, which in turn may be internal or external to the sector"* (p. 388, ch. 14 in Fagerberg et al, 2005). If accessibility in a sector is high, competitors may due to low appropriability learn about new products and processes and if they are capable enough they may produce imitations of these. The external environment may affect organisations through the types of knowledge and level of that knowledge contained in the human capital, or through technological knowledge generated in firms or non-firm organisations like universities or research & development (R&D) facilities (Fagerberg et al. 2005).

Sources of technological opportunities differ from sector to sector. In some sectors opportunities are marked specifically to scientific breakthroughs in universities, in others from R&D advancements. In some sectors, external sources of knowledge, such as clients, users or suppliers may have a marked effect on generation of opportunities. External knowledge isn't always easy to transform into innovations. Only when easily accessible, transformable into innovative products or processes and exposed to a lot of actors external knowledge may become an innovative entry (Fagerberg et al. 2005). If advanced capabilities to combine and integrate opportunities are necessary the industry may be composed of large, well established firms (ibid.).

The second dimension of knowledge is the possibility of iterative aggregation, i. e. "*the degree by which the generation of new knowledge builds upon current knowledge*"(Fagerberg et al. 2005, p. 388). This cumulative nature is highlighted and happens through the three segments below (Fagerberg et al. 2005);

1) Cognitive. Learning processes and past knowledge hold reins on current research, while simultaneously generating new questions and knowledge
2) The organisational capability of the firm, and the firm itself. These capabilities are firm-specific and creates knowledge, which is very path-dependent due to the cumulative

choices that have been made, and the cost of retooling, among other self-reinforcing effects(ibid.). These capabilities also implicitly define what a firm learns and what it may be able to do in the future.

3) Market feedback from successful innovation. This success generates profits that can be spent on further R&D and thus increasing likelihood of further innovation.

A high cumulativeness in the sector implicitly generates a high appropriability of innovations (Fagerberg et al. 2005). Cumulativeness may be present both at a sectoral and a local level, such as through knowledge spillovers in an industry (sectoral) or through low appropriability conditions in a local area that create local knowledge spillovers. At last, cumulativeness at the technological and company levels generates first mover advantages (ibid.).

The Boundaries of Sectoral Systems

"The boundaries of sectoral systems are affected by the knowledge base and technologies"(Ch. 14 p. 389 Fagerberg et al, 2005) Types of demand and its dynamics are part of a major factor in how sectoral systems transform. *"The same holds for links and complementarities among artifacts and activities. These links and complementarities are, first of all, of the static type, as are input-output links"* (ibid.) Additionally we have dynamic complementarities, which consider the interdependencies and feedbacks that happen at the demand and production levels. These dynamic complementarities are major causes for transformation and growth in sectoral systems, and they may inspire cycles of innovation and change. Links and complementarities all change over time which greatly affects a lot of variables of how a sectoral system will look such as *"firm's strategies, organization, and performance; the rate and direction of technological change; the type of competition; and the networks among agents."* (ibid,) The boundaries are therefore susceptible to change at a more or less rapid rate over time, based in the dynamic processes related to how knowledge transforms; the change and convergence of demand; as well as alterations in the learning processes and competition by firms (Fagerberg et al. 2005).

Together this means that the features and sources of knowledge *"affect the rate and direction of technological change, the organization of innovative and production activities, and the factors at the base of firms' successful performance."* (Ch. 14 p. 389 Fagerberg et al, 2005)

Actors & Networks

The second dimension of a sector is its actors and networks. A sector is a series of heterogeneous actors that are organisations or individuals as e.g. consumers, entrepreneurs and scientists. The organisations may be defined firms or non-firms such as producers, users, suppliers or universities, government agencies, unions and associations. Additionally organisations may include subunits of larger organisations such as R&D or production departments, and lastly there are also groups of organisations such as clusters and industry associations. These actors and networks have a series of specific "*learning processes, competencies, beliefs, objectives, objectives, organizational structures, and behaviours (Fagerberg et al. 2005, p. 385)*", which all interact and are processed through "*communication, exchange, cooperation, competition, and command(ibid.)* ."

Within a sectoral system of innovation, innovations are considered as a process that is systematic in its interaction among various agents for the "*generation and exchange of knowledge relevant to innovation and its commercialization (ibid.).*" These interactions are both market and non-market relations. Due to the variety of ways they interconnect such as through technological licensing, knowledge, alliances between firms, formal networks of companies; it makes it difficult to measure the entire output of a specific sector, especially in the more common systems we use to measure economic output. (Fagerberg et al. 2005)

Firms are the most important actors in the creation, adoption and application of new technologies. They are marked by *"specific beliefs, expectations, goals, competencies, and organization"* and continuously engage in knowledge accumulation and learning (Nelson & Winter 1982, Malerba, 1992, Teece and Pisano 1994, Dosi, Marengo and Fagiolo 1998 and Metcalfe 1998 in Fagerberg et al. 2005, p. 390). Firm heterogeneity and its extent is the result of *"opposing forces of variety creation, replication, and selection"* (Nelson 1995, Metcalfe 1998 in

Fagerberg et al. 2005 p. 390). Homogeneity comes about through selection, while heterogeneity results from technological and organisational innovation. Firm heterogeneity is also influenced by the knowledge base and its characteristics, the experience of the firm and its learning processes, as well as the dynamic complementarities and its inner workings. (Fagerberg et al, 2005)

Actors additionally contain users and suppliers with differing relationship types with firms that sell, innovate or produce. These users and suppliers are marked by "specific attributes, knowledge, and competencies" with varying degrees of significant relationships with producers. (Fagerberg et al. 2005 p. 391)

Non-firm agents that are present in a sectoral system are *"universities, financial organizations, government agencies, local authorities and so on"*(Fagerberg et al. 2005 p. 391). In a multitude of ways these non-firms support innovation, the diffusion of technologies and the production within firms. Their role differs greatly from sector to sector (Fagerberg et al. 2005).

Demand is not considered a group of homogeneous buyers that all want the same thing, they are heterogeneous agents, and they interact in different ways with producers. Thus demand becomes composed of a varied group of "individual consumers, firms and public agencies" which are characterized by "knowledge, learning processes, and competencies" ultimately affected by social phenomena and institutions (Fagerberg et al. 2005). This means that demand and its emergence and transformation is a very important part of the dynamics and evolution of sectors. Additionally, demand is often a major factor in redefining the boundaries of a sectoral system. Demand is an important stimulus for innovation, and key in shaping the organisation of innovation and production (ibid.).

Heterogeneous agents are connected in a series of ways through market and non-market relations. In the traditional sense they are connected through *"processes of exchange, competition, and command"*(Fagerberg et al. 2005 p. 391), but in modern analysis *"processes of formal cooperation or informal interaction among firms or among firms and non-firm organizations"*(Fagerberg et al. 2005 p. 391-392) have been studied in depth, as there is a wide range of these behaviours and interactions (Fagerberg et al. 2005). In these changing and unclear environments networks emerge due to agents being different, not because they are similar. Therefore networks *"integrate complementarities in knowledge, capabilities and specialization"* (Lundvall 1993, Edquist 1997, Nelson 1995, and Teubal et al 1991 in Fagerberg et al 2005). Sectoral systems are composed of interspersed relationships among heterogeneous agents with *"different beliefs, goals, competencies and behavior"*(Fagerberg et al 2005, p. 392). These relationships affect agents' actions, and they are quite stable over time.

Institutions

Institutions include actions, cognition and interactions, and they shape how agents act within a sector, it additionally includes norms, routines, habits we share in common, established precedents or practice, rules, established law, sectoral standards and more (Fagerberg et al. 2005). They may bind or impose an actor to proceed in specific ways, imposed by law or rules or industry standards created between agents such as through contracts and contractual obligation Institutions can be formal, such as rules and laws (North, 1990) or informal such as conventions and code of conduct (ibid.). Many institutions are national such as e.g. patent systems, while others are specific such as e.g. the sectoral labour market and sectoral financial institutions and regulatory practices (Fagerberg et al. 2005).

In all sectoral innovation systems the institutions that comprise them play a major role in affecting *"the rate of technological change, the organization of innovative activity, and performance"*(Fagerberg et al. 2005, p 394). Institutions may be the result of deliberate planned decision by firms and organisations, or as unpredicted result of interaction between agents (Fagerberg et al. 2005).

Some institutions are specific to sectors, while others are national. The relations between the sectoral and national systems are quite important in the majority of sectors. National institutions have varying effects on sectors such as through patent systems and antitrust regulations. However these institutions vary from nation to nation by the result that they also affect the sector differently from nation to nation (Fagerberg et al. 2005). Additionally, because the characteristics of national institutions tend to favour specific sectors that fit better the makeup of national institutions, such as Norway's strong focus on maritime and petroleum industries(Meld. St. 31 (2003-2004)); some sectors become dominant in countries due to suitable conditions that benefit these sectors over others. In other cases the national institutions of a country constrains or constricts development and innovation in certain sectors, or a mismatch between national and sectoral institutions may happen (ibid.).

The relationships between the national and sectoral institutions are not always unilateral. Sometimes it goes the other way, with the sectoral system affecting on the national level. This may be a result of sectoral institutions that are extremely important to a nation's *"employment, competitiveness or strategic relevance"*(Fagerberg et al. 2005, p. 395). When they end up emerging on a national level of importance they also become relevant for other sectors. During this process of becoming national they may change some of their original specific features. (Fagerberg et al. 2005)

Spinoffs

Spinoff innovations

A spinoff innovation is a transfer of an innovation where a corporation or organisation retains no ownership of the innovation. It is essentially a divest option where the organisation passes on the total responsibility of the activity, commercially and administratively. These things may be due to unrelated strategies, strategic redundancy or changed corporate or organisational focus. A complete spinoff allows the parent organisation to realize the value of the innovation while maintaining their focus on their core business and goals (Tidd & Bessant, 2013)

NASA Spinoff details a NASA by highlighting that: "*A NASA spinoff is a technology, originally developed to meet NASA mission needs, that has been transferred to the public* (NASA, 2015E)". Further it states that it now provides benefits to the world as a commercial service or product. According to NASA these spinoffs enhance many aspects of public everyday life in sectors ranging from "*[...]health and medicine, transportation, public safety, consumer goods, energy and environment, information technology and industrial productivity* (NASA, 2015E)" The spinoffs are made available to the public through licensing, funding agreements, assistance from experts residing at NASA, through using NASA's facilities, as well as other partnerships and collaborations between NASA, private industry, other government organisations and agencies as well as academia (ibid.).

