High-Risk and Long-Term: Future Narratives of the Space Industry

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January 2015

ABSTRACT

This thesis examines the use of future narratives in high-risk industries, using the case study of the United Kingdom (UK) space industry. Situated at the intersection of prior scholarly work on both futures and narratives, future narratives are stories, roadmaps or predictions that are orientated towards a long-term perspective – years or decades ahead – and seek to present a coherent outcome for a given technology. Drawing on a textual analysis of in-depth interviews conducted with actors in the public and private space sectors in the UK, this thesis proposes a three-part typology for understanding the forms of future narratives generated to promote, defend and further the cause of such technologies. The first is the *finite future.* This is a promissory narrative which has a clear goal, a clear end-point, and a number of systems for keeping those within a high-risk development programme tied to the success or failure of that programme. The second is the *normalized future* – this serves as a stark contrast to the promises of cutting-edge technology, innovation and exotic science from the earlier days of space technology, and positions space as a mundane and normalized technological industry that is merely 'a part of everyday life'. The third is the *adaptive future* which consists of qualifications and other forms of credibility, and projects the viability and trustworthiness of a technology indefinitely into the future. By studying these narratives the thesis contributes to a body of work on high-risk technologies and the industries that produce them. The findings from the project lead me to argue that future narratives of this sort are crucial to understanding contemporary high-risk technologies; that the temporal dimension of such development programmes is of critical analytical importance; and that future narratives point the way towards subsequent research for understanding this particular form of technological development.

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ACKNOWLEDGEMENTS

I wish to express my sincere appreciation to four groups. Firstly, the academic staff at the University of York who supported this work. This means my supervisor Brian Loader for his regular feedback, constant ability to identify parts of my work that required greater focus, and for teaching me to avoid the endless tangents which fascinated me throughout the research; Nik Brown for his help working through the most theoretically challenging chapters and bringing clarity to my arguments; and Andrew Webster as a source of moral (as well as academic) support.

Secondly, I am very grateful to several people in my personal life. I owe immense thanks to my parents Kathryn and Martin Johnson for their endless support during both this research and my contemporaneous near-fatal ill health, and also for their unshakeable confidence over the past two decades in my ability to pursue whatever intellectual and/or creative pursuits I might desire. I must also thank Rebecca for being a superlative friend and confidante, and for displaying a level of confidence in my ability to finish this project that was sometimes lacking on my side of the Skype call.

Thirdly, I must thank all my interviewees in the space industry who gave time up in their schedules to talk to me (often for many hours) about their work, and without whom this research would have been impossible.

Fourth and lastly, special thanks go to the legions of online fans I have somehow accrued for my creative work outside academia in the last few years – you have no idea how much you all mean to me.

DECLARATION OF ORIGINALITY

In accordance with University regulations, I hereby declare that the contents of this thesis are based entirely on my original research and analysis, and have not been presented or submitted for any other degree or qualification. Based both on this thesis and additional interview data not relevant to the core questions of this work, one publication is currently in press and another is under review at time of submission:

- Johnson, M. R. (In Press), 'The Social Impact of Space Science' in Dickens, P. & Ormrod, J. (Eds) *Society and the Universe: An Interdisciplinary Reader*, Palgrave Macmillan: London

- Johnson, M. R. & Martin, D. (Under Review), 'The Predicted Futures of Space Tourism' in *Mobilities* (special issue invitation)

Chapter One: Introduction

1.1. Research Outline

This thesis examines the use of ‘future narratives’ in high-risk industries, using the case study of the United Kingdom (UK) space sector. Situated at the intersection of prior scholarly work on both ‘futures’ and narratives, these future narratives are stories or predictions that are orientated towards a long-term perspective, years or decades ahead, and seek to present a coherent outcome for a given technology. By studying these particular forms of narrative the thesis contributes to a body of work on high-risk technologies and technological industries. This is achieved by using the space industry as an example of technological industries that are defined by their approach to risk, and – this thesis will argue – their approach to potentially very lengthy timescales as well.

Space is an industry where the technologies produced are highly complex and tightly coupled – meaning that small failures have the potential to cascade into larger failures – according to Perrow’s (1999) definition of high-risk technologies. Such a definition includes a range of industries and scientific programmes including nuclear power and nuclear weapons, chemical plants, aircraft, dams, and indeed space technology. Alongside space technology, space agencies – national bodies tasked with coordinating space activity – can be understood as an example of ‘High-Reliability Organizations’ (HROs) (Weick *et al,* 1999; van den Eede *et al*, 2006; Boin & Schulman, 2008). These are organizations wherein variables of profit, efficiency and turnover are secondary to the primary concern that their technologies must *never* suffer accidents or failures – submarines, air-traffic controls and nuclear power are other examples. Both high-risk technologies and those managed by HROs have or have had a number of common features – many are state-run, or previously state-run, or have significant state oversight, and much of their internal planning (e.g. Lachow, 1995; Symmons, 2010) and public discourse (e.g. Wynne, 1983; Sjöberg, 2008; Mort, 2008:94) is centred upon the risks that have to be managed.

However, these commonalities rarely take explicit account of the often significant temporal frames within which space technologies (and others) operate. In the light of the research data acquired, this thesis explores the temporal dimension to such industries in addition to their risks, and proposes that the space industry, and potentially many other high-risk industries, should be analytically re-framed as ‘high-risk long-term’ (HRLT) sectors due to the equal importance of both dimensions identified in this work. Programmes within industries of this sort may take years or even decades to reach completion in addition to the significant levels of risk throughout. This thesis thus explores the space industry as an example of an industry which produces extremely ‘risky objects’ (Latour, 2005:81) over long periods of time, and proposes a three-part typology for understanding the forms of narratives generated to promote, defend and further the cause of such technologies and those involved in their construction. In this way the work is grounded in and contributes to Science and Technology Studies (STS), an interdisciplinary field that aims to study the effects of science and technology on human society, political and economic decision-making on technological matters, and the social and political construction of scientific and technological matters (Hackett *et al*, 2007).

Through this process the thesis aims to answer two research questions about high-risk technologies via the case study of the UK space industry. These two questions are:

- *What role do future orientated narratives play in the development of high-risk technologies?*

- *How are such narratives constructed and utilized in the development of high-risk technologies?*

The findings from this project lead me to argue that these two questions are fundamentally related, and that what I call ‘future narratives’ – detailed stories and predictions that promise particular forms of outcome for a given technological programme – are absolutely crucial to contemporary high-risk technologies. It also finds that the temporal dimension is more prominent than in prior work on high-risk technologies, and thus encourages the adoption of the ‘HRLT’ terminology. Within the space industry the creation, management and use of these future narratives present coherent narratives for space technology as a whole, and also for individual space programmes. These futures support and sell the value of contemporary space technology and also take forms which offer potential insight into other high-risk industries. This thesis puts forward a model of three different forms of future narrative developed to support and promote high-risk technologies, each of which is covered by a different chapter.

The first of these is the *finite future*, explored in Chapter 4. This is a promissory narrative which has a clear goal, a clear end-point, and that relates to a specific mission or programme. The second of these is the *normalized future*, examined in Chapter 5 – this serves as a stark contrast to the excitement and promises of cutting-edge technology, and the innovation and exotic science that were a feature of earlier eras of space technology. It instead positions space technology, and in turn the space industry, as a normalized technology industry that is merely ‘a part of everyday life’, thereby carrying out a significant reorientation of the sector’s technological goals. The third of these is the *adaptive future*, discussed in Chapter 6. This future narrative utilizes qualifications and other forms of credibility, and project the viability of a component indefinitely into the future. They set no objectives or offer conclusions; rather they provide reassurance about a component’s successful functioning within unspecified and potentially infinite future programmes. This third form of future narrative can be adapted to fit into any programme having been transformed from a contested technology into a working and trusted component.

The data collection for this study was achieved through interviews with key personnel in leading space technology organizations. This research method was chosen due both to the scarcity of available documentary evidence on the internal workings of the UK space industry, and in order to ascertain information directly from those within the sector on the types of narratives created and circulated, the uses to which they are put, and what space sector employees believe the new dominant narratives are. The first of these organizations was the Swindon-based UK Space Agency (UKSA), the agency responsible for the UK’s civil spaceflight programme. It serves a central coordination role for UK space activities except those involving the Ministry of Defence. Subsequently employees were interviewed in a range of other institutions, including the European Space Agency’s (ESA) research facility in Britain (Harwell, Oxfordshire); the International Space Innovation Centre (focused on technology development and spin-offs, also at Harwell); the Technology Strategy Board, a government body with a remit to boost private investment in technology in the United Kingdom (Swindon); and Reaction Engines Limited, an Oxfordshire aerospace company designing and attempting to manufacture a ‘spaceplane’ called ‘Skylon’, which will serve as an illustrative study of the ideas discussed in Chapter 5. Remaining interviewees were drawn from a number of other smaller space organizations from across the UK.

This introductory chapter will now explore the concept of narratives which are integral to this thesis, and then considers the history of narratives within the case study of the space industry. It explores space technology narratives generated at the birth of the industry, the changes these narratives have undergone, the contemporary state of the space industry, and why the space industry was selected as an appropriate case study to answer the questions of this thesis. The chapter concludes by summarizing the structure of the remainder of the thesis.

1.2. Narratives

The concept of the future narrative proposed by this thesis lies between prior work studying both narratives and futures. This section (1.2) will summarize prior scholarly work on narratives before examining the early narratives of the space industry. Chapter 2 explores the additional importance of 'futures' to this work. The sections after this (1.2.1 and 1.2.2) explore space industry narratives up to the past two decades in order to lay the foundation for understanding its current narrative forms which are explored in the analysis chapters. Many of the new narratives identified in this work express either explicit continuity or explicit disjuncture with the space industry's past, and therefore that past must be established before moving forward.

Sociology has long noted the key role of narratives in the resolution of scientific or technological issues or disputes (Elzinga, 2004). Most narratives serve as postscripts to contested events in which the narrative presents a sanitized and well-ordered version of history (Deuten & Rip, 2000; Law, 2002; Elzinga, 2004). Many authors have argued for a central role of the narrative or account in social life and research (e.g. Polkinghorne, 1988; Bruner, 1990; Orbuch, 1997). That central role may be expressed as the object of research, the method of research, or the product of research (Ewick & Silbey, 1995). In the case of this thesis, it is the object of research. Narratives are situationally produced and depend on the context and organization of their creation (Ibid). In technological industries they are used to demonstrate the value of the programme and illustrate the link between the product and its embedding within society (van Lente, 2000).

This is often done via material documents, web pages, roadmaps (as explored in Chapter 4), and other similar written codifications of a given narrative. As the thesis will show, space sector narratives take a wide range of different forms which are marshalled to convince different actors at different points in a space programme. Narratives also generally possess an explicit temporal order (Ewick & Silbey, 1995; Orbuch, 1997) which can mask uncertainty and ambiguity. As we shall see, the temporality of high-risk future narratives is a crucial part of the analysis presented in this thesis – the length of time that completion of such programmes may take results in very specific forms of narrative.

Narratives offer an insight into accepted truths, but are not a way of discovering those truths (Orbuch, 1997); they do not represent an objective reality (Schatzberg, 2004) or a dispassionate history. A narrative orientated towards the future therefore cannot actually seek to make accurate predictions about the reality of a future that has yet to happen, but must nevertheless be convincing and 'believable' enough to sell the goals of the programme in question. Narratives emphasize 'legitimacy' (Barnes, 1974:140) and objectivity even though the social world lacks inherent narratives (White 1987:24) or overarching themes (Radder, 1992). Narratives may invoke similar ideas of universality, coherence, and sense in the social world (Ewick & Silbey, 1995), and many of the futures within the space sector explored in this thesis serve to legitimate space technologies in these ways.

As well as claims to objectivity, broad concepts and buzzwords may be useful when trying to describe a narrative to those within a range of different industries or agencies that each have their own particular institutional or working cultures (Elzinga, 2004) – this was reflected in the interview data. Equally, the contents of personal accounts can provide significant insights. Upon asking them to explore the narratives used within the space sector, many interviewees used personal experiences or anecdotes to illustrate their points throughout the research, and these were often used as examples of broader trends or concepts within the space sector which they understood themselves to be working within. The micro-narratives of interviewees reflected, were informed by, and arguably themselves informed, the wider macro-narratives of the space industry. Even personal narratives invoke collective symbols (Comaroff & Comaroff, 1991; Ewick & Silbey, 1995) or political positions about current projects or past activities. To understand the specific forms of narratives that interviewees described within the space industry and their relation to other high-risk industries, it is important to first assess the narratives that were created and distributed at the birth of the industry. This highlights the work these narratives did to support these nascent technologies, why they have since faded in recent decades, and describes the background to the three-part narrative typology presented in this thesis.

1.2.1. Early Space Narratives and the Space Race

Prior to the end of the Cold War, a distinct set of narratives for the space industry can be identified. These are essential to understand as they serve to elucidate the origins of the space industry, and the *lack* of these narratives in the contemporary space industry highlights the importance of developing an understanding of the new narratives that support the sector. Equally, this section will show that the presence of narratives has been important to the space industry since its inception, and this importance has not diminished in the last several decades. As we shall see, many parts of the space sector today have taken the forms they have due to the sector's historical roots, even if the narratives that supported those roots have long since faded. This section will thus explore the origins of the space industry and the initial narratives that came to dominate, what these meant for the directions in which the space industry developed, and how these narratives foregrounded particular interests that were deemed to have a stake within the nascent space sector.

Interest in spaceflight began long before the possibility of launches was taken seriously, either politically or technically. Mackenzie (1990:44) argues that in the 1920s and 1930s there was a ‘technological social movement’ that formed around rocketry; an aura of ‘science fiction, crankishness and amateurism’ suffused it, but the interest was there. As early as 1946, the Rand Corporation noted the potential value of artificial satellites for both research and national defence (Krige & Russo, 2000). Spaceflight subsequently began in earnest after the Second World War, at which point science policy became effectively institutionalized within the National Aeronautics and Space Administration (NASA) and other space agencies. The United States’ decision to create NASA and race against the Soviet Union to reach the moon has been extensively covered by political scientists (Launius, 2000), so relevant aspects will only be covered briefly here and with a focus on the broader theme of the narratives behind this decision.

The narrative of space technology at the start of the Cold War was epitomised by competition between the US and USSR as an alternative or proxy for war (Ibid; Ehrenfreund & Peter, 2009). The US space programme accelerated once Sputnik (the first ever low-orbit satellite) had been launched and the subsequent ‘frenzy’ (Ellul, 1964:145) within the US government and technologists to catch up with the USSR resulted in US space and missile systems becoming ‘crash programme[s]’ (Hill, 2012:5) that were granted access to almost unlimited state resources. Despite President John F. Kennedy’s statement in 1961 that humanity should ‘explore the stars together’ (Cowen, 1995:312), the Apollo programme became representative of US-Soviet competition (Launius, 2003). This was made public by perhaps one of the most well-known future narratives of recent times – Kennedy’s declaration of the same year that the US planned to land on the Moon by the end of the 1960s – which exemplified the expectations placed upon US technologists and industries. It was politically essential for both sides to demonstrate their technical abilities, but the technologies themselves would only be disseminated to their existing allies (or those they wished to cultivate). Space technology in this era was not seen in terms of the sophistication of the technology in question nor the services they offered: the technology was the means to an end, and the overarching narrative was one of great political blocs competing to reach technological milestones and the accompanying assumptions about the supremacy or inferiority of each bloc's technical capabilities. This demonstrates how high-risk technologies like the space industry may be supported by a strong set of connected future narratives. Fear of the Soviet Union coupled with an emphasis upon national pride resulted in a powerful future narrative that relevant actors – researchers, politicians, military and citizens – could all support. It was one which both promised great technological benefits whilst simultaneously threatening dire consequences if the success did not materialize.

Missions out of the public eye also held political weight. It was believed by US policymakers that in the longer term, worldwide satellite communications could support third-world nations (Launius, 2000) seeking 'self-realization' and serve as an anti-Communist instrument of 'communications, education and propaganda' (Slotten, 2002:328). Here a future narrative was put forth whereby this nascent technology could have its first promised *social* impact, and yet even this social impact remained defined within the broader narrative of NATO/Warsaw Pact competition. This not only projected a use for the space programme into a potentially uncertain post-Apollo future, but also highlights the role of implicit assumptions in future narratives – the objective of enabling anti-Communist resistance would make no sense were the Cold War expected to end before such a programme could be brought to fruition. As Chapter 4 explores, even today many significant space narratives hinge upon a similar concept that outside conditions must remain within a certain realm of possibilities in order for the narrative to maintain coherence – interests must remain aligned, or outside technologies must be developed at a sufficient speed, for the programme to remain viable.

In addition to the key roles of states, state militaries were the other crucial actors within this early era. As Rappert *et al* (2007) note, since 1945 a significant volume of scientific and technical personnel have been employed within defence industries, even in peace-time, and many of these were involved with nascent space programmes after the conclusion of the Second World War. Identifying space technology's origins as being firmly within the military, from the capture of V2 scientists to the development of ICBMs and the US's desire for reconnaissance satellites, Fisk (2008:176) argues that space programmes changed swiftly into a 'highly visible, aggressive and comprehensive *civilian* space programme'. This was an early 'Faustian bargain' (Ibid) where the military desire for missiles – space launch vehicles in another guise – was accepted as the way forward in the absence of a viable alternative. At the same time the possibility of space emerging as a fourth military sphere, beyond land, sea and air, drove technical development in a space arms race (Peterson, 1997) within the nominal peace of the Cold War. Huntley *et al* (2010) also note an early assumption that military uses of space were *inevitable* – many predictions for future policy were made on this basis and until the 1960s there was a clear stress on the 'military and space' combination (Elzinga & Jamison, 1995:584). This shows another early example of a future narrative, one where the assumption that other militaries will be developing military space technology acts as an impetus for one's own development of the same (possibly imagined) capabilities.