For the purpose of this master thesis I would like to compare briefly a NASA spinoff to university spinoffs with this phrase from a study by van Burg, Romme, Gilsing & Reymen (2008) "*[...] university spinoffs [...] serve to transform technological breakthroughs from university research, which would probably remain unexploited otherwise.*"

Innovation Models

Companies and organisations are often individually focused on a single model of innovation, though they may still include a certain combination of models, they tend toward an emphasis on one of the two core models. (Isaksen in Abelsen, Isaksen & Jakobsen, 2013) There are three recognised models. These are designated by three sources, science (STI-oriented), experience (DUI-oriented) and a combination of the two (CCI-oriented)(Isaksen & Karlsen, 2010; Isaksen & Nilsson, 2013; Trippl, Sinozic & Smith, 2015) The first model is Science, Technology, Innovation (the STI model) which is a science based model for innovation, and is often considered the traditional way to generate innovation (Isaksen & Karlsen, 2010). The second type, the Doing,Using, Interacting model, (the DUI Model) describes companies' innovative activity that is not based on coded knowledge, but rather on knowledge garnered through long experience with a specific type of work, often known as tacit knowledge. (Isaksen & Karlsen, 2010; Isaksen & Nilsson, 2013) An alternative to the STI- and DUI-model is Combined Complex Innovation (the CCI model). An innovation model is seldom cultivated as just STI or DUI. Different innovation models lead to multitude innovation processes, both radical and incremental (Isaksen in Abelsen et al, 2013).

Science, Technology, Innovation - STI

STI innovations happen primarily as a result of science activities. These organisations have their own research & development (R&D) departments, or they are small research-intensive spinoff-companies from for example universities where the whole business is built around R&D (Isaksen in Abelsen et al, 2013). These companies are in product and technology areas where research is necessary for competitiveness. The innovation in these organisations is based on scientific knowledge even though these companies may have considerable contributions of experience based knowledge as well in some phases of the innovation processes (ibid.).

Doing, Using, Interacting - DUI

With DUI being an experience driven innovation process we are talking about businesses that are generating innovations through the routinised daily work to solve practical problems and issues in their own production or to adapt solutions to specific needs with clients (Isaksen in Abelsen et al, 2013). These being companies that find solutions through trial and error and using experience from what they know works, without necessarily always knowing how it works. This is often knowledge anchored in key personnel and routines in the workplace, which means it tends to be regionally specific and anchored. Knowledge generation often happens as a result of entrepreneur/innovator by which sees an opportunity for improvement in process or product, as well as through specific customer requests. In the last years several businesses and organisations have started streamlining the process of innovation and their innovative activity, increased their cooperation with research milieux and have started moving toward a third model of innovation, Combined Complex Innovation, the CCI model (ibid.).

Combined Complex Innovation - CCI

Studies show that those companies and organisations that combine the STI and DUI models manage to be more product-innovative than those who focus solely on one mode of innovation (Jensen et al, 2005, in Abelsen et al, 2013). Isaksen & Karlsen (2011, in Abelsen et al. 2013) are detailing an alternative model, what they define as a combined complex innovation, or CCI model. One of the core tenets of CCI is that businesses build core competencies through creating technology platforms through systemizing the implicit knowledge and making it explicit. In this way they are making it possible to improve and innovate differently. It makes it possible to bring in new knowledge and technology from other firms or through new workforce and thus upgrading the technology platform through new technologies, material science or other research. This way it becomes possible to meet the needs of the customer and incorporating worker experience. (Isaksen in Abelsen et al, 2013) A coupling between customer driven innovation (as in the DUI model) and technology push (such as what happens through STI) generates new and upgraded platforms.

Another tenet of the CCI model is system integration. That means connecting research based and experience based knowledge throughout the organisation and across organisation borders. This type of innovation activity is often locally anchored due to the difficulty with which to move experience based knowledge to other countries. (Ibid.)

Analysis Model

There are multiple points of interdependencies that need to be highlighted to answer the two research questions. NASA is a unique sectoral actor across the aerospace industry in the United States, but who also works with international partners to develop technologies for their purposes(Airbus Defense and Space, 2013) as well as using subcontractors for much of their large scale developments (NASA, 2012A). These interdependencies can be found in a sector's technologies and knowledge domains, which will be important to understand the origins of a spinoff, and later how it spins out and possibly disaggregates from a NASA technology into everyday technologies, and in the cases I am covering, whether or not they are also disaggregating from the aerospace sector itself.

The analysis will take into account how the original invention was generated, its innovation model, its inventors and connection to NASA, that is, how sectoral factors contributed to the generation of innovation. Which NASA subunits and field centres are involved will also be looked into, in order to understand and spot case differences and similarities. To understand the development of the innovation model I will look into the various ways a technology from NASA finds use, and how the spinoff capitaliser, the company that acquires the spinoff further develops the technology, if applicable.

Fagerberg et al. (2005) leaves an important clue on how to evaluate sectoral systems, and I will utilize this while looking at the cases at hand: *"Often the most appropriate units of analysis in specific sectoral systems are not necessarily firms but individuals (such as the scientist who opens up a new biotechnology firm) firms' subunits (such as the R&D or the production department) and groups of firms (such as industry consortia)."* (Fagerberg et al. 2005 p. 391).

Thus, for the purpose of this thesis I will discuss four examples, understood as four cases. Each case is presented by the innovation history and relation to NASA and sectoral integrations, and tries to detail innovation models through the history of the cases, as well as integrate that history with the theory at hand. This will be followed by a comparative analysis and discussion of the research questions after the exploration of the cases to be able to properly answer them and come to a conclusion.

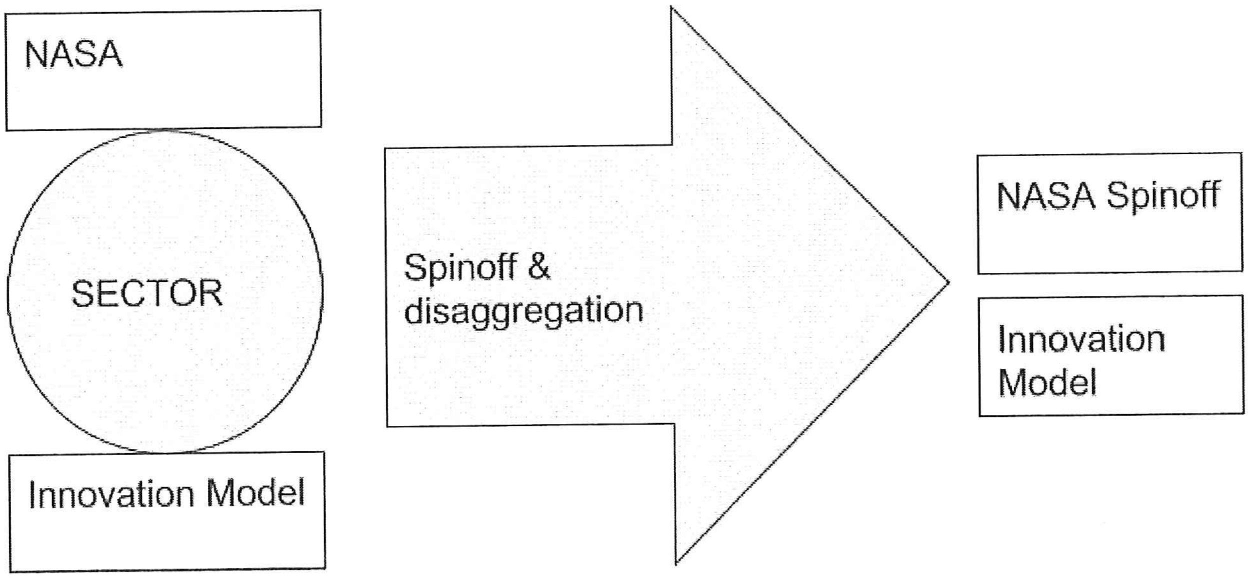


Figure: A theoretical model for the system of innovation that may explain the research questions.

This model looks at NASA, its sectoral tie-ins, and the innovation model that together leads to the invention that spins out into a spinoff. The disaggregation and spinoff in the arrow is the invention leaving the aerospace sector and NASA and moving into its new space as an everyday technology, and how the innovation model is affected by this.

The segments before the arrow seeks to explain how NASA generates the spinoff-innovation, while the arrow and the boxes after the arrow attempts to explain how NASA spinoffs innovation models may transform or be affected by the process of spinning out.

Cases

CASE: Temper Foam - Memory Foam

Temper foam, first referred to as "*slow spring back foam*" (NASA, 2005), was developed in 1966 in order to produce better shock absorption, as well as better impact protection and comfort during long flights in airplane seats. NASA Ames Research Center created an "*open-cell polyurethane-silicone plastic foam*"(ibid.), that takes on the shape of objects impressed on it, but even under 90% compression it returns to its shape. On sudden impact there is no shock or bounce; three inches thick foam pads can absorb a three meter fall by an adult (ibid.). The foam is sensitive to temperature and softens by heat, while it gets firmer by cold. The material distributes the body weight and pressure evenly over its contact area, and thus it offered better impact protection for accidents, as well as enhancing comfort.The temper material "[...] *consists of billions of open, spherical-shaped cells that are viscoelastic, meaning solid with liquid properties. This viscoelastic property, in addition to the foam's temperature and weight sensitivity, enable the cells to shift position and reorganize to conform to body contours*"(NASA, 2002).This initial innovation was clearly an STI approach. NASA, being a public organisation and not being in development for demand, but rather for specific cause seem to make science a natural approach for the organisation in developing new technology, additionally having brought in Southwest Research Institute which is a non-profit R&D institution helps maintain a science driven focus on the innovation that was needed for NASA's purpose.

Charles Yost was an engineer working with the Systems Dynamics Group at North American Aviation Inc. (NASA, 2002; NASA, 2005). In 1962 he had helped NASA by building a recovery system for the Apollo program command module, four years later this experience made sure he got contracted by NASA, through the Stencel Aero Engineering Corporation in Asheville, North Carolina. He was to assist in the improvement of seating on airlines to protect against crashes and vibration, as well as the development of energy-absorption for increased survivability. During the research he created the memory foam material, or temper foam as it has come to be called. It was unusual in being both highly absorptive and being soft at the same time (ibid.) Yost' work lay the groundwork for all future spinoffs of this material. It is interesting to note that NASA has not developed this technology alone on its own, but rather through contracting. This is a known practice for NASA.

In the early 1970s NASA further developed this technology together with Southwest Research Institute (Southwest Research Institute, 1998) to be used as cushioning material in the Space Shuttle (Space Foundation, 1998). The point of the material became to relieve the intense pressure of G-forces experienced by the astronauts during the launch of the rockets. Here we see NASA contracts with yet another organisation for further development of the temper foam material, while it was primarily developed here for the Space Shuttle, it also founds its way into healthcare, as we will see a little later.

Memory foam was eventually released to the public in the 1980s (NASA, 2002). I will show in the coming passages how the technology disaggregates from being an aerospace technology, but it keeps aggregating its knowledge.

Various Spinoffs

Bedding & Sleep Products

Scientists at the later-merged companies Fagerdala, in Sweden, and Dan-Foam, in Denmark, continued the development on NASA's technology. It took almost a decade and millions of dollars, but eventually these two companies created the material some may know today as Tempur (Tempur-Pedic, 2015). A Kentucky resident, Bob Trussell, visited Denmark and met with the researchers at Dan-Foam. After this meeting he saw the opportunity for creating mattresses and started the company Tempur-Pedic. Tempur-Pedic built an R&D and engineering centre in Duffield, Virginia, in addition to a second factory in Duffield, Virginia. It was after this that a somewhat famous "wine-glass" commercial took place (ibid.;The World Famous Tempur-Pedic Wine Glass, 2014). Eventually Tempur-Pedic and Dan-Foam (after Fagerdala merger) merged yet again, becoming a global sleep products company headquartered in

Lexington. The TEMPUR products have multiplied into not just various mattresses, but also pillows, linens, cushions, as well as sleep masks and slippers.

There is an indication here that after the initial seemingly STI heavy focus on creating a mattress, a shift towards more DUI innovation takes place after firmly disaggregating the technology from aerospace utility towards sleep products. In addition, Tempur-Pedic's own statement on their website tells of an active pursuit of improvement of the TEMPUR material "*With an international team of scientists and engineers working in concert, we'll continue to develop new ways to use TEMPUR material, as well as new formulations of the original to help people sleep better.*" indicating a slight focus on STI, but with a path-dependent focus they could be considered as a firm using CCI, due to the reliance on customers, market competition, and experience garnered over time in the work and development of these products. Additionally it shows that they have a focus on making explicit on making the engineer knowledge together with scientists.

Modellista Footwear

In spinoff 2002 (NASA, 2002), Modellista Footwear, is put forth as another temper foam spinoff. It is headquartered in Wellesley Hills, Massachusetts. They licensed Tempur-Pedic's Tempur material and used it to create a new line of shoes. The material is used in the shoe insoles of their products. The insoles allow the shoe to alter itself to each wearer's foot as well as generating shock absorption and cushioning for the foot, additionally it is able to shape according to the foot's shrinking and swells through the day, thus eliminating uncomfortable pressure points. David Froment, the inventor of the footwear, was inspired by Tempur-Pedic's mattresses. After acquiring the license him and his team spent 22 months of R&D. They solved a problem other shoemakers interested in the same material had failed to solve. The Tempur material is very heat and moisture sensitive, which causes it to deflate in contact with steam, which is normally used to shape shoes. Therefore they devised a way to shape the shoes without using steam. The problem of hot and sweaty feet persisted however, and therefore they added an antibacterial lining that took away the heat and moisture. Froment's research included among others the use of his teenage daughter walking around with different densities of the material tied to her feet (ibid.). It would seem that in multiple spinoffs following the principal innovation need to do STI innovation in order to form the first marketable product they envision.

The goal in developing these shoes, was to provide comfort without the sacrifice of style. According to Froment healthcare professionals and chefs go to work using less attractive shoes in exchange for comfort. Modellista therefore has an industrial line of shoes for these professions, these products are also stain-resistant against multiple damaging elements.

Moving on from the research Modellista is looking to introduce more fabrics, other types of shoes, such as sandals, among others (NASA, 2002). This indicates that Modellista is undergoing a transfer from STI approach to solve a specific problem with science, towards a DUI, with constant improvement on their initial product.

Dynamic Systems

In 1969, Charles Yost formed Dynamic Systems, Inc, in order to sell the technology he had developed as "Temper Foam", this was the first commercial application of the material. The company ended up selling the rights to the technology in 1974, but later returned second- and third-generation versions of the foam, versions that were less temperature-sensitive and more environmentally friendly. Dynamic systems have provided products across a wide array of sectors (NASA, 2005). After having been contracted with NASA and learning the important knowledge in an STI driven innovation process one of the principal engineers form his own company based on this knowledge. While this knowledge is initally sold off, the company returns to market with improved versions of the material, and ends up being featured in Spinoff.

Healthcare

Though at this point the rights to the material is shared among various producers, the original maker, Dynamic Systems, is producing various temper foam products. Together with NASA and Southwest Research Institute , Dynamic Systems primarily expanded the technology from aircraft seating to medical cushions and seating systems, for the severely disabled (Southwest Research Institute, 1998; NASA, 2005). 80% of Dynamic System's sales go to the medical industry. Its SunMate viscoelastic cushioning material is used for orthopedic seating pads, mattress pads as well as the "Foam-In-Place Seating (FIPS) system" which is a custom-molded seating product for the severely disabled. The FIPS system was featured in Spinoff 1988, being another of the multiple times the basic NASA innovation has spinned out into the public sphere (ibid.). With three sectoral actors involved, these being NASA, SwRI and Dynamic Systems, the knowledge is brought out to the market for the first time by Dynamic Systems. This is also the first disaggregation from aerospace technology.

Dynamic Systems also produce a product called Pudgee. Whereas SunMate supports weight, Pudgee's function is to compress and conform, thereby it provides relief that helps skin breakdown. It generates less friction and pressure on skin that has tender areas, as well as transfering moisture away from the body (NASA, 2005).

Further they took these two systems, Pudgee and SunMate and developed a cushion they named Laminar. The Pudgee on top alleviates pressure, and the SunMate layer underneath gives a distributed weight support. The Laminar cushion provides extra pressure relief, and customers are deeply involved in the process and choosing combinations tailored for their requirements (NASA, 2005). All three products designed to meet customer needs indicate a high need for DUI innovation

All of the products from Dynamic Systems are available for customization [indicating a high level of DUI, connection with clients to produce innovation] and the company is deeply involved in the implementation of their products through offering technical support (NASA, 2005).

The FIPS system is made for people with complex positioning needs such as deformities or muscle tone problems. [This requires a great deal of customer involvement in the innovation process, and an indicator of DUI innovation] Used mostly in wheelchairs a FIPS insert gives advanced control over posture by holding a person gently in position. Due to even seating pressure distribution, FIPS improves the blood circulation as well as relieving pressure from pressure points (NASA, 2005).

The FIPS process is also well-suited for prosthetics. Prosthetic limbs containing SunMate materials has the feeling of flesh, and it can be molded into muscle tones and dyed to match skin colour. Otto Bock Healthcare PLC is one such global supplier that uses FIPS to develop prosthetic arms, specifically designed for those missing an entire arm from the shoulder joint, the SunMate material prevents friction between shoulder skin and prosthesis, and due to material properties it prevents a heat buildup. These same applications have been used in veterinary applications. Equine Prosthetics, Inc. in Florida applies SunMate in splints, braces and prosthetics for dogs and horses (NASA, 2005).

Different variants of the spinoff seems to stick primarily within their original spinoff sector, and innovate heavily within that new knowledge domain - showing path dependency of knowledge. However, as is shown , they stick to their core technology, but are able to reach new markets through customer driven innovation.

Cars & Racing

The FIPS system has also opened up for Dynamic Systems viscoelastic foam applications outside of medicine. In stock-car racing the FIPS shock-absorption has altered the comfort of driving during the rough conditions. This has moved on to NASCAR and Indy League racecars. Aside from FIPS, Sunmate Materials are being used in Formula 1 for head and neck supports, due to its light weight, comfort and versatility (NASA, 2005).

Performance Analysis, an engineering firm, uses FIPS for cars due to its low level of toxic emission in the event of fire. The SunMate doesn't normally contain fire retardant additives but it is included when regulations require that it be able to pass specific tests (NASA, 2005).

Dynamic Systems have further pierced into the automotive sector by placing saddles on motorcycles. These improve the comfort of driving because motorcycles aren't typically outfitted with good shock absorption and lumbar supports. Both SunMate and Laminar cushioning works for motorcycle saddles (NASA, 2005).

The innovation process seem to be highly customer driven, based in the properties of the material. There is a lacking indication of the market outreach from the firm itself in the collected data, which provides potential for further research into the complementarities that take place.

Horses

Further on from Motorcycle saddles the applications of SunMate, Pudgee as well as FIPS systems are being used by Kentucky based Equine Environmental Consulting, Inc. for highly specialized lines of saddle pads and saddle-fitting products, specifically for racehorses. Additionally Master Saddlers Association from Maryland, and County Saddlery, also from Maryland have used SunMate under saddles to correct the saddle fit which is better for back and shoulder soreness in horses as well as protecting the horse's skin. Toklat Originals, Inc of Oregon also uses SunMate for saddle shims to correct asymmetry and other irregularities in the horse's back. Lastly SunMate is used to line gates at racetracks to prevent injury to excited horses (NASA, 2005).