1.2.2. Post-Cold War Space Interests

However, with the end of the Cold War these narratives have now faded – the context within which they were relevant no longer exists. As the above narratives can no longer propose relevance – and the assumption of the indefinite continuation of the Cold War no longer applies – it is crucial to understand the new *position* of space technology in industrialized nations as a background to exploring what new narratives have arisen to support these changes. With the loss of the Space Race future narrative, the space sector hit a problem of negative perceptions, both in the United Kingdom and internationally. This is despite profit of over £7bn in 2008/9 (Department of Business, Innovation and Skills [BIS], 2010a) growing to £9.1bn 2011/12 (UKSA, 2012) – and globally – despite an estimated $260bn yearly profit for global space technology as a whole (BIS, 2010b), and continuing commitments to space technology by most developed nations (Peter, 2006; Balogh *et al*, 2010, Balogh, 2011). In industrialized nations spaceflight is now often seen as something 'wasteful', or failing to deal with 'real' social problems on the ground (Goldman, 1992; Vedda, 2008). Lacking a narrative that emphasises the national importance of space now the Cold War is over, many find it difficult to perceive much direct benefit from space technology. Deciding 'whether the great powers should waste money in space or spend it on Earth' (Goldman, 1992:21) is for many the dichotomous perspective with which the value of space missions is assessed. Even those outcomes perceived as positive – links forged by communication satellites (Elhefnawy, 2004) for instance, ubiquitous to developed and developing nations – are rarely understood by the public as being *from space technology* (Vedda, 2008; Pass, 2011). Policy areas dealing with rapid change (generally technological) may be misunderstood by the general population (Goldman, 1992:51) who might not view technology as a 'latent public good' (Nelson, 1992:61) in the same way as the state does.

Space Policy remains a ‘low salience’ issue – it does not win elections, drive campaigns nor inflame public passion (Vedda, 2008:27), and the current body of scholarly space policy work contains relatively little non-historical examination (Hoerber, 2012). The reason for this lack of academic interest lies, at least in part, in the inability to consider space policy without reference to the Space Race narratives (Siddiqi, 2010) discussed above, despite their minimal continued relevance (Marshall, 2008). This state of affairs leaves post-Cold War space capabilities unexamined. The emphasis on the Space Race which is long over – at least in its original form – explicitly positions space technology as something of the past; something out-dated; and something only relevant within the specific political situation of an international superpower duopoly. The lack of new public narratives for space technology (Vedda, 2008) leaves its uses, values and impacts unclear, unexamined, and broadly unknown to those outside the space industry.

However, as the space sector continues apace and is more profitable today than ever before, it is prudent to explore what new narratives may have arisen to justify the value of investment in this high-risk technological industry, and how these narratives function. As the impacts of contemporary space technology are far greater than many realize, the agendas they represent merit a far more detailed understanding than we currently possess. In turn, such understandings contribute to STS by providing an insight into how high-risk complex technologies are socially calibrated, and the essential role of narratives within this process.

1.3. The Contemporary Space Sector

Of the three types of future narrative this thesis proposes, the finite future narrative proposed in Chapter 4 is most strongly reminiscent of the future narratives of the Space Race era discussed above, focusing on scientific advance, national pride and inspiration. However, whilst international relations and implicit state scientific competition remain powerful shaping forces of space programmes (Launius, 2000), contemporary spaceflight includes not just states but ‘industries, universities, and other NGOs’ (Peter, 2006:108), as well as private companies. This has led to a range of new promised benefits for the scientific programmes, and these new benefits mark the departure of the future narratives in Chapter 4 from the traditional Space Race narrative elucidated above. Many space programmes now seek to offer benefits to a significantly greater range of actors than only states and militaries, expanding the remit and potential interest of this ‘older’ model of space programme.

By contrast, the normalized and adaptive future narratives of Chapters 5 and 6 are very different. These future narratives are a result of a significant change in the space industry in one primary area – the increase in the number of actors relevant to space programmes and, as part of this, the growth of ‘private spaceflight’ and the reorientation of much of the space industry towards ‘service provision’ (broadband, communication, television, etc) instead of scientific or technological advancement. This shift has introduced new actors to the space sector and contributed to the necessity of developing new future narratives of the sort seen in the later two analysis chapters. The next section will summarize prior literature on private spaceflight, conclude this chapter’s analysis of the space industry up to the current day, and highlight the importance of this new context to the analysis presented in subsequent chapters.

1.3.1. Private Spaceflight and Service Provision

As the Cold War ended, space programmes changed from being the domain of the superpowers to being available to a greater number of states and non-state actors. This shift was characterized first and foremost by space technology becoming a multi-regional arena (Goldman, 1992:31; de Montluc, 2009; Sheehan, 2007:9) as China, India, Japan, Brazil, Europe and others began or grew space programmes. A number of developing nations have also initiated space programmes (Peter, 2006:109) outside of the global 'North'. For nations with existing spaceflight experience, space technology is an increasingly cooperative exercise (Broniatowski *et al*, 2006; Peter, 2006; Horneck *et al*, 2010). Although it was not until 1972 that a non-superpower launched a satellite (Peterson, 1997), now over a hundred states have a stake in at least one satellite (Union of Concerned Scientists, 2011). Depending on definitions, roughly ten countries now have *direct* space access (de Montluc, 2012) and more than 6000 satellites have been launched since Sputnik (Siddiqi, 2010). Given the idea of space exploration as being normatively Western as a result of the United States' victory in the Space Race, non-Western programmes are traditionally understood as 'aspirations for a Western modernity' (Siddiqi, 2010:435). However, these states have taken up a number of different and fundamentally non-Western-normative agendas, preferring instead to focus upon the construction and management of communication and infrastructure (Luukkonen *et al*, 1992) rather than the pursuit of abstract science. Many other countries, although invariably relying on technology already developed elsewhere (Smith, 1993), have taken to serious engagement with space technology, but only with the side of space technology concerned with infrastructure, not scientific advance. This remains akin to the kind of 'technonationalism' (Sheehan, 2007:9-10) the US and USSR practised during the Cold War – connecting success in space technology to national pride and achievement (Huntley *et al*, 2010) – but with different programmes, different desired futures, and different technical goals.

Taken as a global industry, therefore, much of the contemporary space industry is unconcerned by scientific and technological advances via space technology. The industry is interested instead in pursuing infrastructure and services, not cutting-edge research. However, this observation holds not just for emerging space actors but also for long-established space-faring nations such as the UK. The past two decades have seen a newfound emphasis on privatization and, in turn, a service-provision mentality for much of the well-established space industry in the UK and beyond (Salomon, 1996; Slotten, 2002; Ehrenfreund & Peter, 2009). The cause of this shift even within nations which do possess the capabilities for space science is important to unpick, and is integral to much of the future narrative analysis presented in this thesis.

After the Second World War, fundamental transformations of the role of science in politics led to the conflation of scientific research with economic production (Elzinga & Jamison, 1995; Jamison, 2006). This was the model of 'Big Science' – the coordination of large numbers of people; the 'legitimation of, and advocacy for' large amounts of public money; and transforming 'contested knowledge' into 'accepted facts' through discourse and rhetoric around the (often experimental) results the programme produces (Kinsella, 1996:65). Blankenship (1974) defines 'Big Science' as a research system in which there is a large commitment of resources *on a governmental scale,* the normally decentralized structures of scientific communities are replaced by clear bureaucracies between which there is a dependency relationship, and disciplinary boundaries in science and technology are crossed. Examples include particle accelerators, the Human Genome Project, and the space industry (Ibid). However, governmental funding for Big Science has declined in recent decades and those who now advocate programmes that were once understood within a Big Science paradigm – high-risk technologies and the scientists associated with these industries – are forced to look for other means to sell the value of their programmes and convince potential investors, supporters and stakeholders of their value (Autio *et al*, 1996). A previously collective focus on science – that the best scientific research may be achieved by cooperation and state funding – has been replaced by a neoliberal model of research and technological development (Lave *et al*, 2010). This new outlook emphasizes relationships between science, technology and their sponsors (Kinsella, 1996), rather than the pursuit of high-end science from state support alone.

In the wake of this change, Andre Lebeau (former Director of ESA) has argued that competition and bloc prestige for space have now vanished (Salomon, 1996) and space agencies cannot extract the same 'unswerving support' from states they could in the past (Ibid:86). He claims that because of this, the balance of power has shifted towards industry, both reducing the role of the state and simultaneously 'revealing the maturity of space technology' (Ibid:86) when deployed straight into the market. A 1994 Eurospace report similarly argued that the space industry is now fundamentally driven by customer demand, not innate concern over the health of the space industry nor a feeling one's state 'should' be involved in space (1994). This is what Feenberg identifies as the contemporary trend for 'technology' to be understood within the broader constructs of 'economy' and 'innovation' and therefore reduced it to 'common sense instrumentalism' (Feenberg, 1999:1). This new market-orientated understanding of technology proposes a model of economics and technology wherein 'the market' drives technological development, a narrative which this thesis shows is represented in the contemporary space industry. Such a view is reflected in economic literature on space technology (Greenberg, 1993; Lee, 2000; Hertzfeld, 2007; BIS, 2010b; etc) which focuses on technology cycles, innovation and similar concepts wherein development is taken for granted, and the only question is how to speed the process up – Ehrenfreund and Peter, for example, point very explicitly to industries and private actors 'innovating' and playing a key role in the current open market space situation (2009) in addition to many other actors already mentioned (Levine, 1985; Launius, 2003; Sadeh, 2005; etc). This new facet of the industry has become known as 'private spaceflight' (von der Dunk, 2011).

As well as the decline of Big Science, additional factors including contemporary 'economic, commercial and financial liberalisation' along with developments in technology and communications (de Montluc, 2009:20) have also contributed to allowing private spaceflight to come to the fore, with its proponents predicting three decades ago 'competition and deregulation' becoming the future 'hallmarks' of space operations (Levine, 1985:562). Private spaceflight seeks efficient, reliable, cheap and routine launches (Sadeh, 2005) and safe and flexible access to space (Launius, 2003), both a long way from the predominantly risky, costly and long-term space industry epitomized by Big Science (Elhefnawy, 2004). Outer space has recently been termed an 'industrial park of unfathomable size' private actors wish to develop, and every year from 1997 onwards private expenditure on spaceflight has exceeded that of governments (Vedda, 2002:201). Private actors will have different agendas and thus present different narratives to those of governments – business seeks not to develop or research space, but rather to turn a profit (Elhefnawy, 2004).

Private spaceflight is therefore primarily concerned with providing *services* – weather monitoring, Internet access, broadcast abilities, communications (Slotten, 2002; Sadeh, 2005; Sadeh, 2011). The *normalized* and *adaptive futures* uncovered by this study, although of course unpredicted at the time of this literature review and the beginning of the research, are both responses to this rise of space industry privatization. The former (in Chapter 5) emphasizes the *normalization* or mundane scope of the programme in order to appeal to risk-averse private actors, whilst the latter (in Chapter 6) is tied to a specific component or technology via the reassurance that the technology can be used for any future programme – an entire line of communication satellites, for example.

1.4. Selection of the Space Industry

The space industry was therefore selected as the case study for this thesis for two reasons. The first of these was the domination of political science and policy research in prior work examining the space industry (as explored above), and the relative scarcity of sociological work on the sector. This is not to say that there have not been sociological examinations of the space industry before now (e.g. Redfield, 1996; Entradas, 2011; Pass, 2011) but these are few and far between when compared to other high-risk industries. It was apparent that this thesis could mark a major contribution to the sociological analysis of this sector and to high-risk sectors more generally, whilst also leaving this examination quite open and flexible in the direction it would take given the scarcity of prior sociological work to influence interpretation of the findings.

The second reason was the strength of the older space industry narrative which even those with no prior knowledge of the industry will be aware of – the Space Race. I was struck by the endurance of this older narrative for the space industry as one that emphasized competition, scientific advancement, and the roles of scientists and technologists as fundamentally pushing the boundaries of technology and in the process doing something ‘for all mankind’. These were legitimizing concepts (Barnes, 1974) for the immense volume of government money placed in the space programme in its first few decades, but as the above section showed, these hold little continued relevance in the present day in even well-established space-faring nations. Instead the increasingly-privatized outlook of the contemporary sector stresses the roles of many different actors (Kinsella, 1996) and means that such programmes can no longer expect access to unquestioned high levels of public funding and support, as in the Space Race.

The previous Space Race understanding of the space industry has been explored in this chapter in order to both give background to the case study in question, and to highlight the prior existence of a strong future-orientated narrative within the sector. This summary also showed that although the Cold War is long over and the unquestioned state funding reduced to a fraction of its previous size, this narrative remains the dominant one in public discourse for the space industry (Siddiqi, 2010). The space industry thereby seemed a clear choice to study these questions. It was both under-explored by sociology and had already demonstrated its ability to create narratives for lengthy high-risk programmes, but the dominant narrative of this sort seemed clearly outdated from my literature review due to the reduced scientific objectives of the space industry and the coterminous growth of private spaceflight. The space industry’s continued success in the United Kingdom (BIS, 2010a; UKSA, 2012) and abroad (Broniatowski *et al*, 2006; Peter, 2006) strongly suggested the creation of new future narratives which lacked prior scholarly examination.

1.5. Thesis Structure

The structure of the thesis is as follows. Chapter 2 explores the analytic and conceptual tools I use to study my research questions on the role of future narratives in high-risk industries. It first covers existing work in STS on technological development and describes why the Social Construction of Technology (SCOT) was selected as the theoretical perspective for this work. It then highlights the gap in prior scholarly work on the development of high-risk industries and explores the concept of ‘futures’ as an avenue by which we may understand the development of these technologies by combining it with work on narratives outlined here. It summarizes existing literature on futures, considers how actors and interests may be positioned and managed via such future narratives, and also covers prior work on categorizing different types of futures and the uses to which they may be put. It also notes a range of futures questions which were relevant to this research, and summarizes how this thesis' three-part typology – *finite, normalized* and *adaptive* futures – will subsequently build upon the existing body of futures work within STS.

Chapter 3 discusses methodology, and covers issues of data collection, interviewing and research ethics. It starts by explaining the selection of interviewing as the research method for this study, before summarizing relevant literature on interviews such as gaining access to interviewees. It discusses the sampling method used for the research interviews, notes challenges in the process of gaining access to interviewees and how this may affect a study's outcome, and then lists the interviewees for the thesis in terms of their affiliation and the self-defined categories to which they belong. It then explores questions of data analysis, the use of grounded theory for the creation of analytic concepts, and concludes with a summary of appropriate ethical considerations.

The three subsequent analysis chapters each cover one form of future listed in the typology outlined in this chapter. Chapter 4 is the first of these and proposes the concept of the *finite future narrative*, a type of narrative formed by the creation and management of a 'roadmap' and a set of promised objectives, and specifically designed for *space science* programmes. The chapter begins by exploring how space programmes are planned and the importance of roadmaps in this planning process. It considers the place of roadmaps within the space sector as predictions of a programme's development which appeal to a wide range of actors, and how they are designed to encourage those outside the space industry to invest within the programme and subsequently to remain within the programme until its completion. It examines the legitimizing work such roadmaps do, how they are designed to both predict and alter the future, and their negotiation of long timescales. The second part of the chapter then moves on to consider what the predicted outcomes and promises of space science programmes are, and how these are used to sell the value of programmes that are commonly thought of as pursuing only ‘abstract science’. It considers the purely scientific promises of scientific missions, the oft-repeated claims that space programmes are inherently ‘inspirational’, and the belief that space programmes enhance national pride on the global stage. It then explores the concept of ‘spin-off’ technology as another contemporary promise of space science. The chapter concludes by summarizing how roadmaps and promises are brought together to create finite future narratives, and why these are specifically used to support a subset of space programmes which are ordinarily perceived as producing only ‘pure’ scientific research with no other benefits or outcomes.

Chapter 5 explores the creation of *normalized future narratives* by highlighting the conservative tendency which now dominates the space industry, despite the common perception of the space industry as a highly experimental and innovative sector. The chapter explores the perception of risk, reliability and failure in the space industry, and then covers three major sources of conservatism identified from the research data. The first of these is the changing customer base in the space industry away from governments and towards private and commercial actors and the subsequent emphasis on the provision of services (as introduced in this chapter); the second is the preference for the use of older components within the space industry, and the long-established employees of the space sector who reinforce this preference; and a third is a three-part theme focused on the cost of satellite launch, the impossibility of satellite retrieval, and the required lifespan for launched satellites. The chapter explores how even very cutting-edge technologies in the space sector are defined within existing discourses and expectations for space technology, rather than being presented as new and innovative. This examination is done in part via the case study of the ‘Skylon’ spaceplane. The chapter concludes by summarizing both the reasons for presenting these high-risk technologies as being mundane and ordinary, and how space industry future narratives have subsequently become normalized as a response to these pressures.

Chapter 6 explores how space components become ‘credible’, and how this credibility is translated into *adaptive future narratives*. The chapter argues that those within the space industry understand credibility as being ‘acquired’ by a new component over three stages – early credibility, technical development credibility, and launch credibility. These forms of credibility, if successfully acquired, can be used to create an adaptive future narrative which emphasizes the universality and wide applicability of a component for use in future space programmes. The first part of the chapter analyzes how credibility is gained early on in the creation of new space components – this may be via accreditation by a trusted body of experts, or via government funding which ‘de-risks’ the component for private investors. The second part of the chapter assesses how credibility is acquired, negotiated and maintained throughout the technical development process of a space component. A key part of this is the discursive use of ‘Technology Readiness Levels’ (TRLs) as a method for quantifying the ‘stage’ a component’s development is at (within a linear and deterministic model of technology) which the chapter analyzes in depth. This is followed by an examination of different definitions and metrics of the TRL system, the process of testing which space technologies undergo, the creation of ‘standards’ and ‘margins’ by which the results of these tests are understood, and the role of testing in the development of space components. It then analyzes the third dimension of credibility – consisting of ‘qualification’ and ‘flight heritage’ – and how these aid a component in being considered a reliable and a viable option for a satellite. The chapter concludes by summarizing these three forms of credibility and how the evidence of their acquisition may be used to create adaptive future narratives, and the role of such narratives within the space industry.

Chapter 7 is the conclusion of the thesis. It begins with a brief retrospective summary of the research and the methodology before summarizing the core findings of the work, both in terms of the three-part typology of future narratives and the uncovered importance of the temporal dimension to high-risk technologies. The chapter then recaps each of the three future narrative types elucidated in the three analysis chapters. It describes finite future narratives and the two aspects they consist of, and explores the types of space programme to which these narratives are appropriate; the creation of normalized future narratives and the conservative drivers that have led to the rise of this second narrative type; and adaptive future narratives and how forms of credibility are leveraged to create standardized 'off-the-shelf' components. Following on from this summary, the chapter proposes that some 'high-risk' technologies such as the space industry will benefit from being analytically re-conceived as 'high-risk long-term' (HRLT) technologies due to the importance of the temporal dimension identified in the research. The chapter then lastly considers the implications of this study for future research.

Chapter Two: High-Risk Technology Futures: A Literature Review

2.1. Introduction

This chapter begins by exploring the study's grounding within Science and Technology Studies (STS). It describes the relevant background for understanding the field of STS and covers the Social Construction of Technology (SCOT), a leading theory in STS for understanding the development process of new technologies. Whilst highly valuable when considering most technological development, a search of the STS literature reveals a comparatively under-explored region that this thesis will contribute to – the development of high-risk technologies – and this chapter proposes that this gap may be explored via the interdisciplinary field of 'futures'. We then explore the field of futures and its current relationship to STS, focusing particularly on how futures have been categorized in prior work up to this point. The final section of the chapter draws upon the relevant issues from SCOT and futures research to introduce a concept which I describe as 'future narratives'. The chapter then explores the futures work which formed the foundation of the three types of future narrative uncovered in the research that I call *finite, normalized* and *adaptive*, and concludes with a summary of the above points.

Before beginning this examination, a brief note is required about the timescales of high-risk technologies. As the significant importance of the temporal dimension of these technologies only became clear in the course of the research, the STS literature that was drawn on to underpin the study covered only the aspects of risk to such technologies, not the aspects of temporality. However, it was clear from the prior literature on high-risk technologies (covered below) that many of these could take years or decades to develop. Additionally, a large part of prior scholarly work on *futures* is focused on concepts of temporal proximity and distance, and the use of futures as tools for 'navigating' varying lengths of technological development. The identified implicit relevance of timescales within high-risk literature – combined with the importance of time in futures research – later formed the foundation for the analysis of temporality in high-risk industries in this thesis.

2.2. Science and Technology Studies

Science and Technology Studies is a field of academic investigation that seeks to understand the social, political, cultural, philosophical and economic aspects of science and technology development (Hamlin, 1992; Giere, 1993; Bowden, 1995; Elzinga & Jamison, 1995; Sismondo, 2010). It aims to demonstrate that science and technology are closely tied to this wide range of other interests and agendas (Bijker, 1993). This is in clear contrast to non-sociological accounts of science and technology which produce claims of neutrality, technological linearity and objectivity (Borup *et al*, 2006:290). Hughes defines this issue with 'traditional' accounts of science and technology thus:

> 'Histories [present] invention of artefacts and discovery of facts in a chronological narrative. Technology was usually defined as the technical artefacts; science as knowledge.' (Hughes, 1986:282)

To attempt to counterbalance such accounts, STS grew from the 1960s and 1970s onwards and sought to create a sociology of science with political impact and relevance (Hamlin, 1992) that would acknowledge and examine the social dimension to science and technology. In addition to critiquing these unproblematic narratives of science and technology, world events such as the invasion of Vietnam and the Space Race raised further concerns about the power wielded by the military-industrial users of certain technologies (Elzinga & Jamison 1995:587; Winner, 1986). This generated questions of how best to understand the interplay between technologies and those who wield or control them. STS showed that technological change is not just invention or innovation, but involves the application of science and engineering knowledge, which is an entirely social and political process (Smith, 1993) and one far removed from objectivity and value-neutrality. Aspects such as the direction and application of funding are determined by political processes which will influence future choices of research, and affect how that research is viewed retrospectively. As Hamlin puts it:

> ‘However much one might claim to be neutral, open-minded, unbiased or impartial, or however one buttressed one's claims with methods, one's claim to occupy a uniquely privileged perspective could always be denied on the grounds that one was inextricably tied to one's social situation.’ (Hamlin, 1992:515)

This perspective on the importance of context is also reflected in STS’ investigation of technology. Originally technology was seen as merely the hardware (Orlikowski, 1992) used towards instrumental goals, and technology was only worth studying if it had a direct impact on how a job was done. However, in recent decades far more scholarly work focused upon technology has emerged (e.g. Hamlin, 1992; Balmer & Sharp, 1993; Cowan, 1994; Akrich, 1997; Rammert, 1997; Berg, 1998; Feenberg, 1999; Klein & Kleinman, 2002; Jørgensen *et al*, 2009). When considering the question of narratives, Rammert offers a key theoretical claim by arguing that technology is only considered to be ‘functioning’ when its elements behave ‘according to the rules’ (1997:176) and according to the predictions and intended narratives of use laid out for it. This definition helps us to understand how the success or failure of many high-technology programmes is dependent on the capabilities and *future expectations* assigned to the final product. What the product was intended to do is essential to its perceived outcome, and these *expectations* are key aspects of the analysis presented in this thesis.

2.2.1. The Social Construction of Technology

What aspects of STS may we draw upon to understand the development of high-risk technologies such as those in the space industry? STS is a broad field and several main schools of thought may be identified. These include the Social Construction of Technology (SCOT), Actor-Network Theory (ANT), and the Sociology of Scientific Knowledge (SSK). The first of these to focus upon studying the development of new technology was SCOT. SCOT was developed in the early 1980s primarily by Wiebe Bijker and Trevor Pinch (Pinch & Bijker, 1984; Pinch, 1996; Bijker *et al*, 2012). It built upon SSK's critiques of previous social scientific work for failing to 'open' the processes by which scientific knowledge was created – natural scientists retained a monopoly on explaining theory, method and testing (Bruun & Hukkinen, 2003) and SCOT aimed to challenge the subsequent empiricist view of technological history. Many of the original targets of this 'social constructivist critique of science' (Giere, 1993:105) were primarily deeply theoretical discussions about concepts like pulsars and gravity waves (Ibid) rather than about 'ordinary' or 'mundane' science or technology. SCOT takes the position that 'artefacts are human products, and marked by the circumstances of their production' (Sismondo, 2010:10) and that the apparently neutral scientific method was created and therefore defined solely by humans via competition and debate (Douglas, 2010). SCOT argued that there is no predetermined path of technical evolution for a given artefact, and the job of historians or sociologists is to deduce why one was taken over the other (Douglas, 2010).

SCOT became especially concerned with *technology* rather than *science* as a result of the 'turn to technology' (Woolgar, 1991:21). Woolgar identifies the original intentions of SSK to make *science* sociologically relevant, that the turn of technology was a shift in the object of research towards the technological rather than the scientific, and that this was one of the key identifying differences between the new SCOT programme and its SSK progenitor. He emphasizes:

> 'The construal of a technology as a causal factor seems to imply that there are definitive, identifiable features and characteristics of that technology, whereas the central thrust of social shaping is to suggest that such features and characteristics are contingent, that any such features we would wish to attribute to a technology are the temporary upshot of a series of complex social (definitional) processes, largely due to the efforts of particular social agencies (groups).' (Woolgar, 1991:31)

These 'definitional' processes are part of what SCOT terms 'interpretive flexibility' (Pinch & Bijker, 1984). This is the concept that there is both a level of flexibility in the *design* of artefacts – it is not simply that the most efficient or useful design wins out – and that there is a similar debate within the eventual *use* of a given artefact (Ibid). A key SCOT study that explored this concept was the case of 'high-wheelers' and safety bicycles (Bijker, 1995:19). The study showed that the bicycle's development path was social and not technological (Ibid:199) and that the design of the 'safety bicycle' was a response to the social issues created by the 'high-wheeler' that came before. This showed the lack of a predetermined technological path, and that different social groups assigned different aspirations and competencies to these emerging technologies. Each social group with a stake in the bicycle 'interacted and competed' to determine the eventual form the technology would take (Douglas, 2010:295) during the technology's ongoing development. Similarly, Bijker's (1995) examination of Bakelite set out explicitly to take a technology with an apparently unproblematic development, and expose that quite the opposite was the case. Other technologies investigated via SCOT include radio (Douglas, 1999), telephones (Fischer, 1992), and the Internet (Abbate, 1999).

SCOT's proponents therefore believe technological change, even at the 'smallest' level, is caused by social processes with no internal 'technological logic' present (Bruun & Hukkinen, 2003:101). Since the criteria of technological functionality are socially defined, technologies cannot simply be adopted because they 'work better' (Ibid). Instead, it is not their ability to 'work' which determines their place but rather their workability within a *context* (which in this research is the removal of the Space Race narrative as explored in Chapter 1, the decline of Big Science, and the growth of the private sector and neoliberal rationales in high-technology industries). To determine whether an artefact works or not, Bijker (1993:117) uses the term 'technological frame' to describe the ways social groups interpret artefacts. A frame comprises everything that leads to the 'attribution of meanings of technical artefacts' (Bijker, 1995:123) and everything that influences the actions of social groups who either have a stake in the technology, or use it. If differing groups operate within differing frames, one group may consider a technology to be 'working' perfectly whilst another may consider it defective. In this way a frame is akin to a narrative that describes a particular concept of the 'correct' working of the technology. The idea of the frame is a crucial part of existing analyses of technological development, although – as we shall see – existing SCOT work offers comparatively little on the specifics of high-risk technologies; thus the departure of this thesis from existing work into new theoretical territory.

It is due to these intellectual commitments that SCOT was selected as the theoretical framework for this research. SCOT recognizes that technology is firmly embedded within its social context (Bijker, 1993; van Lente, 2000). As the previous chapter noted, this was once “the Space Race”, and that narratological context was sufficiently strong and sufficiently all-encompassing for both the actors involved in the space industry (i.e. the US and the USSR) that all explanations for that era draw recourse to it. However, with its disappearance, what new social contexts does space belong to? Similarly, for SCOT acceptance and rejection (or success and failure) are socially determined (Pinch & Bijker, 1984; Bijker, 1995), and I was therefore able to ask why the space industry was still accepted and what it now offered. SCOT’s theoretical framework of the social and the technical allow us to examine how technologies are defined as working (Bijker, 1993), and in light of the shift towards private spaceflight, a new understanding of ‘working’ space technology seems necessary. Lastly, as will be noted in the next section (2.2.2), SCOT brings with it a significant body of work into other high-risk technologies, which could be readily drawn upon for comparisons and contrasts.

It is at this point worth briefly commenting on why Actor-Network Theory (ANT), the other leading STS theory of technological development, was not selected for this research. ANT is an anthropological approach to the study of science and technology developed in the mid-1980s by Bruno Latour, John Law and Michael Callon (Callon, 1986a; 1986b; Latour, 1999; Law & Hassard, 1999). Much of ANT’s research methodology is focused on the idea of ‘follow[ing] the actors’ (Callon *et al*, 1986:4; Winner, 1986; Latour, 1996) and observing the actions they perform throughout the network (Pantzar, 1997). Indeed, the title of a central ANT work, ‘How to *Follow* Scientists and Engineers Throughout Society’ (Latour, 1987, my emphasis) highlights the importance of this following process for much of ANT’s thinking. This procedure is cited as one of the major methodological advantages (Pestre, 2008) ANT holds over traditional accounts. Rather than looking at the ‘end state’ of a technology, ANT rather suggests conducting ethnography within the locations that the technology is produced.

ANT was originally rejected as an analytic perspective due to the strengths of SCOT's intellectual commitments vis-à-vis the social and technical as outlined above, but interestingly, as the research progressed, an unanticipated issue arose which highlighted the unexpected difficulty I would have faced had I pursued ANT research. A core component of ANT's methods of data study is via the examination of 'inscriptions' – documents – that are used within a network of technological development (Bruun & Hukkinen, 2003). Research entails close scrutiny of inscriptions produced in order to produce a final account which traces the use of these inscriptions (Latour, 2005:128). During the course of my research interviews, the scarcity of appropriate documentation became quickly apparent. Many interviewees made it clear to me that detailed data was unavailable either because documents were confidential to the UKSA, or they were confidential due to agreements with private actors, or they were not technically confidential but would require permission from potentially dozens of actors to be 'released', or – in a few rare cases – they had some military or governmental backing that meant they could not be made fully public. In some cases I was offered the opportunity to view a small amount of a document or go through a lengthy process to be allowed to view 'safe' parts of the document. These observations support Balmer's (2004:199) assertion that secret information should not be viewed as a single monolithic whole, but as a complex set of data within which some parts may be more or less secretive than others. Winner (2004) similarly notes that in recent years an increasing amount of information that was once public has been withdrawn or hidden by the state, and reframed as crucial data that must be protected, providing a problem for the researcher (as in this study). This meant the only documents available were those which were designed to be viewed by the wider public and these were generally very representative of the 'official line', or written after the conclusion of the programme the document covered. Had I elected to pursue an ANT study despite the ethnographic concerns, this would have been a significant second stumbling block, but as it is this concern did not impinge upon the acquisition of valuable data via interviewing (as described in Chapter 3).

2.2.2. Understanding the Development of High-Risk Technologies

To what extent can SCOT be applied to studying the development of high-risk technologies? We have identified a core aspect of SCOT that seeks to explain how new technologies are developed – the idea of the technological frame. This is a way to define how a particular artefact is interpreted by different social groups, and shows that the development of a new technology is heavily dependent on the conflict and interplay between these frames. This emphasis on the ongoing conflict between frames is essential to a SCOT analysis of this process, but it is also where existing literature on technological development breaks down and becomes inadequate for a full understanding of high-risk technologies.

Technological development is not just limited to 'mundane' technologies such as lightbulbs or bicycles. These kinds of case studies, although illustrative, do not tell us about the development of high-risk technologies. Many technologies studied by SCOT are low-cost or mass-produced products with small amount of risk and a wide range of actors able to invest, contribute, or shoulder some of that risk. In addition to the classic studies of bicycles, Bakelite and bulbs (Bijker, 1995), such technologies studied by SCOT include examinations of musical synthesisers (Pinch, 2002), digital libraries (Kilker & Gay, 1998), mountain bikes (Rosen, 1993), automobiles (Kline & Pinch, 1996), mobile phones (Campbell & Russo, 2003), wheelchairs (Woods & Watson, 2004), personal computers (Selwyn, 2007), radio (Douglas, 1999), and many others. By contrast, high-risk technologies normally require massive financial commitment (e.g. Galison, 1997), are produced in small number (e.g. Law, 2002; Mort, 2008), interact with a smaller number of actors (e.g. Mackenzie, 1990), and of course possess significant levels of risk. To demonstrate the importance of these distinctions, this section will now explore existing scholarly enquiry into high-risk technologies, consider these differences in detail, and propose ‘futures’ as an essential tool to studying high-risk technologies within a SCOT framework.

A key work within this field is that by Perrow (1999), whose book offers a high-level overview of the field and a range of case studies. Perrow analyzes examples including the Challenger Disaster and the Three Mile Island accident and suggests that two features determine the high-risk nature of such technologies: they are highly complex, and they are tightly coupled, meaning that a failure within one aspect of the technology is likely to have knock-on effects and result in an overall catastrophic failure of the system. A related definition is that of the ‘High-Reliability Organization’ (Boin & Schulman, 2008:1050). This concept is instead focused on the social structures that utilize the technology rather than the complex and tightly-coupled nature of the technology itself. Boin and Schulman argue that the social use of high-risk technologies is often structured around a principal governing tenet that the technology *must never fail*. This means that other metrics of cost, efficiency or regular upgrades must all become secondary to the *reliability* of the technology. Although both these works propose a number of high-risk and high-reliability examples (as described in Chapter 1), the current body of case study work into such technologies is substantially wider, and serves to further illustrate the differences between these technologies and their more ‘mundane’ counterparts. Additionally, whilst the ‘high-risk’ and ‘high-reliability’ models as described here emphasize the *use* of the technology, scholarly examinations of specific high-risk technologies have tended to focus instead primarily upon the *development* of those technologies.