Fits in with both health and seating concerns, as well as the racing systems. Indication of a convergence of knowledge. Cumulativeness of knowledge on this particular material and its innovation is rather high. Appropriability seems high, so using it for new products in various industries appear common.

Art

SunMate and Pudgee cushions have been used in several art exhibits with new and special materials applied in unusual ways. Pudgee, due to its skin-like properties and the benefits it provides for skin, as well as for the sensation it evokes upon feeling it, was chosen to display at the Smithsonian Cooper-Hewitt National Design Museum. There have also been major shows at the Museum of Modern Art, at the Harvard Graduate School of Design, the Rhode Island School of Design, and the Royal College of Art. Art students have created contemporary furniture such as a lounge chair made from a ball of Pudgee foam, or Pudgee-stacked benches and Pudgee sofa lounges. Dynamic Systems actively assist artists and designers with the necessary technical detail of transforming their products into art (NASA, 2005).

Experimentation, accumulation, and connections are made due to increased knowledge of a young product group. Maybe an indication of an opening up to new sources of innovation in Dynamic Systems.

Fashion & Design

A company named Design Studios in Washington is using full-size body casts made from FIPS in order to create customized dresses for their clients. The company was started in order to be able to accommodate the need for custom-tailored dresses in different sizes and shapes, as well as reducing the number of fittings and alterations that are normal in tailored clothing. Several materials was tested for these molds to create body casts, most didn't work. FIPS successfully created body molds that fit their needs (NASA, 2005).

Firm disaggregation from aerospace as it moves into many new industries. This becomes clearer and clearer as Dynamic Systems increase their repertoire of unique uses for their core products, and increase their knowledge of their products.

Recreation

U.S. Aqua Sport, Inc. in Colorado designed an inflatable raft that will not sink if punctured. The circular raft made for rapid water attractions in theme parts features an internal chamber with SunMate foam. This layer enhances the safety of patrons who choose the rugged attractions (NASA, 2005).

SunMate is also used for archery targets as it can absorb severe impact, it weathers down well, and can take thousands of shots, allowing for the long use of a target. An additional advantage is that the material is near to self-healing (NASA, 2005).

Security & Safety

SunMate may also be used to provide bullet impact pressure reduction in bulletproof vests, as well as a shock absorber in military vehicles that cross over landmines (NASA, 2005).

Going full circle to the initial NASA application, SunMate and Pudgee materials are making a comeback into private and commercial aircraft, in addition to the seats of helicopters. The impact-absorption has made it for use in ejection seating in aircraft of the military variety (NASA, 2005).

High capability makes it interesting again for military and NASA with high requirements to what they need the technology for. This may be a result of the accumulated knowledge and experience Dynamic Systems has had and their ability to generate new innovations.

Back to NASA

It spun all the way back to NASA, using SunMate for a soft obstacle course to test astronaut post-flight performance. Astronauts who return from space have difficulties with balance and walking as they need to adapt to gravity again. Three such SunMate floors have been made, one which was sent to Russia for the astronauts returning from the ISS (NASA, 2005). Showing the sectoral and international nature of the aerospace industry.

A New Sector Rises

An interesting result of this technology is that it has largely created an entire sector centered around the memory foam. The sector has itself grown a sector-wide interest organisation called Polyurethane Foam Association, and this organisation has been operating for the past 35 years.

We can identify several different actors and agents that sparked this sector. SwRI and NASA are clear R&D institutions, and it included subcontractors and later on licensing to interested parties as well as the release of the technology to the public. While not all of the involved actors are clearly linked together, NASA is at the centre of the system that allowed this innovation to take place. The lines are drawn in two different directions, the two clearest spinoff capitalisers of these technologies were Dynamic Systems and Tempur-Pedic. While at Dynamic Systems spawned to become a market relation from NASA, the core invention was made under non-market relations between R&D institutions, engineers and scientists.

This sector has a fairly homogenous selection of core technologies. It is the organisational and technological innovation in these firms that lend it its heterogeneity, as well as through their individual experience and learning processes.

Most firms working on the technology are looking for a specific result during the early phase of their innovation process, and can therefore be ascribed to the STI model of innovation. Later on this sector by and large is very demand and customer driven, and new product offerings seem to be a result of needs found in the market, not necessarily from technology push. Though there are indications that at least initially there can be elements of technology push, such as in the cases of Modellista and Tempur-Pedic, and the way their products came to market. The sector is very heterogenous, considering that its products are sold for healthcare, security, equestrianism, automotive, and even returning to aerospace purposes. The sector heterogeneity comes in part from its diverse customer base. It is however based around a core product group based in the NASA-derived memory foam technology. The heterogeneity can also be explained by the selection of technologies by companies, as well as variety creation between them.

The interactions that happen that cause these spinoffs are varied. Firstly, there is the need that NASA found in the airline industry. Given that NASA's mission is not just space technologies but aerospace technologies in general, pushing this industry forward, it looks for ways to produce safer and better technologies. As we have seen one of the main scientists engaged in this effort, after working together with experienced sectoral aerospace actors such as NASA and SwRI, the important aggregation of knowledge that took place in meeting NASA's needs, both for the airline seating, as well as further on to improve the technology for the Space Shuttle led Dynamic Systems by incidental demand from an outside health care facility. This shows how NASA also was a door of opportunity for dynamic systems, as many organisations come to NASA with express interest in technology that helps them. Such was the case with for example modern fire-fighting gear (Space Foundation, 1988), as it was based on the need of fire chiefs across the country. These are examples of how the external environment affect organisations and the type of knowledge that is generated. It also indicates that the innovation model that lead Dynamic Systems into healthcare is combined complex innovation, because much of the knowledge base and technology had already been perfected, and it needed to meet the needs of a specific customer demand.

The variety of ways Dynamic Systems has reached market indicate that there are some intricate interdependencies on the demand and production levels. This may be due to a variety of factors but due to the vast dispersion of different customers, the customers demands seem to be at the forefront of the way Dynamic Systems transforms as a company. With Tempur-Pedic and Modellista their transformation seem more strategy driven with a coherent focus on improving on their core product lines of sleep products and shoe lines.

The dynamics of demand affected the way these spinoffs happened in the first place. As we have seen with Dynamic Systems their products came about as a result of a pull to market, where clients sought out a specific technology, and it seems that this has been a common model for Dynamic Systems. With Tempur-Pedic on the other hand their products were a much more clear push to market approach, considering the fact that they had a much more clear STI model entry to their technology. It took a decade of research and millions of dollars to produce the mattress in a way that could be marketed.

The sources of technological opportunity are also somewhat different among the different actors that are using the NASA derived technology. While Dynamic Systems is a direct result of working inside the aerospace sector, for Tempur-Pedic the opportunity came as NASA opened the technology to the public in the 80s after their direct involvement with the technology was over, that is, once the Space Shuttle started flying. For Modellista the opportunity came through licensing directly from Tempur-Pedic, and we see that in the way many of Dynamic Systems' clients are using the technology as well. While all these sources of opportunity are tied to the early R&D done under NASA's umbrella, the further development led to opportunities coming from the manufacturers and suppliers of the products that reached a wide variety of markets. It may have helped that this material has been gradually exposed to more and more actors over time, as this leads to higher accessibility which allows for external knowledge to be transformed into innovative entries to market.

With regards to how the knowledge accumulation and aggregation in this sector develops we have already marked a few notes. It started out as research with a purpose to develop a specific product, which transformed into the improvement of these products and the expansion of the product lines of these products. This attests to the cumulative nature of knowledge. Once the primary goal has been achieved, cognitively, the firm alters its learning processes. This may hold reins on current research, but it also generates new questions and knowledge tied into the core product and core technology and knowledge domain of the firm. This is shown with how all the companies develop a core technology and a range of products from them, and these find various ways to market.

Another interesting point regarding the knowledge production is the organisational capability of these firms. While the different companies develop their core technologies themselves, they leave it to other companies to customize them into new types of products, such as how saddle makers are making custom built saddles for horses, and how the core technology of Tempur-Pedic was licensed to Modellista for them to produce their shoes. In this way the companies utilize the organizational capabilities of other firms to generate new paths for the technology, while they themselves may be relatively path-dependent.

Successful innovation leads to positive market feedback, and this is seen through how both Dynamic Systems and Tempur-Pedic are generating spinoffs of their own technologies into newer and newer markets. Success produces profits that may lead to more research.

On an institutional basis the proximity of national institutions, R&D capabilities as well as favourable laws and innovation climate seem to lead these companies to settle in America. While some of them clearly spun out as a result of participation in the principal innovation, others spun out as a direct result of NASA's Technology Utilization Program or the further licensing of the technology. Institutional factors like ITAR may have helped in this, because it prevents knowledge of aerospace innovations to reach undesirable nations. It would seem that a lack of patenting, or that the variety with which the core technology can be applied in this case has lead to a vibrant sector of various companies, allowing for more innovation.

This leads to a variety of innovation models that transform over time and through increasingly path-dependent knowledge development. This has been shown on multiple counts in the path of the development of these core technologies that the companies of this sector relies on. The fact that the core product is so versatile may also reduce the need for scientific knowledge production to stay competitive, indicated by the three core product segments that Dynamic Systems delivers to its customers. The main focus of Dynamic Systems then, seems to be the development of new products based on their core technologies, not to change these core technologies. That means it is an experienced driven innovation process, or that it is based on specific customer request, signifying a DUI model of innovation. Similar indications can be seen with Tempur-Pedic that sticks to its brand as a company producing sleep products and working on innovating in this area, however there is an indication of more CCI approach at this company, at least in the way it focuses on science in the way it talks about innovation.

However, Dynamic Systems and Tempur-Pedic have both held a strong focus on developing core competencies, which is a cornerstone of combined complex innovation. By making the implicit knowledge at these companies explicit they are able to innovate and improve differently. This means a combination of customer driven innovation and technology push can generate new and upgraded platforms at these companies, and there are some indications of this in their product lines. Modellista, being a fashion company, having developed their core technology, talks about changes in the fashion aspect of their product line, which indicates a much stronger DUI focus in their innovation model.