Scholars have examined the development of a range of technologies that fall into these high-risk and high-reliability categories. This includes work on nuclear power (Winner, 1986; Cowan, 1990), air traffic control (La Porte & Consolini, 1991; Downer, 2011), civilian aviation (Downer, 2010), military aerospace (Law, 2002), supercolliders and particle accelerators (Galison, 1997; Knorr-Cetina, 1999), fusion research (Kinsella, 1996, 1999), biotechnology (Balmer & Sharp, 1993), nuclear weapons (Rosenberg, 1983; Mackenzie, 1990), chemical plants (Perron & Friedlander, 1996), submarines (Mort, 2008), space telescopes (e.g. Luukkonen *et al*, 1992; Chompalov & Shrum, 1999; Baldesarra, 2005), and missile defences (Lakoff & York, 1989). In doing so many of these works note the arrival and departure of new financial, technical and governmental actors during the developmental programmes, but rarely record significant changes in the programme *objectives* during this process. Once resources have been committed and the many-year timescale has been accepted, the end goals of such technologies appear to shift significantly less than their more 'mundane' counterparts.

In producing these analyses, many of the above had to use declassified data only available years or decades after the programme. This is often required because the development of many of these technologies remains a predominantly secretive affair carried out behind closed doors. This may be state secrecy (e.g. Alexander, 1983) or private secrecy of commercial actors unwilling to divulge or share sensitive information on such expensive and often cutting-edge programmes (Unikel, 1998). It is therefore very possible that the documents available show a bias towards consensus or unified thinking which does not accurately represent prior debate and flexibility within these programmes. These scholarly enquiries nonetheless predominantly display significantly less evidence of shifting objectives throughout the years or decades of the technology's development than SCOT might lead one to expect. This is not to say objectives and agendas are rigidly unchangeable in high-risk development programmes, but it is difficult to identify in these case studies the kind of rapid, regular and highly-contested frame competition that Bijker (1993) identifies as taking place *during the development* of the technology. Based on this reading of existing high-risk literature and the reduced sense of ongoing debate and deliberation these works display, it is apparent that this tenet of SCOT's frame competition is not analytically well-suited to the particular nature of high-risk technology.

In addition to this problem of ongoing debate and flexibility, Bijker (1993) argues that frames compete in an open marketplace of competition. In SCOT the development of the technology is open and allows for many actors to enter and leave the programme and attempt to enforce their own preferences and agendas onto the final product. Although criticized for this inherently pluralistic stance (Klein & Kleinman, 2002), it remains a core tenet of the SCOT theoretical framework. However, just as the high-risk technology case studies demonstrate a comparative paucity of regular and significant frame shifts during a technology's development, they also highlight the reduced number of actors who are able to compete within these technologies, and the considerable influence and power these actors wield. This is especially apparent in the works of Lakoff & York (1989), Mackenzie (1990), Kinsella (1996), Knorr-Ceinta (1999), Law (2002), and Mort (2008), but is prevalent throughout the above literature. The actors that are able to compete are those with enough social and political capital to access the closed market of debate, and significant financial and technical capital in order to propose contributions to the programme.

We have therefore now identified two points of disjuncture with existing work on technological frames for high-risk industries. High-risk technologies are developed in a relatively closed market, not an open one; and a dominant frame is almost always firmly established *before* the commitment of resources, rather than the dominant frames being challenged and altered *throughout* the commitment of resources. In this light the traditional model of interpretive flexibility and the ongoing open-market situation it implies struggles to explain the developmental process of high-risk technologies. However, despite the resources apparently marshalled before development begins and the bias towards powerful and influential actors, many high-risk technological developments are ‘unsuccessful’ (Lakoff & York, 1989; Gooday, 1998). What, therefore, determines the technological outcomes of these industries, if it is not *ongoing* open-market frame competition?

Since the frame competition in high-risk technologies all but ceases at an early stage, there must be another factor at play. To identify this factor we turn back to the high-risk case studies described above. These case studies are replete with examples of struggles over *continued* support from governments, the military, private investors, and so forth. There are also examples – such as Lakoff and York’s analysis of the US ‘Strategic Defense Initiative’ anti-missile programme – where high-risk technologies did not meet their objectives and ceased development. Whereas in a mundane technology the loss of confidence or support in a dominant frame may lead to it being replaced by a new dominant frame, for a high-risk technology this loss of support will in most cases bring the programme to an end. In order for a high-risk programme to reach its end goal, therefore, continual support must be present – a dominant frame must be compelling enough to warrant commitment on a scale and timespan that the programme requires. SCOT argues that once there is a single, widely-agreed-upon dominant frame for an emerging technology, that interpretation becomes the truth of the artefact and its *functioning* (Pinch & Bijker, 1984; Bijker, 1993; Bijker, 1995; Bijker & Pinch, 2002; Klein & Kleinman, 2002). In this way a dominant frame for a technology *which has not yet been developed* must contain a narrative of the future – the technology does not yet have functioning to *show*, and so a dominant frame must be supported by predictions and promises about its future functioning in years or decades to come. This will be distinct from any frame that exists in an ongoing competition within an open-market situation, for it is related to a technology that only exists on the drawing board rather than a technology-in-development.

As such, a gap in the literature is identified here which this thesis will aim to fill. Although the initial stages of a high-risk development are reflected in existing SCOT work on interpretive flexibility and the competition between frames in a market situation (even a closed market), this form of competition fades as the programme proceeds. If the high-risk programme is unable to present its goals as being desirable and compelling, it will simply not continue, *rather than continuing under the guise of a different frame*. In order to present its objectives as desirable, dominant frames must contain a future-orientated aspect that is far more crucial than in comparatively ‘mundane’ technologies. Establishing this strong orientation of high-risk technologies towards the (potentially very distant) future does not, however, explain what these future-orientated narratives do, or what they promise, or how they are designed to offer compelling conclusions to lengthy and high-risk technologies. We therefore return to the research questions outlined in the previous chapters. What roles do these future-orientated narratives play in high-risk technological developments, and how are they constructed and utilized? We have established that some form of future-orientated narrative must be integrally tethered to dominant frames in high-risk technology programmes, but the functioning of these narratives is unexplored, and elucidating this is the goal of this work.

However, one potential objection to this model is clear when we consider the rise (discussed in the previous chapter) of private spaceflight. Surely private spaceflight and its emphasis on competition and open-market space technology means that there *are* multiple frames competing throughout? To pre-empt and deal with this criticism we should return to SCOT’s understanding of frames. In the ‘classical’ model there are multiple interpretations of the technology that may change or rise and fall in influence *throughout* the development of a technology; the ongoing development of the technology and the flexibility and change in the dominant frame(s) occur at the same time. However, the prior examination of the literature shows that in high-risk technologies the resources that must be committed are so significant that little or no active development of a technological programme begins until a dominant frame has been established. The concept of future narratives thus does *not* argue that there is no competition to decide on the objectives of the technology, but rather that once resources are committed, there is little change in the objectives *throughout* the programme. Once the objectives are selected, the programme will only then begin to marshal resources, and subsequently succeed or fail based on its ability to convince actors via the 'future narratives' presented. Given the understanding presented here of high-risk technologies being compelled to sell the value of the *future* predicted in a dominant frame, the field of 'futures' is essential to understanding the development of technology within high-risk industries. This thesis will now explore this field in detail to understand what it contributes to this work.

2.3. Futures

As Brown *et al* (2000:5) state in their work *Contested Futures*, 'the future has become big business'. Long-term thinking, environmental concerns, the creation of potential future scenarios, 'horizon scanning' and other considerations of the future have become key methods to legitimize decisions ranging from policy choices of international scope to the planning and objectives of small companies or individual actors (Sans-Menéndez & Cabello, 2000:232). The claim that future impacts of a technology can be predicted reinforces the oft-held linear deterministic conception of technological outcomes (Williams, 2006) that STS has worked hard to challenge. The reasons for this rise in prediction are many; one argument posits that as a result of the drive for progress and expansion, so fundamental to modernity, futures are now seen as things that should be grasped, analysed and understood (Slaughter, 2002). Alternatively, Giddens (1997) argues a new interest in futures stems from feeling a *loss* of control about the future which needs to be mitigated as much as possible via greater analysis. Another rationale is that since all actors have their own desired futures (Smith *et al*, 2005), and any individual industry or group can only have limited influence on that future (de Laat, 2000), organizations which examine futures may be better placed to anticipate the actions of rivals, impending regulation, or the emergence of new markets (Georghiou, 1996). 'Futures' is an interdisciplinary field concerned with studying these predictions – how they are created, who creates them, what purposes they are used for, and the methods used to attempt to quantify the inherent uncertainty of forecasting any social or political phenomenon ahead of the present. To study these futures, Brown *et al* (2000:4) suggest we should examine how a given future is 'constructed and managed, by whom and under what conditions'. Futures are socially constructed and are subject to flexible interpretation – in this case the constructed future is that of a high-risk programme, and the flexibility is over the desirability of such a future. A number of scholars have proposed methods of categorizing the differences between different forms of futures, and it is to these categorizations we will now turn to examine the existing ways in which futures have been understood and their value to the study of technology. Subsequently the chapter then explores specific aspects of futures literature highly relevant to both high-risk industries and technological development programmes as a whole, which will subsequently be built upon and further developed by the three types of future this thesis proposes.

2.3.1. Categorizing Futures

This thesis proposes three new kinds of future, termed here future narratives. I have called these three categories *finite*, *normalized* and *adaptive* futures. Each of these is grounded in existing work on futures coupled with the original research undertaken in this study in order to explain the dynamics of lengthy technological developments in high-risk industries. Examining this futures work will make clear the methods by which we can begin to arrive at this new three-part categorization.

There have been to date a number of attempts to classify and categorize futures. Smith *et al* (2005:156) suggest five major uses of futures: identifying possibilities and plausible outcomes; acting as ‘problem-defining tools’ or heuristics; stabilizing activity via a common reference-point shared between actors; generating metaphors and visions about relevant actors who carry symbolic value; and as narratives for the ‘marshalling of resources’ and focusing inputs and outputs. These are all uses to which futures may be put, and Smith *et al* (2005) thereby categorize and typify futures according to their eventual objectives.

Alternatively, Michael (2000:24-32) suggests five axes upon which futures can be measured in terms of their structure, not their objectives. The first is distance – something taking a week is seen as more feasible than something taking a year, while long temporal distance also reduces urgency. Defining the temporal distance of the future positions the reader for immediate action or a long-term measured plan, and makes assumptions about the roles opportunism or strategy may play. The second is the subject – futures can either draw recourse to individuals, or to broader societal themes. The third is the ‘form of rationality’ – substantive or instrumental objectives will affect the presentation of the technology; ends-orientated futures may be criticized as utopian or hailed as visionary, whilst process-orientated ones may be praised for realism and pragmatism or derided as business-as-usual (Michael, 2000:28). The fourth is valency – a positive future is something to be worked towards whilst a negative future is to be fought against (Sans-Menéndez & Cabello, 2000), but ‘positive’ futures may be negative for some actors and vice versa. Fifthly, Michael distinguishes between futures that are slow and fast, as well as far and near – a fast future might be one we mindlessly rush towards or one focused on ‘entrepreneurial grasping of the future moment’ (2000:32), whilst a slow future may be one we drift towards or one that can be reflexively examined and legislated on (Ibid).

The three types of future narrative which are identified in this thesis can be understood as cutting across many of the definitions proposed above, but also pushing the understanding of futures (and their uses in high-risk industries) in new directions not discussed in these typologies. They also draw upon specific bodies of futures work concerned with issues other than categorization. The next three sections examine prior futures work on technological development which cut across these two five-part definitions, and will subsequently serve as the background to the new high-risk future narrative typology proposed in this work.

2.4. Future Narratives

2.4.1. Towards *Finite Futures*

There is a range of established futures literature on technological development, beginning with work which notes the importance of a distinct and clear end-goal for a future. Michael (2000) argues that technological futures orientated towards a specific and distinct goal can be strengthened by that explicit declaration of intent. He emphasizes the importance of the *distance* towards this objective, a theme this thesis will return to several times in its analysis – many programmes in high-risk industries take years, whilst others may even take decades. Elzinga (2004) has also explored how temporally distant futures of this sort are designed to reinforce a message and maintain a consensus across such potentially substantial periods of time. In designing such lengthy futures, their authors construct amongst themselves a full 'repertoire of promises and expectations and strategies' (Jørgensen *et al*, 2009:84) with which to encourage other stakeholders into a programme. They also serve as 'taken-for-granted' frameworks and perspectives to act as the foundations for understanding the programme (Wynne, 1983:15) – they ensure that everyone is 'on the same page', or at least close, in order to sustain collective discipline and movement towards potentially temporally distant shared goals. A collectivization of goals keeps all actors focused upon a very distinct objective with a fixed endpoint. With so many stakeholders in a programme and a clear set of objectives, the potential technology becomes an '[object] of widely shared speculative promise' (Brown, 2003:16; cf. Borup *et al*, 2006:29), and it is this *sharing* of promise that such futures aim to ensure.

High-risk futures in the literature above (e.g. Galison, 1997; Kinsella, 1999; Knorr-Cetina, 1999; Lakoff & York, 1989) are presented as being far more distant from the present than many other futures for 'mundane' technologies explored by SCOT. This type of very long-term prediction relevant to high-risk industries has been examined by Adam (1995:118, 2004:87), who argues that it becomes increasingly challenging to accurately predict effects as future predictions move into decades and beyond (cf. Nordlund, 2012). Futures that predict over such a temporal range have to produce convincing outcomes for a wide range of actors who are all tied to the success or failure of the programme, but in a scenario where the outcome may be years or decades ahead. At the same time, such programmes do still have a distinct end – once stakeholders have been involved for some of the programme, the existence of a distinct endpoint serves to discourage a premature departure from the programme.

Although existing scholarly work acknowledges the importance of both keeping those within a programme on the same page and the value of a distinct and clear end goal, little has been written on how these aspects play out over programmes that are highly risky and take a long time to completion, beyond this acknowledged potential inaccuracy and the importance of maintaining long-term consensus.

The concept of the *finite future narrative* that emerged from this research builds upon this work. The term *finite* was selected as a label for this type of future due to both the distinct conclusion and 'cut-off' for the programme, and also the emphasis on a clearly-defined step-by-step process towards that promise and the lack of flexibility within this defined path. As the thesis will show, this path serves to both bring actors into these high-risk development programmes, offer intermittent points or milestones where the ongoing success (or failure) of the programme may be measured, and to maintain their commitment throughout the process of technological development. Its objectives and goals are designed to offer compelling benefits to a wide range of actors, all of which stem from the central objectives of the programme's dominant frame. This is the closest of the three forms of future narrative to existing work on futures – within the categorizations discussed above, the conception of futures from Smith *et al* (2005:1506) as fundamentally designed to 'stabilize technical and other innovative activity' is highly relevant to the study of finite futures, along with the work of Michael (2000) on the temporal distance of future planning. These will both be drawn on in Chapter 4's analysis of finite future narratives.

2.4.2. Towards *Normalized Futures*

As with the finite future narratives above, all technological futures are designed to mobilize other actors (Jørgensen *et al*, 2009), seeking to bring them into a programme and discourage departure. However, such actors outside a high-risk industry may not necessarily be interested in the *technical* specifics of a programme, but are instead assessing potential future value of the programme's *outputs*. This can be understood as a shift in language away from that used in Big Science to denote change, progress and discovery, and towards universal and mundane terminology to enhance the applicability and ease of understanding of a programme (Hilgartner, 1990). In futures of this sort, outside actors are not concerned with the specifics of a new technology being used, but may be more likely to appreciate the value of the programme in terms of profit or service coverage. Within Michael's typology these would be process-orientated futures (2000:28) concerned with purely instrumental outcomes, rather than the bolder objectives described in the above section.

For any high-risk industry this would mean a reorientation of how a programme's goals are expressed. New futures must contain compelling messages to bring in these new actors, but not offer too much innovation or discontinuity with existing technology. As Geels and Smit (2000) argue in their study of futures, this results in a balancing act between promising enough to entice, and sufficiently little that the inevitably more down-to-earth outcomes – communication coverage instead of space telescopes – do not disappoint. This interplay between the bold promise and the more 'realistic' prediction is echoed by Elzinga (2004), who suggests a second balancing act exists between the 'reality' of the claim – derived from concepts of scientific or technological objectivity and therefore predictive reliability – and the promise of a future which, by definition, is only an extrapolation from current reality. These works argue that constructed futures must be simultaneously able to promise enough to entice actors into a programme, but not show too much disjuncture with the present that they are considered implausible. Although these works emphasize these points, little has been written on making a *change* towards such pragmatic futures in an industry long established as producing bold and dramatic futures that denote clear disjuncture with the present. What (if anything) is unique to producing these forms of ‘mundane’ future when they are within a technological industry that is innately associated with cutting-edge science and high-risk technology?

The *normalized future narrative* emerged from the research as the answer to this question and a continuation of this body of futures work. The normalized future is a type of narrative that positions itself in explicit contrast to the rationales of Big Science – the advancement of ‘abstract’ knowledge via massive state-sponsored financial and technical commitment – and instead attempts to sell space technology (or any other high-risk equivalent) by attempting to reposition the technology as an ordinary part of everyday life. This attempted repositioning of such technologies as ordinary parts of social or economic life is reflected in the kinds of promises normalized futures make. These normalized futures are a clear shift towards promising more ‘mundane’ future objectives, and the above authors provide us with an initial understanding of the interplay within futures between the scope of the promised outcome and the believability of the future. A mundane promise, or a promise ‘close’ to the present, is a future more likely to prove accurate (Michael, 2000). These futures herald a reorientation of some aspects of the space sector away from innovation and towards a more conservative and ‘plausible’ outlook (Smith *et al*, 2005:1506). This thesis argues that normalized futures do not promise extreme discontinuity with the present day, but instead offer services that are incremental enhancements, not major shifts, in what type of service is currently available, such as phone communication or broadband. The term *normalized* has therefore been chosen because this second type of future narrative is used to promise standardized market or service outcomes. Within this form of future, ‘technical’ descriptions of the programme’s aims are less useful than service-orientated equivalents, and this second type of proposed future narrative will mark a significant departure from the promises and assumptions from earlier iterations of high-risk industry futures (Blankenship, 1974; Kinsella, 1996).