CASE: Carbon Capture

"What we're doing for Mars has a lot of applicability on Earth." — Gerald Sanders, Johnson Space Center (NASA, 2015F)

Robert Zubrin, Pioneer Aeronautics & Pioneer Energy

Robert Zubrin, aerospace engineer, and founder of Pioneer Aeronautics and Pioneer Energy worked together with Johnson Space Center and their In Situ Resource Utilization (ISRU) Team in the 1990s. Robert Zubrin is also founder and president of the Mars Society, an American interest organisation dedicated to the human settlement of Mars (Mars Society, 2015), he is the author of a mars design reference plan for sending humans to Mars, which is often referred to by NASA and other organisations, this plan is called Mars Direct. Zubrin has published 10 books, and at the age of 20 he patented a 3-player chess (NASA, 2015F; NASA 2015G).

Zubrin is clearly a driven individual, both a scientist and an entrepreneur. He has positioned himself in systems where he could contribute to his ideals of putting humans on Mars. Working together with NASA, Martin Marietta and, Lockheed Martin, him and his companies gained important knowledge of carbon capture and other chemical technologies for systems that would be in use for resource production on the planet Mars.

The Martian atmosphere is 95% CO2 gas, and ISRU technology can therefore be used to make rocket propellant (fuel) on Mars. Zubrin puts it like this *"It can be done by combining hydrogen, perhaps from Earth, with Martian carbon dioxide—the atmosphere is 95 percent CO2 —to produce methane and water. You can electrolyze the water and make oxygen, recycle the hydrogen off the electrolysis, and doing that will yield a lot of methane and oxygen, which is a good combination for rocket fuel. With that, you can return home to Earth* (NASA, 2015F)"

The work Zubrin and his team did together with Johnson Space Center was in this line of technologies. They re-engineered these technologies to be able to decompose methanol and water into hydrogen and carbon dioxide to produce lifting gas. Pioneer Astronautics has been part of over 60 Small Business Innovation Research (SBIR) contracts, most of them together with NASA. These have lead Zubrin to develop a Mars hopper vehicle that can use Martian CO2 as propellant, a magnetic sail for spacecraft as well as precision-landing parachutes designed for Mars atmosphere, which is 1% the thickness of our own (NASA, 2015F; Phoenix Mars Mission, 2015).

Zubrin and his team has clearly accumulated a lot of knowledge during their work with NASA. This work was highly STI driven, working to solve solutions on how to live on other planets.

In some of these earlier SBIR contracts, Pioneer Aeronautics worked with NASA Johnson Space Center to create rocket fuel through molecular mixing and matching of the composition of Martian soil and atmosphere (NASA 2015F; NASA 2015G). This followed work Zubrin had earlier done as a NASA contractor while working with Lockheed Martin as well as Martin Marietta Astronautics Company, in developing space exploration strategy. At Lockheed Martin, Zubrin took part in building one of the early prototypes for collecting carbon dioxide in the Martian atmosphere, and transform it into oxygen and Methane (ibid.).

This is where Zubrin developed the core competencies that laid the groundwork for the spinoff innovations.

Zubrin experimented with other chemical processes in his firm Pioneer Astronautics. They looked into ways of making oxygen from carbon dioxide by using a technique called reverse water-gas shift with water electrolysis - that is, using electricity to separate hydrogen and oxygen from water. Through this trying many things that may eventually be interesting to NASA for space exploration. These technologies aren't just useful for fuel production, but also for life support, systems of power. NASA Johnson Space Center's ISRU team is still working on tying all these types of systems for space exploration together as future spacecraft visiting Mars, that includes crewed missions, will likely be using Martian resources for the trip home. Knowing there is water on Mars simplifies the process somewhat as electrolysis can produce oxygen for both fuel and life support and hydrogen, hydrogen combined with carbon becomes methane, a rocket fuel, All this could be powered by a small nuclear plant and some additional tools such as a soil processing plant and carrying rovers to dig and transport soil. This means 4500 kg less of transported equipment from Earth to Mars (NASA, 2015F).

Building on this work Zubrin developed and commercialised a series of different technologies that has had various kinds of Earth applications, like a system that can extract oil from defunct oil wells as well as another system that can harness natural gas that is burned of as waste from many oil rigs today, and additionally he developed systems for microbreweries to recapture their carbon for carbonation of their beverages (NASA 2015F; NASA, 2015G).

Gas Conversion Systems

The work Zubrin had done on this molecular chemistry together with NASA led him to develop two projects that will work with the oil and gas industry here on Earth. Running some of the technology they had developed backwards would make it useful for oil recovery (NASA, 2015F).

Therefore, in 2008, Zubrin founded Pioneer Energy. While CO2 would be combined with hydrogen for methane and water on Mars, on Earth we have methane as a natural gas, which can be reacted with water to produce carbon dioxide and hydrogen and split them. This allowed for carbon-free electricity using hydrogen, and the CO2 could be used to pull the oil out of previously closed and defunct oil wells. This is Mars ISRU technology in reverse (NASA, 2015F).

This experience and accumulated knowledge allowed for the spinoffs of small scale systems of what are otherwise large-scale operations, normally in the millions of dollars. Due to the complexity of the technology these technologies likely still require a good deal of STI focus. Zubrin's companies are science heavy companies, requiring a good deal of scientific knowledge. The human capital and the knowledge contained in the human capital of Zubrin's companies requires significant insight and maybe also experience into the sciences on which their technology is built.

Only 4% of US oil currently uses CO2 pressure systems to bring up more oil, the reasons are mainly geological or matters of scale, as systems until now have been very large, requiring pipelines or trucked in CO2 which is expensive. Pioneer energy developed the Pioneer Portable Enhanced Recovery Technology (PERT) which offers a cheaper alternative, which allows to produce onsite CO2 from methane and water that is trucked in, a considerably cheaper alternative to trucking CO2 (NASA, 2015F).

While working on the CO2-production system Zubrin had another idea. During early stages of a drilling operations, before CO2 is necessary to produce more oil, natural gases may be released from the earth. The industry calls this “flare gas” because normally they require plants and pipelines for processing them, so instead they burn them in flares (NASA, 2015F).

These innovations seem to have come on top of each other because of the links between the problems they solve, as well as through the technological opportunity presented through the core competencies they already had in place. An interesting point to make is that this industry is traditionally made up of large, well established firms due to the need for advanced capabilities to combine and integrate opportunities. The work at NASA allowed Pioneer Energy to bypass this.

Pioneer Energy thus developed the Mobile Alkane Gas Separator (MAGS) which separates the flare gases through three streams: one to capture in tanks for future sales (propane, butane and pentane), another for power generation in the drilling operations, methane that replaces diesel, and the third powers the MAGS system (ethane)As the name suggests this system is mobile and can be transported to and from necessary sites. (NASA, 2015F).

Microbrewery CO2 Recovery

Zubrin later took the technology he had developed and put it to use cutting cost for craft breweries that produce anywhere from 3000 to 300,000 barrels of beverages per year. Pioneer energy calls it the CO2 Craft Brewery Recovery System (NASA, 2015G).

This is a further cumulation of knowledge, having garnered knowledge through making their initial technologies the distance to this system has been short.

When beer is fermented it produces CO2, and CO2 is also necessary to carbonate the beverages. While major breweries normally have systems to capture the CO2 produced during this fermentation, these are large, multi-million dollar systems. Small breweries are left to release the fermentation gas and buy CO2 from outside vendors. Pioneer's system fills that gap. Their system produces five tons of CO2 per year, and is modular in order to deal with greater needs. It was two of Zubrin's engineers that saw the need, and which sparked the team to develop the system. The general NASA technology applied to a very different situation. When you take CO2 from the atmosphere of Mars you compress it and then liquefy it, and you do the same when you capture CO2 from beverage fermentation in order to carbonate and put bubbles into beer. NASA says the technology changes that were introduced could go back to NASA for washing clothes during a Mars mission (NASA, 2015G).

Further illustrating the cumulative nature of knowledge is seen in how systems introduced in these new technologies are of interest to NASA again, as they help to solve problems NASA needs solutions for.

Additional similarities to Mars technology is the use of desiccant beds which remove water molecules from the CO2 prior to storage, as well as using mechanical compressors and cryocoolers. The only change from NASA technologies here is the different refrigerants being used by Zubrin and his team. These systems are all fully automated, as they were developed at NASA in order to circumvent the 4-24 minute time lag of information, a communication delay, passing from Earth to Mars and vice versa.. The reason for this being that a spacecraft for a return vehicle from Mars to Earth for human crews would be sent 26 months prior to their arrival, so that it could utilize the resources to fuel up and be ready to return the crews immediately upon arrival if necessary, as well as providing resources for the mission at hand such as environmental control systems (NASA, 2015G).

The carbon dioxide from this system is cheaper, cleaner and provides reuse of a greenhouse gas that would otherwise be released into the atmosphere (NASA, 2015G)

Zubrin credits his work with NASA for his success, and says that this is just one of the many ways NASA's R&D plays out across the whole economy *"The intellectual capital is the big spinoff* (NASA, 2015G, p. 104)".

Space Idealism Ignites Earth Technologies

These technologies have been born out of idealism. While these technologies were not the original intent of their creators, the knowledge that became accessible to them during the creation of technologies for outer space allowed for spinoffs along the same line of technology. The experience built a series of core competencies in Zubrin and his team, having worked on over 60 SBIRs. Both firms and non-firms helped inspire these technologies' base components.

The sectoral actors that ignited the knowledge that became these spinoffs were all clearly aerospace actors. There is no indication of an external environment that affected these innovations other than perhaps the knowledge of our planet, these technologies improve on climate issues related with the industries they are introduced to. Maybe it is tied in with the idealism of Zubrin and his team. The sectoral actors that took part were heterogeneous, and mainly focused on aerospace usage of their technologies. This is likely the reason that Zubrin did not make these technologies as part of Pioneer Aeronautics, but rather started a new company for better organisational capability to innovate on these products. There may be an indication of a need for disaggregation in order for a spinoff to fully come into its own.

When it comes to demand, Pioneer Energy is pushing new technology to the market. Being a young company, there is not a lot of information that allows us to see how this will transform the company. The transformation of the company and how it innovates seem to lie more in its strategies and performance, and its rate of technological change. What we can see is a clear disaggregation, the knowledge is becoming less connected with aerospace and more with carbon-related matters. This appears to be increasing.