2.4.3. Towards *Adaptive Futures*

As discussed in the previous two sections, I have proposed the applicability of two bodies of futures work to high-risk technologies – that on long-term planning and objective-setting, and that of instrumental or pragmatic benefits (as a reorientation of high-risk technology agendas). However, there are three significant other bodies of prior futures work which possess clear relevance to high-risk technologies, and each poses a question for our understanding of future narratives within these industries.

Michael (2000:22) explores the relationship between the future and the past within futures. He argues that a research programme both makes statements about the past – how the current state of affairs was reached, what technologies have been mastered, what the context is – as well as the future. Examples of this phenomenon can be seen in other STS research: in Brown and Kraft’s (2006) exploration of blood stem cells, they argue that the current expectations on such cells are historically constituted from engagements with blood and medical innovation. The work of Tutton (2012) reinforces this importance of understandings of the past to conceptions of the future, showing how past medical history is carefully positioned as part of articulating a vision for future personalized medicine. What does the mastering or understanding of *previous* technologies in the space sector or any other high-risk industry do for future programmes that might build upon that technology, and how is this reflected in the futures they produce?

Futures can also be a method for extending the lifespan of an existing programme. Winner identifies the phenomenon where a programme that seems to be coming to the end of its lifespan or original remit will also '[seek] a mission to match its technological capabilities' (Winner, 1977:244). Even if the intended use has been concluded, the system will have gathered (if successful) commitments of manpower, expertise and financial resources, and may not wish to go 'gracefully into oblivion' (Ibid). The programme will then attempt to align itself with new objectives, new uses and new developments, and try to stress the importance of taking on a new task. Within the space industry, for example, NASA's post-Moon work with human astronauts has sometimes been derided as being a result of NASA having little else to do with all the infrastructure and expertise required, and instead its searching for new roles and new programmes (Ibid:245). The system tries to adapt and influence the 'needs it also serves' (Ibid:246) to extend its own lifespan. Are there aspects of this adaptation process distinct to high-risk industries where the existing lifespan is likely to already be significant?

The third piece of current futures literature with questions for high-risk technologies is that which is focused on the deployment of expertise and the authority granted to experts. A convincing and authoritative narrative backed up by experts will have much more impact than the same narrative deployed by other actors (Rip, 2003; cf. Sjöberg, 2008). This is what French and Raven (1960:262) call 'expert power' and which Hilgartner (1990:520) considers the 'gold standard' of epistemic authority. This chapter has already considered the importance of proposing convincing and compelling promises, but 'expertise' is an important part of the process that goes into creating these promises, and making these promises appear realistic and credible. Given the length of testing and development regimes within the space industry and other high-risk sectors, what forms of expertise are sufficient to convince others of the value of their programmes, and to lend them credibility?

The third and final future narrative in the three-part typology presented in this work, the *adaptive future narrative*, was developed from my original research data and answers these questions. It marks the furthest theoretical move away from existing scholarly work on futures. Adaptive future narratives are not focused on a specific programme or mission, but rather on a physical component. Rather than having a distinct end, they instead emphasize the *successful functioning* of this component in a potentially infinite number of possible future programmes. This form of future narrative is termed *adaptive* because it is focused on creating a component that can be trusted in any range of possible future programmes across an indefinitely large temporal range, and on minimizing the limitations placed on what this component might be used for in the future. Although a future narrative of this sort may seem to challenge much of the existing scholarly work on futures – which as we have seen emphasize the importance of offering futures with a clear temporal end – there is nevertheless a rich theoretical background explored above that we can draw on for beginning to understand this third unusual form of future narrative. This background is the importance of the past as evidence of the correct functioning of the component, the desired continued development of the component, and the role of expert knowledge for creating authority and credibility.

2.5. Summary

This chapter has summarized existing work relevant to this research and proposed the concept of the future narrative. It began by isolating the gap within existing scholarly work in STS that this concept aimed to fill – the question of how high-risk technologies are developed, and what is unique about these technologies compared to other, more 'mundane' technologies. The chapter summarized the key points in the Social Construction of Technology (SCOT) relating to technological development, and emphasized the importance of the ‘technological frame’. A technological frame is a way that a particular social group interprets an artefact, and often takes the form of a narrative for the intended use of that artefact – there may be many such frames each held by different groups, and these frames compete for acceptance and dominance during the development of the artefact in question. However, the chapter subsequently argued that the concept of the technological frame, and the associated *ongoing* competition towards the emergence of ‘dominant frames’, does not adequately describe high-risk development. This is due to the SCOT assumption of an open-market circulation of frames and the rise and fall of multiple dominant frames throughout technological development, whereas prior scholarly work into high-risk industries showed that neither of these is the case within these sectors. Once resources have been committed, the interpretive flexibility of the programme lies in perceptions of whether or not it will succeed, not in what form the technology will take. This chapter identified from the literature a strong (but not absolute) level of stability in programme *objectives* over these long time spans, although from this prior work it does appear that the potential for minor changes still remains.

In light of this period potentially stretching over many years or even decades and the need for a dominant frame to make promises about a future that that remains distant, the chapter then proposed looking towards the field of ‘futures’ research to help understand how such programmes are developed in the absence of ongoing frame competition. This led to the conception of the term ‘future narrative’ – a form of narrative unique to high-risk industries and specifically orientated to produce a compelling story for a programme’s future development that will maintain interest from actors over a significant length of time. A future narrative consists of statements designed to sell the predicted success of the dominant frame. Future narratives do not compete with other frames once development has begun, but they do compete for acceptance or rejection based on how convincing and compelling they are able to make the dominant frame appear.

Thus, in proposing the concept of the future narrative to fill the gap within STS literature, we can identify a break from traditional work on narratives – this form of narrative is located in the future, not the past (cf. Deuten & Rip, 2000; Elzinga, 2004). There is also an important distinction between futures and future narratives. Futures are normally focused upon specific markets or industries (Georghiou, 1996; de Laat, 2000; Sans-Menéndez & Cabello, 2000), whilst future narratives are concerned with much broader ranges of stakeholders including governments, militaries, scientific communities and 'the public', as well as commercial enterprise. Future narratives are constructed to tell a *story* (Akrich, 1997) about the value of the planned development of a technology – this is an act which imbues the development and subsequent use of that technology with far broader social and political meaning (cf. van Lente, 2000, Elzinga, 2004) than one confined to market dynamics or technical specifics. The concept of the future narrative proposed by this thesis is therefore designed to marry future predictions with narratological meaning outside the confines of the high-risk industries they are developed within – within the case study of the thesis, this context was found to include a wide range of 'non-space' actors who are now involved with the space industry.

In addition to the overall research question focused on the construction and utilization of future narratives, the chapter identified more detailed and specific sub-questions drawn from existing futures work which refined my interview questioning. Do high-risk technologies utilize promises and detailed plans as in other futures, and if so, how? How do they represent instrumental (Michael, 2000) or 'plausible' (Smith *et al*, 2005) futures? Identified in prior work as important determinants of successful or failed futures (e.g. Winner, 1977; Michael, 2000; Rip, 2003), what roles (if any) are played by the past, the desire for programmes to continue into perpetuity, and expertise and expert knowledge? Although unknown at this juncture what (if any) answers to these sub-questions would be found in the space industry, issues and questions about technological futures already raised by futures research were a valuable starting point for this investigation. Having established over the past two chapters both the theoretical underpinning of the research and the existing literature which formed my investigation of futures, narratives and the space industry as an illustrative case study, the next chapter explores my research methodology.

Chapter Three: Research Methodology

3.1. Introduction

This chapter covers the research design of the thesis for the exploration of future narratives. It begins by discussing the selection of semi-structured interviews as the focus of the research design and the reasons behind this choice, before then listing the interviewees who took part in this study, their points of origin and the demographics within the space industry to which they belonged. The chapter then outlines how sampling was carried out to attempt to ensure a representative cross-section of the UK space industry, and the importance of grounded theory in the research design. In keeping with grounded theory the three-part typology of future narratives for high-risk industries the thesis proposes – finite, normalized and adaptive futures – was created without any prior assumptions about the forms of narrative the research would identify. The final section of the chapter then covers appropriate ethical considerations for research involving human participants, before concluding with a summary.

3.2. Research Method: Semi-Structured Interviews

Interviewing is the primary source of data for this thesis. Interviewing was selected in order to understand the use of future narratives from the perspective of those who directly create and deploy them as part of their roles within the current UK space industry. Hermanowicz (2007:629, emphasis original) considers interviews to be a method for asking '*what do you think about what you do*?'. It directs our attention to the experience of work instead of questions that may only get information about self-presentation (Veroff *et al*, 1993) or the 'official line' about a development programme. In this regard studying the official line from distributed media such as press coverage or official documents would only have yielded a sanitized version of any future narratives. This choice of interviewing also allowed the interviewees to define their own roles within the space sector and expound on how important *they* felt future narratives were. Actors *themselves* should be allowed to define and describe their social world without any interaction from the analyst at all (cf. Vikkelsø, 2007). Once they have finished describing their world, sociologists can then understand how they define their lived experience (Hermanociwz, 2007) and what takes place within their social worlds (Ashforth & Kreiner, 1999). This perspective stresses the importance of how the actors themselves interpret their settings, their parts in events, and how they have gone about their jobs and roles. Interviewees may in this case describe how they perceive the roles of future narratives (if any), which may be hidden within documents that (as noted in the previous chapter) are unavailable for public access, or only exist temporarily in discussions, meetings or debates within the industry itself that are closed off to outsiders.

This type of semi-structured interview can thus be used to ascertain and examine individuals' 'interests, attitudes, relationships, roles, power and influence' (McBride, 2003:270). Whereas a documentary analysis may fall foul of retrospective constructions of events and narratives, or documents being made significantly after a contested event and only recording the eventual stabilized outcome, semi-structured interviewing of those involved allows for a first-hand appraisal of what went into the construction of a narrative or a programme of technological development. These interview techniques allow for issues to be studied that cannot be directly observed by the researcher. Points of interest may have happened far in the past, or lack physical records, or be closely related to the interpersonal dynamics within an organization (Bryman, 2008:466-468). They also reduce intrusion compared to an ethnography, allow for a retrospective longitudinal study – appropriate when none of the space programmes interviewees worked on either began or concluded within the three-year period of my research – and give the potential for a greater breadth of coverage by engaging with those in different ranks and positions in the studied group (Ibid).

In interviews the narratives that interviewees provide are considered to be of particular importance when relating past events of how their world came to take on the configuration it currently has (Bryman, 2008:388). The narratives presented would show how those within the space industry understood their own work. Researchers must not misattribute or misreport the statements of interviewees (Venturini, 2010) but instead use the understandings put forward within the research, not those generated beforehand by the researcher. The thesis therefore sought to listen to the 'voices' of actors above the researcher's assumptions – for example, interviewees were categorized according to their own self-definitions of their jobs and their positions in the space sector, and this is the key used throughout the thesis to denote the origins of the interviewees. As Bryman (2008:375) puts it, 'the social world must be interpreted from the perspective of the people being studied', and it is from this perspective that the thesis proceeds to examine the space industry.

3.2.1. Interviewees

A total of 26 people were interviewed for the research. 28 were contacted, but one was unable to make meetings for which I was available and the other did not reply. The first nine interviewees were all from the UKSA. This was via permission from the Chief Executive of the Agency (at the time of first contact – this position has since shifted to another individual) and through the Chief Executive these interviews were arranged. Individuals such as this who allow or restrict access to research settings are known as gatekeepers (Rubin & Rubin, 1995:65-67). In this case identifying the initial gatekeeper in the UKSA was very simple and there were no significant issues or disagreements with either the then-Chief Executive or subsequent interviewees. Although I made contact directly with all interviewees, many were also contacted by earlier interviewees and encouraged to take part in the study. Some interviews were concluded by asking for recommendations about who to talk to in order to gather a broader and more holistic image of the space industry, which was coupled with my own investigations into relevant UK space organizations. This process next moved the research in the direction of the Technology Strategy Board (TSB), a UK public body that works on developing and marketing new and emerging technologies. As a link between the public space sector and many private actors, from this point onwards the range of interviewees broadened out significantly to include those in a range of private companies. One interviewee was an individual who had previously worked in the Ministry of Defence's space operations; one was a senior member of the British Interplanetary Society, the UK's primary space advocacy body; whilst one interviewed at a conference was from ESA and dealt with the UK's interests within the larger space agency. Twenty-five of the interviews lasted between 60 and 120 minutes and were carried out within interviewees' places of work, whilst one was conducted by phone when a physical meeting could not be arranged. In this case a slightly different informed consent form (Appendix B) was emailed to the interviewee, rather than the standard form (Appendix A) I used in person for all other interviews.

Permission to tape record the interviews was gained as part of the consent form, which detailed their ability to decline, to withdraw at any time, and what the research would be used for. The semi-structured interviews began with a small number of introductory questions about the interviewee's past and career progression in the space industry, and then moved on to questioning about the substantive topics of the research. Within the interview situation most interviewees were very free with their time and offered detailed responses. A small number of interviewees only offered up 'official line' responses, replying to my questions as if I was a representative of a news outlet or a potential investor to whom they needed to provide a pristine image of the space industry. In these instances the interviewees were asked to expand and elaborate on their comments, but further details were rarely forthcoming if an interview began in this manner. At several points in some interviews, notes were made on issues to return to later in the interview or to add to the list of interview questions for future interviewees. The questions asked in the interviews were developed iteratively over time, with an initial broad focus on future narratives which was later narrowed down to attempt to identify more detail about emerging trends in earlier interviews. Interviews began with introductory questions about the career in the space industry of the interviewee, before then moving onto the substantive topics.

Table 1 (overleaf) shows the breakdown of interviewees. Each one has been assigned an anonymous identifier ranging from 001 to 026, and has been listed next to their company or affiliation and the categories into which they fall. In assigning these categories, I have sought to use the definitions that those within the space sector adopted and to let the interviews speak for themselves, rather than trying to organize the interviewees according to a separate metric. As discussed earlier in this chapter the only 'lines of social demarcation' which should matter in social research are those that the actors draw or perceive (Klein & Kleinman, 2002:32) and the definitions assigned below follow this rationale. The categories are *public* (primarily the UKSA, but also a number of other governmental bodies such as the TSB)*, private* (those from for-profit space industries or companies)*, science* (those who work in 'abstract science' missions such as space telescopes or planetary landers)*, technology* (for those who defined themselves as working in technology development, innovation, or similar)*, engagement* (with the public)*, 'growth'* (a term used by the interviewee in question when questioned about their job, which primarily entailed finding and developing new markets for the space industry), *comms* (for those who worked in the communications industry) and *EO* (for Earth Observation, such as remote sensing and weather satellites). We can therefore note that interviewees drew a clear distinction between the 'scientific' and ‘technological’ aspects of the space industry (Pinch & Bijker, 1984; Hughes, 1986; Faulkner, 1994), and this is reflected in the categorization. There were a total of seventeen interviewees involved in the *public* side of space, twelve from the *private* sector, twelve involved in various forms of *technology* development, six concerned primarily with space *science,* four who worked in the *communications* side of the industry, two involved in *earth observation*, one involved in *engagement* and one in *growth*. Where necessary for reasons of space, the following abbreviations have been used in the table: ‘Priv.’ for ‘Private’, and ‘Tech.’ for ‘Technology.’

ID	**Company/Affiliation**	**Categories**
001	UK Space Agency	*Public, Engagement*
002	UK Space Agency	*Public, Science*
003	UK Space Agency	*Public, Technology*
004	UK Space Agency	*Public*
005	UK Space Agency	*Public, Science*
006	UK Space Agency	*Public, EO, Technology*
007	UK Space Agency	*Public, EO*
008	UK Space Agency	*Public, ‘Growth’*
009	UK Space Agency	*Public*
010	Technology Strategy Board	*Public, Technology*
011	Technology Strategy Board	*Public, Technology*
012	Technology Strategy Board	*Public, Priv., Tech., Comms*
013	Technology Strategy Board	*Public, Priv., Tech., Comms*
014	Reaction Engines Limited	*Private, Technology*
015	Reaction Engines Limited	*Private, Technology*
016	Reaction Engines Limited	*Private, Technology*
017	Reaction Engines Limited	*Private, Technology*
018	Ex-MoD (Space)	*Public*
019	International Space Innovation Centre	*Public, Science*
020	British Interplanetary Society	*Public, Private, Science*
021	European Space Agency	*Public, Science*
022	EADS Astrium	*Private, Tech., Comms*
023	Qinetiq Group	*Private, Science*
024	Global Invacom	*Private, Comms*
025	ABSL Space Products	*Private, Technology*
026	COM DEV Europe	*Private*

Table 1. Table of Interviewees, anonymised labels, origins and demographics.

Throughout the thesis all interviewees will be referred to according to their identification number with a note of their categories in parentheses after it.

3.2.2. Sampling

When sampling interviewees the ‘information richness’ of the data is considered a key goal (Denzin, 1998), and from the outset I sought to interview a representative sample of the UK space industry. There are several different methods by which sampling may be done. ‘Extreme’ sampling involves contact with those who ‘exemplify characteristics of interest’, ‘intensity’ sampling focuses on those who have experienced the phenomenon for a long time and have a deep knowledge of it (both non-random samples), while ‘maximum variety’ sampling is used to assess generalised traits (Ibid:73). As the study progresses, sampling can be returned to in a reflexive process to study ‘confirming or disconfirming’ cases (Ibid:74) that will have a critical impact on the theories proposed. Since the characteristics of interest for this thesis’s interviews are perspectives and opinions from those involved in widely heterogeneous modern space programmes, maximum variety sampling was the primary method used to interview as wide a range of individuals as possible. In this regard some potential interviewees were not pursued if their job descriptions and backgrounds closely mirrored those already interviewed, whilst a greater number of interviewees were generally pursued from larger and more important organizations in the space industry to reflect the significance of these bodies in the space sector.