What's interesting to see is that Pioneer Energy has focused its attention squarely on technologies surrounding carbon. They have built a series of core competencies and acquired experience over time within these technologies, indicating a shift from STI-driven innovation towards a CCI system where they improve on their core systems through a combination of customer driven and science driven research. The research and work Zubrin and his team did with NASA was thick with STI, but as they have progressed with Pioneer Energy it has grown in the direction of more CCI-driven research. Additionally, their competitors are all large scale producers who will not sell to groups that need less than certain amount. This gives Zubrin and his team some respite and allows them to grow in experience with their technology, rather than relying fully on their scientific expertise.

CASE: Cordless Tools

The first power tools were not invented at NASA, but at Black & Decker in 1961 (NASA 2009). However major important improvements were made on these tools in order for them to work to NASA's benefit.

This is an interesting case because it is not an invention that was made for NASA initially. It was improved at NASA for NASA needs, and it was these improvements that led to various spinoffs.

NASA needed a tool that would allow astronauts to capture samples from the moon, so that they could do a thorough study of lunar soil. This tool needed to be lightweight compact power drill capable of drilling three meters below the hard lunar surface, it would became a rotary hammer drill that could operate in extreme temperatures and in anti-gravity conditions. It needed its own independent power source (no plugs in space).

These were not small demands, while cordless power tools were not necessarily new, what they needed to be able to do was. This needed an STI-driven focus.

NASA Goddard Space Flight Center, through Martin Marietta Corporation, contracted with the Black & Decker Corporation and developed a battery-operated magnetometer system (Space Foundation, 1989). The first tool Black & Decker developed was a zero-impact wrench for the Gemini Project. This tool was made to spin bolts in zero gravity without spinning the astronaut. Black & Decker also developed a computer program to optimize the design of the motor to ensure minimal power usage. These tools were tested under water and in transport planes that made parabolic flights (flights that induce the feeling of zero gravity or microgravity)(NASA, 1981; NASA 2009).

The work on these projects with NASA gave Black & Decker a series of new capabilities, improving their core technologies, with cumulated new knowledge.

In the years after the Apollo Program, Black & Decker took this spinoff technology and created many more types and groups of cordless tools for many different industries. These tools are used by surgeons in the operating room with cordless lightweight battery powered precision medical instruments, building contractors, DYI-ers (Do It Yourself), gardeners, factory workers and others. The Dustbuster, a handheld vacuum cleaner is one such example. Today these cordless products amount up to hundreds of millions of dollars in sales just in America (NASA, 1981; Space Foundatin, 1989; Plain, 2004).

Black & Decker was able to take action on the leap in their technical capability, and introduce products based on these systems in a wide variety of markets.

Prominent spinoffs like cordless instruments are used by surgeons in self-contained powered instruments that need no connection to a power source. Before such instruments would require tanks with connecting lines or hoses, which presents multiple problems. Black & Decker has developed a series of orthopedic instruments that includes drills for boring through bone, or tools to shape bone, saws for cutting bone without damaging tissue and more. At the time these spinoffs were featured in Spinoff they would provide up to 20 minutes of powered operation on a single charge, and two recharging packs could be powered by a recharging unit in 30 minutes, the power packs are the handle of the instruments. (NASA, 1981)

From Harsh Environments to the Garage

The core technologies of Black & Decker are different sets of tools. They created the first cordless power tools and for this reason attracted NASA's attention for lunar tools. This required a hard STI approach to develop what these tools needed to be able to do. Black & Decker absorbed all the knowledge they garnered through these research programs, and applied them in a long range of everyday cordless tools with increased power outputs and capabilities. Again we see market and non-market relations are included in the process of making the innovations happen. Martin Marietta being a market affiliate in the aerospace industry, and NASA being a non-market actor.

These technologies were developed with NASA subcontracting Black & Decker. Various cases present this as a common way for NASA to generate new technologies and thus also spinoffs.

Given that Black & Decker evolved what was already its core competencies through targeted STI programs their work in those days appear close to CCI, as it was a matter of improving and utilizing their core competencies after NASA to provide the already developed products to market in the various forms. There is no indication to how customer driven or to what degree this needed a technology push to market approach in order to be a successful NASA spinoff, but it has clearly succeeded in reaching many markets.

Black & Decker utilized the external knowledge and demands found in NASA to generate the necessary technology that NASA was looking for. Given NASA's role as a sectoral institution it needs to make knowledge accessible and transformable into the products they need others to develop. Black & Decker's role in making the products an innovative entry, then, is to make sure their products reach a lot of actors.

The cumulation of new knowledge and the capabilities Black & Decker learned in working with NASA allowed them to improve a very path dependent product line. Black & Decker (now Black+Decker; Black+Decker, 2015) still produces tools to this day, so their core technologies have not changed significantly, indicating a transition to a DUI approach over time with.

CASE: Lighting Technologies

Living in space long term will eventually require the production of and plants in situ (on site). This serves multiple purposes, plants provide food, clean air and clean water.

Many technologies NASA has explored for space-farming experiments have returned to Earth and found their way onto the market.

Plants in space will need light to grow, and light requires energy. For that purpose NASA partnered with Orbital Technologies Corporation (ORBITEC), located in Wisconsin (NASA, 2010). ORBITEC also has extensive experience in the SBIR program, having completed over 180 such contracts. One of ORBITEC's early systems in space farming was the launch of the Biomass Production System for its 73-day stay on the ISS (ibid.).

ORBITEC has had a clear STI approach for NASA in the development of space farming systems. ORBITEC is a unique case because it is the only firm among the selected cases whose core competencies are in space technologies.

A few problems come to light in space, regarding the growth of plants off planet. Firstly, the length of day is different, and spacecraft are constantly in motion, and usually not optimized motion for plant growth. Therefore, NASA has been developing methods for growing food using artificial light sources. These light distribution systems use little power, are relatively cool, irradiate leaves with the most efficient wavelengths for photosynthesis as well as automatically adjusting emissions to target changes in plant growth, such as height or spread, to reduce waste of energy-use. Using electric lamps presents problems: It can require valuable energy as well as emit unwanted heating of the plants. The solution for this was LED lighting, using less power than normal lamps as well as radiating minimal heat on the plants. Additionally, LED lighting lasts much longer than normal lighting, they're smaller and lighter in weight, and doesn't contain the same risks of glass breakage as normal bulbs (NASA, 2010).

ORBITEC has been working on a project called the High Efficiency Lighting with Integrated Adaptive Control (HELIAC) system, which utilises solid-state LEDs to grow plants. While NASA, ORBITEC and Purdue University are working for the production of these technologies in further space applications, the HELIAC program has the potential to be used in commercial agriculture and aquarium lighting (NASA, 2010).

LED lighting is robust, maintainable, energy efficient and produce little radiant heat, it also reduces the dangers of pressurized bulbs such as broken glass, mercury and hot surfaces. What makes them better for plant growth is the ability to vary the light output. ORBITEC's HELIAC system is adaptable to specific plant species at specific growth stages, allowing for maximum efficiency in the photosynthesis process. HELIAC is able to sense exactly where the plant is and what shape it has, reducing energy usage (NASA, 2010)

These technologies are highly STI dependent, and multi-disciplined.

The technologies developed for HELIAC include algorithms, include *"advanced control algorithms, sensors, drive circuits, thermal systems* (NASA, 2010, p. 84)*"* have been included into various of its other commercial products. Horizontal light bars that allow real sunlight to pass between the bars has been sold to research universities and manufacturers of controlled environment systems. This allows growers to use both natural sunlight when available, and targeted lighting when not available allowing for growth of plants during cloudy and rainy days, or in the dark season (ibid.).

The University of California has purchased ORBITEC's greenhouse bars to conduct photobiology research, while many others are buying it for small scale research, or evaluating the technology for full scale utilization. The units are still produced and manufactured by ORBITEC, but with growing demand this may change (NASA, 2010).

Here is an indication that ORBITEC actually utilizing this as a spinoff is an unintended consequence of their work. Because of the new way the technology manifests itself is not in line with their core competencies they may have to outsource the production of the spinoff technologies so they can keep their focus on the core competencies. This is one way that learning processes and past knowledge holds reins on current research. Another restriction may be the capabilities of the firm - large scale utilization does not appear to be something ORBITEC is ready for.

In aquariums water temperature has to just right for specific fish and corals to live well or survive. With normal light fixtures the aquariums also needs a chiller to keep the water from heating. With LED's this is not necessary at all. In addition to them being longer lasting LED-based lighting is also programmable. By using software, thermal protocols and circuitry developed for NASA, these lights produce adaptability and precise controls that can be custom tailored to the fish and corals in the tanks. Additionally the lights can be set to dim periodically to simulate illusions of clouds passing, tide changes or lunar cycles, allowing aquarium life to thrive like it would in a natural environment. This technology has been licensed out to two aquarium lighting manufacturers (NASA, 2010).

Another indication of the break with core competencies. Because ORBITEC wants to keep their strategy working with these technologies, they have licensed off their innovations to outside developers. Instead of disaggregating from space technologies, ORBITEC disaggregates itself from the spinoffs.

The technology led to the astronauts on board the ISS this summer being the first to eat food grown in space (DiCicco, 2015). While growing plants in space has been experimented for decades, this year was the first time plants had ever been eaten, rather than brought back to Earth for examination. This system that grew these plants, developed by ORBITEC, is known as Veggie. Many of the features of HELIAC and the Biomass Production System has been incorporated into Veggie and the company's commercial products. Their LEDs use 60% less energy than traditional grow lamp systems (DiCicco, 2015).

NASA Kennedy Space Center together with the National Space Biomedical Research Program (NSBRI), a group of institutions funded by NASA, noticed that the lamps could produce specific wavelengths of light. The Kennedy team that was growing plants built LED systems for a team from NSBRI that used it to research sleep. This helped the test subjects stay awake and fall asleep by using different wavelengths of light. This was in turn, together with a NASA contractor named Bionetics, used to develop the ISS' first LED lighting system to help astronauts getter a better circadian rhythm, given the fact that ISS astronauts see more than a dozen sunrises and sunsets every 24 hours (DiCicco, 2015; NASA, 2015G).