However, an issue arose in deciding when to consider the range of interviewees ‘complete’. Social networks are potentially endlessly expansive, and therefore the number of potential interviewees is too, and the artificial construction of a limit or boundary then lies with the researcher. The universe of relevant groups can be infinitely expandable (Cowan, 1994; Krige, 2000). The researcher will always be able to expand any given point of study even further (Levins, 1998), and thus an informed decision must be made about where to ‘cut’ the network (Bijker & Pinch, 2002). This makes the objects of study themselves ‘intellectual constructs’ as the investigator chooses the system and the boundaries (Levins, 1998:559). During the course of the research it became quickly apparent that with the unit of study being ‘The UK Space Sector’, this could expand to almost any number of individuals. Several interviewees themselves highlighted the level of vagueness when defining who and what is part of the space sector. Should Sky TV be considered part of the space sector? Should those who provide GPS services be considered part of the space industry, or only those who manufacture the GPS equipment, or somewhere in the middle?

Neither theory nor methodology actually explains how the research process should be concluded or at what point interviewing should end (Strathen, 1996), so focusing on the specific way the network is cut (regarding both intellectual and practical concerns) should be considered constructive to good research (Jensen & Zuiderent-Jerak, 2007; Bijker & Pinch, 2002). Cutting the research in this case focused on an iterative principle of sampling and interviewing until a level of ‘saturation’ of information had been achieved. A point was reached where no new interviewees could be identified who were employed in aspects of the space industry from which I had not yet interviewed anyone, and where little new data was being gathered from those I was continuing to interview. This occurred once a little over twenty of the eventual twenty-six interviews had been conducted; the final few interviews were carried out after reaching this point either because of prior arrangements with the interviewees, or in order to pursue particular points which had not been sufficiently explored in the prior interviews (most other relevant topics having been saturated by this point). The resulting selection of interviewees – twenty-six, all with in-depth semi-structured interviews, generally lasting between one and two hours but sometimes even longer, from a wide range of space sector backgrounds – provides a detailed cross-sectional image of the space industry, and is more than adequate to explore the key questions of this thesis about the creation and role of future narratives.

As above, the point at which the research was cut was upon reaching a level of theoretical saturation. This ideal of theoretical saturation refers to the state when data cannot be reviewed any more to gain new insights from it, and no new concepts are appearing from its analysis (Bryman, 2008:542). It is in this way an ongoing process concerned with 'the refinement of ideas, rather than boosting sample size' (Ibid:415). A judgement that theoretical saturation had been reached was thus behind the conclusion of the interviewing for this research after twenty-six interviews. However, 'volunteerism' can skew interviewees if only certain types of people (or those in certain positions) are willing or able to participate in the study (Heckathorn, 2002). There is little evidence to suggest that much of this happened – as previously mentioned, 26 out of 28 interviewees contacted both responded and agreed to interviews and the twenty-seventh was willing but unavailable, marking a very high response rate.

Nevertheless, other issues arise with a 'chain-referral sampling' method, similar to 'snowball sampling', where participants refer the researcher to other appropriate participants (Rubin & Rubin, 1995:67-8). This risks homophily, a condition where interviewees only refer the researcher to those they know or those with similar views, which raises the importance of varying the initial sample (Heckathorn, 2002). This was undoubtedly possible in this case as those I might wish to pursue for subsequent interviews were from time to time recommended by prior interviewees. However, due to the significant variation between different parts of the space sector, the fact that it was normally *organizations* and not *interviewees* that were directly recommended, and my decision to select the majority of interviewees entirely independently of any 'recommendations', I believe little of this problem arose in the research. Some snowball sampling was conducted, but the final choice to pursue or not pursue a potential interview was taken solely by me, with the objective of achieving theoretical saturation across a wide range of space sector employees. Recommendations mainly served as a useful secondary tool and a sometimes very useful way to bypass gatekeepers in other organizations. By the conclusion of the research a varied group of space industry employees had been interviewed who cut across the public and private sectors, a range of different space applications, a reasonable balance between sexes (although with a statistical bias towards male interviewees) and a range of age groups from early-20s to retired.

3.3. Grounded Theory

The data from the research has been analyzed via a fundamentally inductive approach; the 'concepts are derived from the data' (Elo & Kyngas, 2008:109) and prejudgements about views on contemporary future narratives in high-risk industries were avoided. Prior reading on futures and narratives highlighted detailed *questions* about the roles of future-orientated narratives within the space industry (see Chapter 2), but were not used to pre-judge answers from the data. This approach is Grounded Theory, which involves generating theory from collected data, not slotting the data into prior theoretical models (Bryman, 2008:541). Many social research epistemologies argue that research should begin with theory (Charmaz, 2000), rather than produce theory as the eventual output of data in the way grounded theory proposes. Glaser and Strauss (1967) argue that the initial development of grounded theory was important as a response to the emphasis on grand theories in social research into which all data was expected to fit, and a concurrent need to make qualitative research more systematic as a response to challenges from quantitative social research. Using grounded theory the causal chain of research begins with data and moves gradually towards theory, whereas a positivist or deductive approach would begin with theory and gather data which either proves or falsifies initial standpoints (Hodkinson, 2008:82,96). With grounded theory the formation of theory is an inductive process which takes place during and after the collection of data, as was the case with the typology presented in this thesis. Such data must be interpreted by the researcher, in this case resulting in the formulation of ‘finite’, ‘normalized’ and ‘adaptive’ futures. This is therefore a challenge to ‘grand’ theories or high-level abstraction, such as the sort favoured by space industry analyses to date which focus on nation-states (e.g. Siddiqi, 2010), militaries (e.g. Lachow, 1995), or international agreements (e.g. Lee, 2000). Within grounded theory these are irrelevant propositions unless the data explicitly supports such constructs (Ibid:84). The questions of this thesis – what roles do narratives play in the development of high-risk technologies, and how are they utilized within this development process – did not presuppose what forms of theory would emerge to answer those questions.

Inductive reasoning and grounded theory both ensure that theoretical positions cannot be developed until ‘practices have been researched and the relevant local categories and differences have been encountered’ (Gad & Jensen, 2010:76). Actors should be ‘given voice in their own categories’ and allowed to classify and explain themselves (Ibid). In this way grounded theories draw directly from the actors – even if the actors disagree – with such information in turn informing subsequent directions of research, and all of their ‘voices’ should be represented, however disparate (Denzin, 1998:173). This is why the categorization of interviewees as displayed in the *Table 1* was informed entirely by how interviewees described their roles within the space sector, not those the researcher might assign to them. This also carries implications for the sorts of questions asked by interviewers – a deductive approach would follow structured interviewing where the questions and topics are known in advance, while grounded theory necessitates open or semi-structured interviews (Ibid:84), as used in this research project.

3.4. Data Analysis via Grounded Theory

Data analysis began concurrently with the initial interviews. The process of data analysis followed the guidelines suggested by Charmaz (2006), who emphasizes the importance of carrying out data collection simultaneously alongside analysis of that same data; deriving analytic codes (categories and concepts which aid in organizing data) from this process rather than preconceived ideas; and that new transcriptions are consistently compared back to older transcripts to re-examine any previously-identified codes. This means theory was developed gradually and consistently throughout data collection, as in a grounded theory model.

The questions posed by prior futures work in Chapter 2 formed the basis of my initial questioning. After approximately half a dozen interviews, it became apparent that (as discussed in the previous chapter) documentary evidence within the space industry would have been scarce and difficult to acquire had I pursued such a research design. As time progressed it also became clear that very little of the data I was gathering could be understood within the Space Race model I'd already examined (in Chapter 1). Upon concluding the initial dozen interviews at the UK Space Industry, several new major themes involving the importance of different forms of futures began to emerge and recur. The questions asked in the semi-structured interviews were also adapted as time went by, causing subsequent interviews to be slightly different from those that had come before. My questions were adapted over time as themes emerged in the early interviews, and the questions asked in later interviews – although similar – sought to pursue theoretical saturation on the themes that had emerged earlier.

I transcribed all twenty-six interviews, totalling a little over 100,000 words. I elected not to use a third-party transcription service in the hope that themes would emerge during the transcription process, and that the process of writing would aid me in identifying the connections between the comments of different interviewees. Although this process was difficult and time-consuming, it was indeed rewarding – many times throughout transcription I was able to identify potential codes, or note a theme that had come up many times previously, or notice that interviewees were talking about the same themes from varying perspectives. There were a number of points where in the process of transcription I picked up on a small comment or observation which might have been missed had I merely read them through after a third party transcription. These initial observations formed the foundation of subsequent coding.

At the start of the research I intended to carry out coding activity using a software package, likely NVivo. However, I eventually elected not to make use of any electronic software for coding. My initial coding was done by hand in the transcription files in question, with the intention of shifting towards using software once more of the transcriptions were complete. However, this initial process immediately yielded concepts that were highly interesting and following these up by hand subsequently delayed my intended adoption of the software. The further I went with this coding by hand, the less I felt a piece of software would enhance the process. After a point I became concerned that using NVivo or another software package would risk breaking the flow of iterative interviewing and transcription that I was building up by hand, and might miss some of the nuances I was finding by having to read the transcriptions in more depth to identify themes, instead of simply searching for keywords. Instead of a software package I therefore closely examined the transcripts I had typed up and began an iterative process of cross-referencing between them. This cross-referencing was originally based on the broad themes identified during the transcription process. I attempted to collate as many interviewees as possible who had made similar comments to those identified in a given transcription, or who made disparate comments about the same themes. In this process I also identified new themes that had not been observed in my first reading, and several detailed themes not identified in prior futures work (which the analysis chapters will explore). In each subsequent reading I continued to carry out this two part process – further reinforcing identified themes, and attempting to discover new ones. That was a recursive process where both the codes I listed and the new literature I examined in response to these codes fed into one another, and this back-and-forth proved an excellent way to pursue new avenues for understanding. New codes could be both explored in other transcripts and in prior scholarly work to verify their applicability to the research. Each transcript was read multiple times, approximately five times on average, although the densest transcripts were examined several times more and those from the interviewees who responded with only ‘official line’ answers were studied less.

When creating the codes I was responsible for defining them, deciding what fell ‘within’ the purview of each code and what was distinct, and for deciding where to draw the line between broader and narrower codes. This also meant identifying which parts of the transcriptions had analytical value and which did not. There were a number of cases where part of a transcription was relevant to a number of codes – in this case I maintained that piece of interview in all the different codes, but in the analytical chapters I sought to avoid repeating a quote, and instead used them only in the sections where they were the most appropriate. This choice aided in clarifying and making more explicit the differences in the future narratives proposed in the three analysis chapters, but also demonstrated that some space programmes use a combination of the three narrative types. In some cases there were lesser themes, such as the reasons for conservatism in the space industry identified in Chapter 5, and these were categorized separately. When the same theme was visible in multiple transcripts I pursued it further. In some cases a single interviewee would produce a lot of information on a topic, and in some cases a topic would be discussed to a lesser extent but by a large number of interviewees. Often it was issues relating to the role of scientific research in the space industry that were focused on a small number of transcripts, and observations about wider changes in the industry that were repeated across many interviewees. The codes identified also shifted as time went by from being primarily descriptive to more analytical in nature, resulting in the three-part typology this thesis presents.

A period of approximately six months was spent examining the transcripts, developing codes, reading appropriate bodies of literature and beginning to write down and analyze my own thoughts. This resulted in a detailed and rigorous examination of the data in terms of both prior work on the space industry, futures and narratives, and also new bodies of work that the themes pointed towards. After an early iteration several dozen codes were identified, but by the final iteration most codes could be understood as belonging to one of three categories – ‘Planning’, ‘Mundanity’, and ‘Credibility’. These three areas were very prominent across both a breadth of transcripts, and in significant depth in some particular transcripts. Chapter 4 is based on this first theme, Chapter 5 on the second, and Chapter 6 on the third. ‘Mundanity’ contained the largest number of smaller codes, whilst the other two consisted of a smaller number of sub-codes.

The three core concepts of *finite, normalized* and *adaptive* future narratives were thereby generated during the research as the most comprehensive and complete way to analyze the future narratives that predominate within the contemporary space industry. They also have significant potential applicability across other high-technology domains. The initial development of this three-part typology *throughout* the interviewing process allowed for its verification against existing and future data, whilst also pointing towards potentially useful subsequent lines of enquiry in later interviews. Existing theories or ideas were either elaborated or challenged by incoming data, and in this way all theory was grounded and also frequently and meticulously examined in the light of prior work (Denzin, 1998:159). Theoretical preconceptions about the forms of future narrative that would be uncovered were avoided altogether by generating them from fresh data (Hodkinson, 2008:83). This thesis was begun with no preformed notions about future narratives in high-risk technological industries, nor the ways in which these narratives were used. As the data progressed, the central three tenets of the analysis – of the importance of planning and promises, the interplay between conservatism and innovation, and the importance of *credibility* – emerged, each with a particular form of future narrative associated with it. These were found to be related to not just the areas of futures work identified in Chapter 2, but also a number of other additional unanticipated fields. These additionally relevant fields included the quantification and qualification of scientific data and the concepts of spin-off and scientific 'inspiration' (Chapter 4), the importance of internal working cultures and the unique nuances of the space environment (Chapter 5), and the roles of testing and standardization (Chapter 6).

3.5. Ethical Considerations

There were also a number of ethical considerations appropriate to the study due to its use of human participants rather than documentary evidence. When considering core ethical obligations to research participants, Diener and Crandall (1978) state that avoiding harm, ensuring informed consent, ensuring against invasions of privacy and preventing deception are the four most important cornerstones of ethical research.

Informed consent involves giving participants as much information as possible about the study before asking if they consent or not to be part of it (Kvale, 1996:112). Informed consent forms for the research stressed the voluntary nature of the study, the ability to refuse or withdraw at a given subsequent time from the study (BSA, 2004), that they will be recorded and transcribed, and the actual recording would be destroyed after transcription (Bryman, 2008:123; Kvale, 1996:114-5). Consent forms should also explain the research in terms which are 'meaningful to the *participant*' (BSA, 2004, my emphasis), not to the researcher, which I endeavoured to achieve. Some participants are likely to be unaware of academic conventions which may need imparting.

Anonymity, another core of ethical research practice, should ensure participants cannot be identified (Bryman, 2008:11). However, Bryman follows on by suggesting a researcher cannot *guarantee* anonymity, and therefore should not claim they can, but rather promise to do everything realistically possible to ensure anonymity (Ibid:124), which was verbally expressed to interviewees. Similarly, the BSA Ethical Framework stresses not to give 'unrealistic guarantees' of confidentiality to interviewees (2004). There is also a practical reason for trying to ensure anonymity and confidentiality, even if interviewees may be talking to each other: if the researcher does not ensure privacy, who will be willing to be interviewed in the future if such a researcher reputation becomes known (Eysenbach & Till, 2001)? Kvale (1996:116) also states the importance of informing participants about the consequences and outcomes of the study and where and how their data will be used. The BSA Ethical Framework agrees (2004) and says that researchers have responsibility for 'the use to which their data may be put' and what effect this could have on participants. As all fieldwork intrudes on established relationships (Stacey 1991), interviewees may insist on privacy at times or on certain issues (Garforth, 2011), and this must be respected. Although the number was small, there were several topics that particular interviewees were unwilling to talk about, even 'off the record'. Whilst interviewees were more willing to discuss certain topics than to provide documentary evidence about those same topics, certain programmes or information about stakeholders in particular programmes remained off-limits at all times, primarily those with any military involvement.

3.6. Summary

The research was carried out via 26 semi-structured interviews with a range of individuals within the space sector. Interviewing was chosen primarily in order to ascertain first-hand appraisals of the creation of future narratives in the space sector and the roles they play, rather than waiting for the 'official line' in subsequent documentary evidence produced about the same events. Whilst this was the primary reason for the selection of this methodology, the appropriateness of this choice was further strengthened by: a commitment to grounded theory and building up a typology based on data direct from *individuals* within the sector, not prior assumptions or official reports; the ability to examine actors within the space industry at different ranks and stations, and different stages in their careers; and lastly due to the paucity of documentary evidence available for an alternative textual analysis. The sampling of interviewees was carried out primarily via maximum variety sampling in order to pursue as representative a cross-section of the space industry as possible. In some cases snowball sampling via organization also took place – I was sometimes recommended an organisation or private company whose members would merit study. In most cases, however, contact would be made with individuals or organizations that I had not been recommended, but had identified myself as representing a segment of the space industry that I had not yet examined. My selections of which potential interviewees to pursue, and which risked being too similar to prior interviews, resulted in a distribution of interviewees across all the key demographics of the space industry (as defined by my interviewees) – public and private sectors, scientists, technologists, and those who worked in communications, industry ‘growth’, and Earth Observation. The last two of these were scarce, and few potential interviewees were identified in these areas, especially ‘growth’ where only a single employee appeared to be defined, or self-defined, as such. All interviews were informed by a strong ethical code of conduct that stressed anonymity and informed consent (to the greatest extent possible within a research design). The subsequent analysis of the next three chapters was carried out via inductive reasoning from the data gathered, and the three forms of future narratives conceptualized and explored in these chapters – finite, normalized and adaptive futures – were generated from the data gathered, and serve to illustrate the unusual forms of future narratives created and deployed by high-risk industries.