Here we see NASA's experience with LEDs moving into adjacent territory that also needs LED knowledge. This is an aggregation of the LED knowledge to other partners.

Later the scientists involved in the project took their knowledge to a company called Lighting Science to bring this technology back down to Earth. Several of the engineers and scientists involved helped in commercialising new LED products for people, animals, plants and the environment. These products were called DefinityDigital and became four different types of LED lights. Awake & Alert, Goodnight, MyNature Grow and MyNature Coastal(DiCicco, 2015; NASA, 2015G).

The Awake & Alert and Good Night lights are used to trigger photoreceptors in the brain where circadian rythms are regulated. One gives daylight cues and keeps you awake, the others support melatonin production, the hormone that helps us sleep. Some of these same features will be featured in the next generation of lighting that's going to the ISS, as Lighting Science is in partnership with Bionetics to develop these (NASA, 2015G).

MyNature Grow was designed for better growth environment for gardening. MyNature Coastal was designed to deliver lighting that does not attract sea turtles, this in order to prevent sea turtle hatchlings to walk towards the light, and rather walk into the sea (NASA, 2015G).

Plants, Wildlife and Humans

NASA's work with LED lighting produces a few different outcomes. While ORBITEC seeks to stick with its original knowledge domain that is centered around space technologies, Lighting Science works both as a NASA contractor and seeks to bring the technology developed by these scientists to the consumer market. ORBITEC's technology is clearly more advanced and multi-disciplined than Lighting Science' technology, this is a matter of accumulated and path dependent knowledge development at ORBITEC, while Lighting Science is a fairly young company. Both are STI focused firms, however. There fact that Lighting Science is using a more customer driven focus, might mean that their innovation model might move closer to CCI or DUI models over time as it disaggregates their core competencies from aerospace technology.

Lighting Science came about thanks to the accessibility of knowledge at NASA, and their products are a result of the prototypes delivered together with NASA and Bionetics, as well as proprietary research as well as the research conducted by the NSBRI team.

ORBITEC has had a long standing research program together with NASA to grow plants in space and have developed considerable human capital, experience and knowledge in this respect. Therefore they have prevented disaggregation of their company from aerospace when necessary, and indicate that they will do so again if demand grows above capacity. Adhering to the aerospace sector, which requires advanced capabilities to undertake the opportunities available to them, ORBITEC might not gain much from pursuing spinoffs on their own. The reason for this is to maintain these capabilities and the human capital, as well as the aggregated knowledge in the work they are conducting. The capabilities of ORBITEC define what it learns and what it is able to do.

While ORBITEC has committed its work only with NASA, a non-market relation, Lighting Systems worked together with another NASA contractor, the market relation bionetics. Lighting Systems, in alliance with Bionetics and NASA created the technologies and the core competencies that underlie Lighting Systems today. The different paths chosen by ORBITEC and Lighting systems attribute the way the have selected different sectors for their main operations.

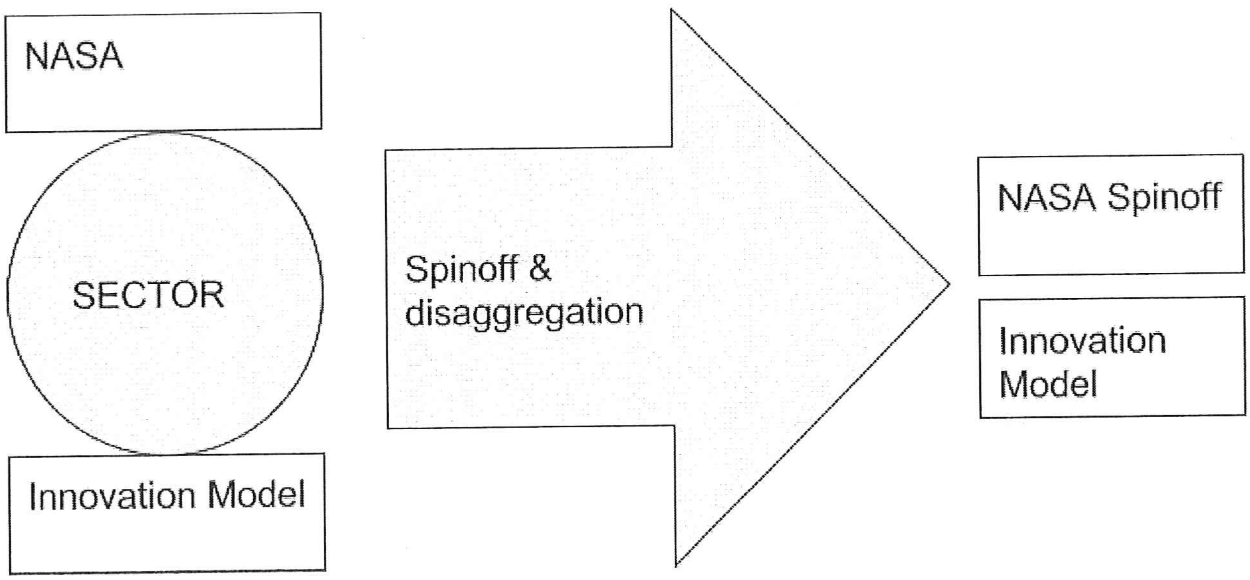
Discussion

For the purpose of the discussion I will look back to my research questions, and go through the results of the cases, to look for answers to these questions, and fit the cases into my model of analysis.

How do NASA investments in space technologies contribute to spinoff innovations in private industries?

and

What innovation model do NASA spinoffs prefer when developing new technology?



From NASA

NASA has clearly set itself apart as a cross-sectoral source of technological opportunity, this can be seen by the great variety of sectors spinoff innovations come into. Being a sectoral actor, delimited to an extent from national constraints NASA provides innovation opportunities outside the borders of the United States as well. Tempur-Pedic's innovations originated from research conducted in Sweden and Denmark. This is an atypical result, however, as we've seen all the other cases presented being American companies - and indeed, Tempur-Pedic has its headquarters in America after the merger with its dano-swedish partners. NASA is also a non-firm and non-market type actor in the sectoral system. It does not commercialise its technology, it does however produce demands that contractors may fulfill.

Knowledge accessibility is probably one of the most important factors that contributes to NASA spinoffs. This is a direct cause of NASA's core mission, to benefit all mankind, but specifically to provide any innovation they make to the public so that it may contribute to economic growth. Thereby constituting an institutional framework for knowledge accessibility to the public at large. We also see that in some ways organisations like NASA and the aerospace sector as a whole has had little removal of aerospace companies due to need to maintain American citizens or permanent residents as labour force under the restrictions of ITAR.

NASA is the source of technological opportunity to all of the provided cases, except for Black & Decker where prior technological breakthrough caused NASA to get in touch with them. In one case the technological competency was already provided, this was also the case of Black & Decker. However, the upgrades made during this work were paramount in the company's ability to produce spinoffs. These opportunities rarely come from prior breakthroughs in science, more often from needs and problems NASA has that these companies have been contracted to solve. However in the case of Modellista and Tempur-Pedic the source of innovation came from licensing or utilizing the technology available from NASA. The work these contractors do together with and for NASA is what provides the technological opportunity. In some cases these opportunities are so advanced only large, well established firms will be in a position to do the necessary work. ORBITEC is an example of this, and they actively position themselves to do this very advanced work for NASA, going as far as licensing away spinoff opportunities rather than producing them in their own company.

One observation made in all cases is that NASA subcontracts for all of these innovation needs they have. This is common as the agency often funds development of space technology in private corporations like SpaceX, Boeing, Lockheed-Martin, and Aerojet-Rocketdyne rather than directly developing many of its technologies directly on its own. Examples of this include the COTS (Commercial Orbital Transportation Services) and CCDev (Commercial Crew Development) through NASA's C3PO (Commercial Crew & Cargo Program Office) which funded and funds the development of private spacecraft designed for cargo supply and crew "taxis" to the International Space Station (ISS). These programs were initiated on the back of the decommission of the Space Shuttle Program (NASA, 2015H).[1] While the new Space Launch System (SLS) innovations are being built in several ways through sub-contracting to Aerojet-Rocketdyne (NASA, 2012A). I speculate that a cause for this practice of subcontracting is directly related to NASA's mission of providing economic growth and generating innovations for the public. It is a much more direct path to generate these spinoff innovations. Subcontracting can be a useful way to produce both high accessibility of knowledge to interested parties, while simultaneously keeping appropriability for these firms high.

Knowledge aggregation is another important factor in the ability of these firms to produce spinoff innovations. The work that is done for NASA generates important new knowledge for these firms that allow them to take their learning and apply it in new ways. In some cases this builds the organisational capability of the firm such as Dynamic Systems which is a new firm established as a result of a scientist working with NASA, and they are subsequently provided an opportunity to work with healthcare through the work done at NASA. Lighting Science has a similar story, the knowledge these scientists gained during their work with NASA that spun out to become this company, as well as the subsequent contracting to work on a NASA contract to the ISS has cumulatively built their organisational capability. All the cases saw aggregated knowledge, but only ORBITEC disaggregated this new knowledge by licensing it out as it was not in their capacity to work with, as the spinoffs they generated were outside of their core competencies, and they might do the same if demand for their grow lights.

Power tools, plants and sleep psychology in space, carbon capture and fuel production on Mars, as well as aircraft and spacecraft seating; these are all technologies that has high requirements for

[1] http://www.nasa.gov/offices/c3po/home/#.VhFjFXqqqkp NASA C3PO

safety and capabilities in outer space. Therefore a clear observation among all of them, is that they all start out with STI-driven innovation, a science driven purpose to meet a certain goal. Some of these spinoffs emerge as R&D intensive startups, such as Lighting Science and Dynamic Systems, which at least at first are STI driven. Tempur-Pedic, while not directly related to a NASA project

Spinoff & Disaggregation

An important observation to be made is that these technologies often seem to disaggregate from the aerospace knowledge and focus their research around the core innovation, the NASA spinoff. This has, in the case of temper foam appeared to spawn an entire industrial sector of products uniquely focused on innovating further with a focus on Temper Foam. In all the cases except for ORBITEC a knowledge domain disaggregation into a new knowledge domain takes place, spinning out into a new sector. While ORBITEC is unique in providing their spinoffs up for licensing, companies like Pioneer Energy are spawned in order to generate the organisational capability to produce entirely new product lines.