Chapter Four: Finite Future Narratives:
Planning and Promises over Long Timescales

4.1. Introduction

This chapter is the first of three analysis chapters in this thesis, and develops the concept of the ‘finite future narrative’. The finite future narrative is the first of three forms of future narrative – termed *finite, normalized* and *adaptive* – developed from the interview data to fill the theoretical gap identified in the first two chapters of this thesis: the role of future narratives in high-risk technologies, and how these are constructed and utilized. A finite future narrative consists of two parts. The first is the creation of a number of intermittent stages throughout the future narrative which allow actors to either yield interim benefits or track that the programme is proceeding accordingly (or both). This ‘roadmap’ is a construct which is designed to keep actors within the programme once they have joined, reduce the rate at which they may leave a high-risk development programme, and potentially entice actors who are not interested in the eventual goal but may be interested by a midpoint objective. The second part of a finite future narrative is the identification of a temporally specific conclusion for the programme, and an objective (or set of objectives) to go with it. This end-point is designed to bring to a close the substantive part of the programme – it should be completed by this date and the resultant technology functional – and also to conclude the temporal part of the programme by delineating a clear date beyond which the programme will not continue, no further resource inputs are required, and most importantly, the *reward* for contributing to the programme will be available. The objectives were also found invariably to be connected to a range of concepts beyond the ‘core’ goals of the specific programme, such as inspirational value, national pride and spin-off potential, which will also be assessed. The roadmaps and the eventual promised outcome(s) form the two-part structure of a ‘finite future narrative’ which this chapter explores; these narratives were found to be focused primarily on mitigating the lengthy *timescales* of space programmes with only minimal reference to the *risks* of such programmes. The subsequent analysis draws on prior work identified in Chapter 2’s literature review of futures including that by Smith *et al* (2005), Michael (2000), and Jørgensen *et al* (2009), as well as a range of other literatures whose relevance emerged during data analysis.

Having defined the finite future narrative and its constitutive elements, this chapter now proceeds to examine the research data gathered which supports this new definition. The roadmapping and planning section of this chapter begins by exploring the process of roadmapping and prediction within the space sector, summarizing the literature around technology roadmapping before then considering what precisely this process entails and what role it plays for a high-risk technology. The second part of the chapter then explores the predicted benefits and outcomes of space missions, the value of making these promises, and what they contribute to the construction of a finite future narrative. This is broken down into scientific benefits, concepts of ‘inspiration’ and national pride, and promises of ‘spin-off’ technology – the claim that technologies used in space missions, scientific or otherwise, will inevitably trickle-down towards commercial products and other non-space uses. The chapter then concludes by summarizing these functions of roadmaps and promised outcomes within finite future narratives, and how this concept helps develop our understanding of the lengthy timescales of high-risk technologies.

4.2. Roadmapping and Planning

4.2.1. Space Industry Roadmapping

Throughout the research it became clear that 'roadmaps' were crucial to the success of high-risk industries such as the space industry, and in the subsequent analysis became classified as one of the two core parts of a finite future narrative. Roadmaps are documents or plans used to identify areas of 'high potential promise' (Kostoff & Schaller, 2001:132), generate long-term plans for a particular technology or area of industry by 'extending planning horizons' (Phaal *et al,* 2004:6), and then to map out the steps required to bring those plans to fruition (Galvin, 1998). From this prior work it is immediately apparent that roadmaps are closely connected to long timescales of technological development, by specifying the temporal distance over which the programme needs to be planned, and then mapping out the steps towards the programme's completion. This kind of planning seeks to overcome the uncertainties of distant futures (Michael, 2000). As Williams (2006) argues, if the future is accepted as being in any way uncertain or nondeterministic, this generates uncertainty in any programmes which project themselves far into that future, and the further the future is (Adam, 1995) the less certain it appears. Many interviewees argued for the value of roadmaps to the space industry when planning distant programme objectives:

> *'Any sector that's worth its salt needs a roadmap.'*
> (010, [Public, Technology])

> *'Every time we were asked to fund – every time there is a big funding demand – I always ask to see the roadmap. For me it's essential.'*
> (012, [Public, Private, Technology, Comms])

> *'[Roadmaps are important because the space industry] is long-term and high-risk, but also because you need to bring a number of developments together, it's not just one person building an instrument.'*
> (019, [Public, Science])

Despite these statements of the integral importance of the roadmap, this praise was not universal. Whilst many acknowledged the importance of the roadmap and agreed that they were required for space programmes, there was a strong vein of cynicism and doubt about their accuracy and efficacy. Although interviewees generally argued that a roadmap was a way to document the process by which the programme can be achieved and that this documentation has a range of potential uses (explored in the following sections), there was equally an appreciation of the uncertainty inherent within future predictions:

> *'The only thing you ever know about any roadmap is that invariably it's wrong.'*
> (025, [Private, Technology])

> *'I am constantly aware that exercises to try and completely scope and predict what you need to do in the future always fail.'*
> (015, [Private, Technology])

> *'I don't know of an accurate [roadmap]. I cannot think of a roadmap in my career that has got it anything like what actually happened.'*
> (015, [Private, Technology])

To explore these apparently conflicting themes – that roadmaps are vital and essential, but may be acknowledged by all actors as being uncertain, fluid or simply incorrect – we turn to the work of Kostoff and Schaller

(2001:132). Their work on roadmaps argues that there are four ways in which roadmaps are designed to navigate the lengthy timescales of some technological developments – they argue that a roadmap ‘provides essential understanding, proximity, direction, and some degree of certainty’. Note that ‘accuracy’ – just as the above interviewees noted that roadmaps rarely turned out to be accurate – is not present within this list. According to Kostoff and Schaller’s work a roadmap is designed to achieve clarity and mutual consensus across a range of actors, to make the programme (or intermittent steps within the programme) appear proximate and less distant, to give a clear direction and focus to the programme, and to give a degree of certainty which can generate consensus and agreement, even if that same certainty (as the research data showed) may not necessarily be borne out as the programme continues. Accuracy, although beneficial and desirable, is not essential. This section will now cover the interview data that pointed towards the appropriateness of Kostoff and Schaller’s description for roadmaps in the space industry context, and will conclude by showing how roadmaps are designed around these four factors in order to negotiate long timescales, and in turn contribute to a finite future narrative for a high-risk programme.

4.2.2. Roadmaps as ‘Understanding’: Frameworks for Achieving Consensus

Interviewee data showed that roadmaps are designed to make the objective of the dominant frame in a high-risk technology appear as clear, transparent, and unambiguous as possible. This, in turn, was a method for achieving a level of consensus between actors within the programme, ideally ensuring that this clear single image of the technology is shared between all actors and that there is neither any confusion over this objective, nor confusion over what is required from each actor in order to make it a reality. One interviewee described the challenge of getting all relevant actors to agree on a vision for a programme, and the importance of a roadmap in achieving this successfully:

> *'A credible roadmap shows there is a lot of thinking behind it, and I think if a company is really investing in something and it's of importance to them, they should roadmap it pretty well, but it's a very difficult exercise. You have 20 or 30 players in the same room [or] different types of technologies, [so] it is a very difficult task.'*
> (012, [Public, Private, Technology, Comms])

This comment shows that a roadmap is designed to reach a middle-ground of consensus between all the actors involved. A wide range of heterogeneous actors may make the creation of a roadmap a 'difficult task', but a successful roadmap should be one that takes account of all those involved. As Brown (2003) argues, developing this kind of consensus roadmap aims to prevent the departure of actors by tethering those actors to the fate of the programme so that all will share in its success or its failure. It stabilizes technical activity (Smith *et al*, 2005) by creating a roadmap in which *all* relevant actors have a part to play, defining their roles and stressing the importance of each and every role to the programme's success. In addition to the number of actors, interviewees also commented on the significance of recruiting a *variety* of actors when creating roadmaps. One echoed the importance of working across disciplinary and industrial boundaries as the above quote implied, and ensuring that a roadmap is something where all relevant actors can 'concentrat[e] effort':

> *'[A roadmap] isn't something we sit in a cubicle and invent. We work very closely with industry and academia in agreeing those roadmaps, so we have areas where we know we are likely to require a level of concentration of effort.'*
> (006, [Public, EO, Technology])

Similarly, another stressed the importance of settling upon agreed objectives at the start of the programme's development and subsequently codifying this appropriately into a roadmap, otherwise it will be a challenge to achieve meaningful consensus later in the programme's development between so many different actors. The Ministry of Justice and the Home Office are mentioned in this quote due to the example the interviewee used being one focused on the concept of using satellite technology to track offenders who have been electronically tagged:

> *'You then look at the procurement contracts coming around defining what the Ministry of Justice and the Home Office need, what their requirements are, and if you don't influence those requirements at the right time, it'll be a right job to get them to change what that requirement is to fit the technology you've designed something to solve their problem. Similarly, convincing them to write the specifications for their future programme about something you haven't even done yet is equally challenging.'*
> (011, [Public, Technology])

Both of these quotes emphasize the importance of constructing consensus – or as Kostoff and Schaller (2001) might put it, generating a shared understanding – for the programme. This consensus must be achieved given both the significant number and significant variation of involved actors. The first quote of the above two shows the roadmap designers' attempts to create a strong and resilient programme by connecting it to a wide number of actors (Deuten & Rip, 2000). The wider the range of actors involved the more robust the programme's scenario of future development will be, and the more resources and interests can be rallied to its support (Borup *et al*, 2006:290). The second quote emphasizes the importance of creating roadmaps at the start of a programme (as part of creating a finite future narrative) in order to line up the objectives of the developers and customers of the technology – the later this process is left, the more challenging consensus becomes after resources and effort become committed in other directions. This returns us to Elzinga's (2004) observation previously noted in Chapter 2, that futures – in this case, roadmaps – can be used to build *consensus* within a programme involving disparate actors. A roadmap is used to create consensus over the shared vision of the future (Brown, 2003), gather as wide a range of actors into the programme as possible, and tie those actors into the success of the programme.

4.2.3. Roadmaps as 'Proximity': Codifying Steps towards Completion

Achieving roadmap consensus across those involved in a roadmap and agreeing upon the roles they will play was identified above as the first stage in the creation of a successful roadmap. This was in turn found to lead to the creation and explicit highlighting of intermittent goals and milestones on that path. High-risk roadmaps are designed to outline and codify the steps required to reach the programme's eventual goal. Kostoff and Schaller (2001:133) argue that technology roadmaps can be seen as consisting of 'nodes and links' which take the form of a step-by-step process which the programme is expected to meet, and this is a concept supported by two interviewees. The first interviewee described the path of nodes and links as a series of 'credible milestones' which all the actors should agree on as part of the consensus described above, whilst the second echoed this sentiment and the importance of milestones to those investing in a space programme:

> *'The roadmap there, the whole idea behind it is exactly to give it the kind of credibility, to put credible milestones into the trajectory to get us to the target we already had.'*
> (008, [Public, 'Growth'])

> *'Confidence for investors: at each milestone that's key, as it builds confidence in the overall programme.'*
> (016, [Private, Technology])

As a part of a finite future narrative, roadmaps lend certainty to a potentially uncertain aspect of the programme – how will we get from our present position to the programme's objective? A roadmap quantifies and codifies the interim steps of the temporally lengthy programme. These steps have not yet taken place, but can be 'reliably' predicted. The objective here is the creation of a 'taken-for-granted' framework (Wynne, 1983:15) which acts as a shared vision of the steps of a programme's development. Much as the roadmap emphasizes consensus over the roles of those involved, it also emphasizes the trajectory (cf. Balmer, 1993:473) that needs to be followed for a successful development. Many of these steps will be within only weeks or months of the programme's development, allowing for initial positive feedback that the programme is on track, and by placing intermittent goals, the distant eventual goal of the entire programme appears more feasible and less distant (cf. Michael, 2000:32). Equally, as the second interviewee argued, each new milestone brings with it confidence that the programme is proceeding as expected, a confidence generated by the programme's continued adherence to the step-by-step process laid out in the initial roadmap. These interim steps could take many forms – conclusion of a particular test, the acquisition of new funding, or most importantly a 'meeting' with another technology at an explicit point in the future, which the next section explores.

4.2.4. Roadmaps as 'Direction': Meeting up with Future Technologies

While many of these points will be metrics of money committed, components finished or support acquired, other milestones may be the acquisition and use of other technologies which are expected to reach a particular state at some point down the line. The research showed that high-risk technological developments are sufficiently long-term that it becomes vital to consider what other technologies may appear *during* the programme's development. These are technologies 'outside' the high-risk development programme, but which – if their developments are completed on-time – will be of use in the high-risk programme at some point in the future. Several interviewees elaborated upon this point:

> *'You've got to do things in the right order and with the right degree of confidence, and you've got to make sure the brick in the wall below the one you're building is firm.'*
> (019, [Public, Science])

> *'Roadmapping when you've got a specific goal is an exercise to make sure you've got all your technology ducks lined up to meet that specific goal.'*
> (015, [Private, Technology])

Predicting the *order* of future technologies and what other technologies will be available in the future to be added to the programme is highly challenging due to the difficulty of generating accurate predictions over large temporal distances (Nordlund, 2012). If there is a particular technology which will be required at a late stage of the programme's development, those running the programme are faced with a difficult decision. If they do not plan to use predicted future technology, their programme may lose out to a competing programme that does organize itself to use future technologies not yet developed; alternatively if they *do* plan to 'meet up' with the future technology, they must acknowledge the possibility of that technology's failure and the subsequent problems their own programme would run into. A space programme might begin in the knowledge that one particular component cannot yet be flown, but on the assumption that the other company or industry working on it will have it finished within X years, the programme goes forward to ‘meet’ that development at the predicted time. Not only must the high-risk programme be planned, but other technologies or processes that may lead into it at later stages must also be accounted for, and in turn, the roadmap *directed* towards those which may be of use. Seeking to understand the likely creation of other future technologies is therefore essential for the roadmapping stage of a high-risk programme. If the future can be accurately stated, products and technologies can be developed now to gain an advantage in that future (Brown, 2003), and the roadmap’s direction can be set to take full advantage of these predicted future technologies.

Crucially, by having a roadmap that handles the uncertainty of future technologies or processes required for the programme by predicting them in the roadmap, a significant source of uncertainty in a high-risk programme is ‘removed’. The roadmap, consisting of a series of interim steps upon which consensus has been reached, serves to reassure actors that many potential stumbling-blocks within a programme have been planned for, assessed, and found to be negotiable when the time comes. This positions the context of ‘the future’ as being exogenous (de Laat, 2000:179) to a given programme, simultaneously acknowledging that the future cannot be controlled, but arguing that it can nevertheless be anticipated. A particular component or process may not exist yet, *but it will*, and it can be planned and moved towards. A major negative impact of the significant temporal dimension is mitigated, though not fully negated, by the use of a roadmap in this way. The roadmap is made to look focused and directed rather than at the whim of an unknown future, and the actors are tied into a consensus about the nature and accuracy of this predicted future trajectory. In this way roadmaps handle the long timescales of high-risk developments by attempting to assess the future changes of other technologies, decide whether any of those will be of use in the future, and then reduce the perception of long-term future uncertainty by including these predictions within the roadmap as milestones that give direction to the programme’s development.

4.2.5. Roadmaps as ‘Certainty’: Accurate Prediction and Backup Options

Last of Kostoff and Schaller’s four observations about the value of roadmapping is the generation of ‘certainty’ (2001:132). As we have seen above, roadmaps serve three other purposes. They are used to build consensus across a range of actors which helps to maintain the programme over many years; to codify a number of intermittent steps so that there is a clear and distinct sense of progress, and offer interim milestones that may be important to different actors; and consider the future, assess the technologies that may arise in that future irrespective of the programme’s development, and attempt to account for some of the programme’s future uncertainty by predicting and promising ‘meetings’ with these other technologies further down the line. The third of these points brings us onto the fourth identified value of the roadmap – using these predicted meetings to emphasize a level of *certainty* in the roadmap's future by stressing the technologies that will be in place in the future for the high-risk programme to use, a concept which builds upon the ‘direction’ concept explored in the previous section.

As we have seen, a roadmap can attempt to ‘meet up’ with a technology in the future, thereby bringing actors surrounding that other technology into the programme and tethering them, at least in part, to its success or failure. However, what happens if that other technology fails to be ‘ready’ in time for use in the high-risk programme a year or a decade down the line? Several interviewees argued that roadmaps contain a level of flexibility in order to deal with this issue, and this section will show that such flexibility is actually designed to increase the level of *certainty* of a roadmap. Interviewees had the following to say about the kind of flexibility worked into high-risk roadmaps:

> *'Your roadmap is useless unless you're constantly tuning it. You do a twenty-year roadmap because you need to, but you're not going to believe the world is actually going to be like that in twenty years. It's just a guide to make sure you're moving in the right general direction.'*
> (019, [Public, Science])

> *'There are some products which have a longer development cycle, and there you can see the roadmap, and there's others which are perhaps a bit easier to develop and bring to market, there the roadmap exercise needs to be a bit looser.'*
> (012, [Public, Private, Technology, Comms])

> *'We give guidance, but I usually leave a loophole that [future technologies] are not exclusive, so if someone's got a good idea, it'll come in.'*
> (005, [Public, Science])

These quotes demonstrate that a sufficiently flexible roadmap helps negotiate the long timescales of high-risk programmes, allowing a programme to adjust and reorient itself if a given technology fails to materialize, or if something entirely unexpected changes the market or the range of available technologies. For example, one interviewee mentioned the Skylon spaceplane currently in development in the United Kingdom (the case study of Chapter 5) in this context. Much of the Skylon programme has been sold on its promise to launch satellites far faster and significantly cheaper than traditional chemical rockets. From the perspective of customers manufacturing satellites for future deployment, Skylon appears to be one of these technologies that can be 'met' and utilized in the future. However, this interviewee argued that satellite-builders are hedging their bets and developing flexible roadmaps that could incorporate Skylon, *or ignore it*, as appropriate to Skylon's status in the future:

> *'Skylon might be viable [in 5-10 years] – let's assume it is. But do you take the risk and design your spacecraft for Skylon, and then Skylon's delayed, or do you make sure that at the very least you have a backup and it can fly on the Ariane 5*[1]*?'*
> (021, [Public, Science])

They may *prefer* to meet up with Skylon's development further down the line, but if Skylon's development slows, they will nevertheless be able to launch on existing rockets. These roadmaps thus adopt something akin to a lay notion of STS into roadmapping – that the successful technology is the one which changes and adapts to the shifting context (cf. Smith *et al*, 2005). If the potential technology is in place at the correct time, advantage may be gained, but there will ideally remain a 'future proofed' fall-back option that can be pursued if the desired outcome is not met. In the case above, therefore, even if an actor wants to use Skylon they will nevertheless future-proof their programme by making sure the same mission can function with existing chemical rockets in case Skylon fails to come to fruition, lending a degree of resilience to the programme.