We see that market feedback in the case of companies like Dynamic Systems is a very important factor in aggregating knowledge. The demand for their products appear to be the primary source of new product groups.

Innovation models appear to be changing in almost all of the cases provided. After the principal innovations at companies like Tempur-Pedic, Modellista, Dynamic Systems, Pioneer Energy, Lighting Science the innovation model changes. While not always dramatically, companies like Modellista and Dynamic systems move far into territories that are DUI heavy. While Tempur-Pedic, Pioneer Energy and Lighting Science appear to be shifting towards CCI-driven innovation. What's common for all of these companies, however, is the development of core competencies around core product groups. The exception to the rule of all the innovations I have looked at is ORBITEC for staying with their original core competencies, and actually providing their technologies as licenses, that being, providing spinoffs to other companies. ORBITEC is also an STI-driven firm, both in their work for NASA and in what they provide for their customers.

Conclusions

To attempt to conclude is difficult, the answers are systemic and boils down to a combination of the systems at work. Knowledge and technology opportunities as well as their availability are the key reasons NASA's spinoff program is so successful. It's definitely clear that in the cases I looked at the STI innovation model is very important to produce the original source of the spinoff; the technological opportunity that follows and becomes the NASA spinoff. However, it varies greatly whether that model of innovation stays important during the course of these companies developments.

Sources

Abelsen, B., Isaksen, A. & Jakobsen, S.-E. (Ed,) (2013) *Innovasjon - organisasjon, region, politikk*, 1st edition, Oslo: Cappelen Damm AS

Airbus Defense & Space, (2013), *Multi Purpose Crew Vehicle, European Service Module for NASA's Orion programme*, last read 24.12.2015 at http://www.space-airbusds.com/en/programmes/mpcv-esm-v15.html

Arbnor, I. & Bjerke, B. (2009), *Methodology for Creating Business Knowledge*, London: Sage Publications Ltd.

Arms Export Control Act, (1993) Purpose & Definitions http://www.ecfr.gov/cgi-bin/text-idx?SID=86008bdffd1fb2e79cc5df41a180750a&node=22:1.0.1.13.57&rgn=div5

Arms Export Control Act, (1993) The United States Munitions List http://www.ecfr.gov/cgi-bin/text-idx?SID=86008bdffd1fb2e79cc5df41a180750a&node=22:1.0.1.13.58&rgn=div5

Black+Decker, *History*, last read 25.12.2015 at http://www.blackanddecker.co.uk/about/history/

Chang, K. NASA's New Horizons Spacecraft Sends Signal From Pluto to Earth, The New York Times, last read 24.12.2015 at http://www.nytimes.com/2015/07/15/science/space/nasa-new-horizons-spacecraft-reaches-pluto.html

DiCicco, M. (2015) Space Farming Yields Crop of Benefit to Earth, *NASA Feature*, last read at http://www.nasa.gov/feature/space-farming-yields-a-crop-of-benefits-for-earth

Fagerberg, J., Mowery, D. C., & Nelson, R. R. (2005) *The Oxford Handbook of Innovation*, Oxford: Oxford University Press

Great Business Schools (2014), *NASA, Spinning Off Since 1962*, last read 24.12.2015 at http://www.greatbusinessschools.org/nasa/

Halvorsen, K. (2008), *Å Forske På Samfunnet*, 5th edition, Oslo: Cappelens Forlag AS

Isaksen, A., & Karlsen, J. (2010). Different Modes of Innovation and the Challenge of Connecting Universities and Industry: Case Studies of Two Regional Industries in Norway. *European Planning Studies, 18(12),* 1994-2008.

Isaksen, A., & Nilsson, M. (2013). Combined Innovation Policy: Linking Scientific and Practical Knowledge in Innovation Systems. *European Planning Studies, 21(12)*, 1919-1936.

Lieberman, B. 2015 The Future of Construction in Space - Is the International Space Station the last aluminum spacecraft? *Air & Space/Smithsonian Magazine*, last read 24.12.2015 at http://www.airspacemag.com/space/future-construction-space-180956237/?no-ist

Mars Society, (2015), *Board of Directors,* last read 24.12.2015 at http://www.marssociety.org/home/about/staff/board-of-directors

Meld. St. 31 (2003-2004) *Vilje til vekst – for norsk skipsfart og de maritime næringer 2004*, Oslo: Nærings- og fiskeridepartementet

NASA (1998) *International Cooperation on the International Space Station*, last read 24.12.2015 at http://www.nasa.gov/mission_pages/station/cooperation/index.html

NASA, (2015A) *NASA Spinoff website frontpage* last read 23.12.2015 at https://spinoff.nasa.gov/

NASA, (2012A) NASA's Space Launch System Overview, Huntsville, Alabama: NASA Marshall Spaceflight Center

NASA, (2013) *Kepler, Photometer and Spacecraft*, last read 24.12.2015 at http://kepler.nasa.gov/mission/QuickGuide/missiondesign/photometer/

NASA, (2015B), *About Spinoff*, last read 24.12.2015 at https://spinoff.nasa.gov/about.html

NASA, (2015C), *NASA Technology Transfer Program website frontpage,* last read 24.12.2015 at http://technology.nasa.gov/

NASA, (2015D) *What does NASA do?* last read, 12.12.2015 https://www.nasa.gov/about/highlights/what_does_nasa_do.html

NASA, (2008)(Last updated, 2015) *What Was Project Mercury?* last read 12.12.2015 at http://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-was-project-mercury-5 8.html

NASA, (2009) *Cordless Power Tools - Did NASA invent cordless power tools?* Last read 20.12.2015 at http://www.nasa.gov/offices/ipp/home/myth_tools.html

NASA, (2011)(Last updated, 2015) *What Was the Gemini Program?* last read 12.12.2015 at http://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-was-gemini-program-5 8.html

NASA, (2014), *NASA's Journey to Mars*, last read 24.12.2015 at https://www.nasa.gov/content/nasas-journey-to-mars

NASA (2015E) *U.S. National Laboratory aboard the International Space Station*, last read 24.12.2015 at http://www.nasa.gov/mission_pages/station/research/results_category

NASA, (2012B), Space Launch System, Huntsville, Alabama: George C. Marshall Space Flight Center

NASA, (2015E) *NASA Spinoff FAQ* last read 12.12.2015 https://spinoff.nasa.gov/faq.html

NASA, (1981), Spinoff 1981, Greenbelt, Maryland: Spinoff Program Office

NASA, (2002), Spinoff 2002, Greenbelt, Maryland: Spinoff Program Office

NASA, (2005), Spinoff 2005, Greenbelt, Maryland: Spinoff Program Office

NASA, (2010), Spinoff 2010, Greenbelt, Maryland: Spinoff Program Office

NASA, (2015F), Spinoff 2015, Greenbelt, Maryland: Spinoff Program Office

NASA, (2015G), Spinoff 2016, Greenbelt, Maryland: Spinoff Program Office

NASA, (2015H), Commercial Crew & Cargo Program Office (C3PO), last read, 25.12.2015 http://www.nasa.gov/offices/c3po/home/#.VnzZWflrtBe

North, D. C. (1990), *Institutions, Institutional Change and Economic Performance*, Cambridge: Cambridge University Press

Plain, C. (2004) Apollo's Small Steps Are Giant Leap for Technology, last read 24.12.2015 at http://www.nasa.gov/missions/science/f_apollo_11_spinoff.html

Phoenix Mars Mission, (2015), *Mars/Earth comparison table*, last read 24.12.2015 at http://phoenix.lpl.arizona.edu/mars111.php

Redd, N. T. Water on Mars: Exploration & Evidence, *Space.com* last read 24.12.2015 at http://www.space.com/17048-water-on-mars.html

Repstad, P. (2007), *Mellom Nærhet og Distanse* Oslo: Universitetsforlaget

Rudestam, K.-E. (2007), *Surviving Your Dissertation*, 3rd Edition, London: Sage Publications Ltd.

Southwest Research Institute (1998) *SwRI-developed Technology Inducted Into Space Technology Hall of Fame* last read 20.12.2015 at http://www.swri.org/9what/releases/1998/fame.htm

Space Foundation, (1988) Improved Firefighter's Breathing System, last read 25.12.2015 at https://www.spacefoundation.org/programs/space-technology-hall-fame/inducted-technologies/improved-firefighters-breathing-system

Space Foundation, (1989) *Cordless Tools*, last read 22.12.2015 at http://www.spacefoundation.org/programs/space-technology-hall-fame/inducted-technologies/cordless-tools

Space Foundation, (1998), *Tempur Foam*, last read 22.12.2015 at http://www.spacefoundation.org/programs/space-technology-hall-fame/inducted-technologies/tempur-foam

Space Foundation, (2015), *Space Technologies Hall of Fame*, last read 18.12.2015 at http://www.spacefoundation.org/programs/space-technology-hall-fame

Tempur-Pedic, 2015, *Our History*, last read 20.12.2015 at http://www.tempurpedic.ca/our-company/our-history.asp

The World Famous Tempur-Pedic Wine Glass, 2014, last seen 24.12.2015 https://www.youtube.com/watch?v=-O7jZKS6A8s

Tidd, J. & Bessant, J. (2013), *Managing Innovation*, 5th edition, West Sussex: John Wiley & Sons Ltd.

Trippl, M., Sinozic, T., & Smith, H. L. (2015). The Roles of Universities in Regional Development: Conceptual Models and Policy Institutions in the UK, Sweden and Austria. *European Planning Studies, accepted May 2015*, 1-19.

Van Burg, E., L. Romme A. G., Gilsing, V. A. & M. J. Reymen, I. M. (2008) Creating University Spinoffs: A Science-Based Design Perspective, *Journal of Product Innovation Management, Vol. 25, No. 2*, 114-128,