Future-proofing is therefore an important aspect of high-risk futures not anticipated in the initial literature review. Whilst currently lacking an explicit definition among scholars (Georgiadou *et al*, 2012), future proofing is best understood as the process of attempting to protect or prepare for unexpected future events. Anderson (2008:561) argues that although the future is not fully predictable, it is far from being 'completely unpredictable'

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[1] Standard European launch vehicle (a chemical rocket).

and current technology and practice can offer ‘powerful hints’ about what may be true in future years or decades, and these hints can be used to future-proof technologies and systems for what may arise in the future. This kind of future-proofing is designed to reduce the risk of technological obsolescence (Woolley, 2003) by constructing technologies or particular infrastructures with a level of flexibility that can readily adjust to new developments. Future-proofing has been identified as being increasingly relevant the longer the timescales that are being assessed (Georgiadou *et al*, 2012), as we see here with space programmes – the longer the programme, the greater the requirement to future-proof the programme in terms of what other technologies may arise in the increasingly uncertain and distant future (cf. Adam, 1995; Nordlund, 2012). It is also useful to note the emphasis in future-proofing on *accepting* future changes, rather than resisting them. Lucquiaud *et al* (2011) explicitly state the importance of future proofing to be ready to *incorporate* future developments, not merely to continue the status quo in light of the future, or to respond to the future. It is this role that roadmaps adopt for the space industry: they attempt to position themselves so that future technological developments may be incorporated, regardless of what eventual forms those developments take.

This ‘flexibility’ therefore actually translates into an unusual form of certainty. The flexibility emphasizes that a future technology of some sort will be ready when it is needed, rather than stating that *a specific technology* will be ready. A high-risk programme that relies on a specific technology being available in the future will look far less certain than one with a range of similar technologies to choose from when the time arises. By utilizing other predicted technologies via future-proofing, a high-risk programme appears certain despite its long timescale, and any uncertainty is instead shifted onto other actors who must strive to complete their own developments on time, or risk being left behind. Therefore, in returning to the work of Brown (2003), we see this as a method to tie these actors into the success of the programme, *whilst not in turn* tethering the programme to the success of these other actors. If the technologies are met, the high-risk programme appears to have accurately predicted the future; if the technologies are not met, the high-risk programme appears to have prudently hedged its bets and kept its options open. Either way the future of the programme appears certain whether or not the 'first choice' technologies and components are ready on time.

In this way roadmaps can bring other technologies and other actors into the programme by *promising them a form of certainty*, as roadmaps are designed to hedge their bets and ensure that there are backups and redundancies if specific technologies are not ready for use at the right time. Roadmaps are able to take some of the inherent uncertainty of a programme that may take years or decades to complete and, in a clever narratological manoeuvre, define this uncertainty by building a level of *expected* flexibility into the roadmap. This reinforces the certainty of the finite future narrative – uncertainty is acknowledged but *contained* within clear, delineated and *finite* boundaries. Rather than treating the uncertainty of the programme's future as an issue, high-risk technology roadmaps instead reposition the uncertainty as an expected and ordinary part of the programme, and one that can actually be predicted and planned for. A good roadmap is therefore designed to use these future promises to both encourage contributions from actors over a long timescale and reduce the perceived uncertainty of that timescale, whilst keeping the high-risk programme secure if these other actors fail to meet their obligations.

4.2.6. Summary of Roadmapping and High-Risk Technology Timescales

Roadmaps are a formalized form of future planning, condensed into detailed documents and plans, which are distributed throughout all those involved in a programme. They possess a clear step-by-step sequence of goals rather than a single end-point objective. They are designed to carry out four activities – to establish multi-actor consensus over the programme’s development, establish the proximity of desirable interim objectives, reduce uncertainty by promising the development of other future technologies which can then be used in the programme, whilst simultaneously seeking to future-proof the high-risk programme itself by ensuring a range of possible solutions to these requirements. As Garcia and Bray (1997) note, roadmaps vary in length from anywhere between a few months to many decades, and the interview and literature analysis above shows that the roadmaps of the space industry are specifically designed for navigating the longest of possible timescales via the above methods.

These roadmaps (both on their own and as an element of the *finite future narrative* this chapter proposes) are concerned with the long timescales of high-risk programmes, not the perceived risk of these programmes. As discussed in Chapter 2, this temporal dimension was a regular theme in the high-risk literature explored at the beginning of this research, but a topic that rarely came to the foreground when compared with the dominant discourse of high-risk as the most important factor in complex and tightly-coupled (Perrow, 1999) technologies. From interviewee comments it became clear that roadmaps were designed with the *timescales* of high-risk programmes as their primary concern and little reference to ‘risk’ was made. This analysis therefore marks the first point in the research at which the temporal dimension appeared to be just as important as the risk dimension, and as research continued the importance of temporality only became more prominent.

Although a roadmap does conclude with the final objective(s) of a programme, the two are analytically separated within this chapter. This is because the concept of the finite future narrative is distinct from a roadmap in one core way – it is equal parts outcome and intermittent promises. Whilst a roadmap must naturally make an eventual promise for the conclusion of the programme, as the second part of this chapter shows there are many aspects of these promises which cannot be seen simply from examining a roadmap, and a roadmap focuses specifically on the process of *reaching* the goal, not necessarily the goal itself. A finite future narrative is the combination of the promises – and any external factors and concepts that accompany them – and the roadmap that leads towards them. Just as Michael (2000) argues that orientating technological futures towards clear and specific *goals* is strongly beneficial to their success, so too is the construction of an explicit *path* to those goals in the form of the roadmap. With the discursive construct of the roadmap described and its temporal orientation examined, we now turn to the range of promises identified in the research as predicted outcomes for space programmes.

4.3. Predicted Benefits and Outcomes

The second part of finite future narratives are the predicted benefits that come with the programme. Although roadmaps do possess a clear conclusion beyond which the roadmap does not extend, their focus is more on maintaining interest and commitment from a range of actors, managing future technologies and developments that may be relevant to the programme, and future-proofing such long-term developments by rationalizing future uncertainty as an expected and managed part of such programmes. A programme’s selection of promised *benefits* (Jørgensen *et al*, 2009) were found to extend significantly beyond the roadmap associated with a technology, and form the second element of finite future narratives. Many of these are connected to concepts or societal developments outside a specific programme, whilst others are designed to recruit the support of actors new to the space industry.

Most of these predicted benefits are specific ways of presenting the dominant frame of a programme: rephrasing or repositioning the programme’s objectives to appeal to a range of interested parties. An objective to study the surface of Mars, for example – an outcome which at first glance may appear to have only abstract scientific benefit – may be presented as a way to demonstrate a nation’s technological supremacy, as a method for testing new scientific equipment, or pushing a certain technology forward which may later have use in other industries. New technologies can thereby be linked by their proponents to desirable social and political outcomes (Laird, 2003) as well as desirable technological ones, even if the *roadmap* may only make explicit mention of the technical.

This section will now outline some of the promises offered by space missions, and seek to understand how these promises are created and used within finite future narratives. It begins by exploring space science missions and how the scientific ‘value’ of these missions is defined. Whilst the focus of the UK’s space policy is explicitly commercial, the UK contributes to a wide number of ESA space science programmes. A number of interviewees worked either primarily or only on science missions, whilst others who were not directly involved also gave valuable input. The discussion then moves onto other benefits promised in the space industry. The first of these is inspiration – the claim that high-risk technologies have an unquantifiable inspirational value – and the chapter explores how this claim can be an important part of a finite future narrative for such technologies. The chapter then moves onto exploring the role of national pride in such programmes, focusing on the extent to which such a concern remains an issue of contemporary relevance for decision-making in high-risk sectors. It then considers the fourth and final identified promise which supports finite future narratives: the concept of ‘spin-off’. This is the claim that some processes and technical knowledge gathered or developed in a high-risk programme may find a use elsewhere, primarily in consumer products or more ‘practical’ applications. The research data showed that spin-off is understood within the space industry through the theoretical lens of ‘basic science’, and that it is subsequently deployed as a method for gaining interest from commercial and private actors. The chapter then summarizes the use of these predictions in finite future narratives, and how they are combined with roadmaps and plans to aid the development of high-risk technologies.

4.3.1. Space Science Programmes

Scientific benefits of space technology have been a central justification for state investment into the sector since the beginning of the 'Space Age' (Swaminathan, 2005). For example, NASA has used a rationale called 'discovery-driven' exploration (Cornelius, 2005:42) in which 'compelling scientific opportunities' are supposed to be the primary drivers behind assigning investment and development. Similarly, ESA carry out science missions to pursue a 'thirst for knowledge' (IBP USA, 2011:18) and international collaboration (ESA, 2014), whilst the UK pursues missions that will 'increase understanding of space science and its practical benefits' (UKSA, 2014). This perspective on the importance of scientific progress in space technology was strongly reiterated by several interviewees:

> *'You should be funding the things […] that expand the intellectual environment as much as possible.'*
> (011, [Public, Technology])

> *'Then you get back into the noble science debate – if we don't do it, it'll never happen – so let's get on and do it. In general [science missions] are done for the benefit of science itself.'*
> (019, [Public, Science])

When I sought to explore the process by which science missions are selected and how those which 'expand the intellectual environment as much as possible' are chosen, one interviewee provided a detailed explanation of how they perceived the process:

> *'[Missions are] very much selected on a science basis. So there are calls for ideas and you find industry and academia working together to submit those proposals, but those proposals in the end are selected for the scientific impact. And they are ranked in that way, so there's a committee of scientific big-bods that are brought together at a European level, and they decide and they rank those missions, and that ranking is then presented to the board that I go to, and we're then told you have to agree with this, or you disagree, but we never disagree.'*
> (006, [Public, EO, Technology])

In this example the interviewee argued that science missions begin by recruiting scientists, who upon deciding on an objective are then able to (in an apparently unproblematic manner) garner political and economic support. In this way the interviewees argued that an eventual objective of new scientific knowledge was the key factor for recruiting those who would be part of such programmes. Scientific objectives are described and *ranked*, and despite the difficulty of producing objective predictions or summaries (Schatzberg, 2004; Adam, 1995; etc), such ranking carries significant weight. As the above quote shows, even if those on the political side of decision-making might not agree with the scientific objectives set or the value of those objectives, they are expected to defer to the scientific judgement. The goal of scientific excellence should, by this logic, be sufficient to garner political support, and be a compelling objective for a finite future narrative. Similarly, another interviewee raised a number of interesting points not just about the process of scientific selection, but how they perceived the superiority of a scientific mission-selection metric above any other:

> *'If you disagree with the scientific recommendation, then each and every one of us will be bringing in their national wants and it would be mayhem around the table. Imagine twenty of us with different priorities. So you have to rest and be guided by what the scientific committee is recommending in terms of the highest science impact, because that's the nature of the programme, then you take that forward. There's a huge scientific review behind it.'*
> (006, [Public, EO, Technology])

This passage makes two very specific points – firstly, that if political factors were allowed to influence a mission ('political' taken here to mean non-scientific) there would be 'mayhem' and an inability to reach consensus. Secondly, it implicitly posits that there can be no disagreement over the scientific value of a mission. This apparently unproblematic assessment brings both a level of security and reassurance to political or economic actors initially involved, whilst also allowing them to deploy these same promises of scientific neutrality and accuracy to recruit future actors in subsequent stages of the programme. According to this model, the agendas for space science missions are determined solely by the scientific consensus, and the scientific community will indeed reach a clear consensus every time it comes together to arbitrate on future missions.

However, other interviews countered these perspectives on space science, and significant debate and uncertainty was identified in the research data in terms of the value of science and the methods of selecting the 'best' possible science. Despite the emphasis on scientific rationality and objectivity (cf. Rip, 2003) displayed in the above four quotes, all future-orientated debates contain implicit goals and conflicts (Laird, 2003) and scientific debates are no different. This was observed by another interviewee, who emphasized that there are internal scientific rivalries with people in the same field:

> *'You have interdisciplinary rivalries. So the solar system people are arguing for their missions rather than the astronomy one or the fundamental physics one. So there is always a healthy process of debate, put it that way. And most often it is healthy…'*
> (019, [Public, Science])

This situation occurs because different scientific missions are 'essential' for different groups, but not necessarily to the scientific community as a whole. Speaking of NASA's priorities, Cornelius (2005) raises this issue, echoing the above quote:

> '[Agencies must make] decisions in subjective and uncertain environments about the relative long-term value of different kinds of scientific discoveries that are seen as equally important to different groups. In this capacity, the agency's leaders will find themselves arbitrating between the desires of various scientific communities that cannot easily generate consensus on objectives or priorities.' (Cornelius, 2005:44)

Those who decide on the objectives of space science programmes will be forced to choose between the equally 'pressing' needs of different scientific communities who may not be able to reach an overall consensus. Two groups may both feel their programmes are of equal importance to their disciplines, but selecting a single mission that is of the greatest importance to 'science' as a whole is the far more challenging task. It therefore appears that the selection of space science programmes may be a more complex task than it first appears, and a significant volume of comments from other interviewees supports such an assertion.

Two forms of scientific promise were identified in the research data which are used to arbitrate between multiple different scientific communities. These are whether the science carried out will be of 'breakthrough' quality, and whether it will produce a large number of publications and citations. The scientific promises made by science missions – and therefore the promises by which science missions are selected – within the space sector break down into these two key categories which will now be analyzed, and each is a powerful driver towards supporting high-risk space technologies as part of a finite future narrative.

4.3.2. Scientific Impacts, Breakthroughs, and Citation Metrics

Interviewees described a two-part system of scientific benefits, whereby the benefits of space science are *quantified* – by tracking the number of scientific papers produced by the development programme – and *qualified* – by the designation of scientific research produced by such programmes as 'breakthroughs', and therefore of benefit to human knowledge (be it 'practical' or 'academic'). It is these two 'pure' scientific benefits of space science we look to first as major promises deployed by the space industry.

Interview data showed that the value of scientific research from such high-risk technologies is quantified by the number of papers published. Although in the case of the space industry one might expect these papers to be limited to physics or astronomy, the outcomes of space science may range in fact across many different domains, and include interdisciplinary thought. Asked about how the benefits of space science are understood, one interviewee said the following:

> *'For scientific missions there's a very specific way you measure the impact.'*
> (002, [Public, Science])

This statement referred to the publication of scientific papers, and the way in which this is used as a distinct promised outcome in high-risk technological development requires unpicking. The use of the word 'measure' stresses that the impact can be quantified, rather than qualified. Most natural sciences value quantitative data over qualitative (Ezzy, 2001) – there is a shared perception that quantitative data is more valuable, more detailed, and more scientific than qualitative, which is seen as being more down to judgement and opinion than objectivity and rationality. As above, this perception of quantitative data – in both planning and predicted outcomes – is essential to recruiting disparate actors into such lengthy programmes. As we have seen in the earlier examination of roadmaps, a compelling argument for objectivity bolsters the apparent realism of the goals, and therefore the potential value of the programme. Following on from this assumption that qualitative assessments are subjective but quantitative assessments remain objective, the idea that the impact can be measured is an attempt to *objectively prove* that space science does have value, and also serves to deflect any criticisms that the impact of space science might be subjective and is only really of use or interest to scientists working on a given programme. In turn, it simultaneously means such programmes can offer clear quantitative goals in their future narratives in terms of predicted publications. Another interviewee expressed it thus:

> *'So with really big missions like XMM*[2] *[…] it produces a new peer-reviewed scientific paper every working day. Someone somewhere around the world is using that data, so literally thousands of scientific papers have come out of it and it has been very impactful, whilst smaller missions might produce fifty or a hundred scientific papers. So that's for science where you measure the impact through the citations in the scientific press.'*
> (019, [Public, Science])

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[2] 'X-Ray Multi-Mirror Mission – Newton', an X-Ray observatory satellite launched in 1999.

The quantification of scientific value through papers and citations is clear from this quote. It also makes an important assumption – that the 'best' science or the most significant breakthroughs will automatically rise to the top. If the only way of measuring scientific impact is through citations, this assumes a perfect system where the number of citations directly correlates to the value of the scientific work. Numerous works (e.g. Peterson, 1988; Aaltojärvi, 2008) have shown this to *not* be the case; citations are heavily dependent on the names of those involved in a piece of work, the countries in which the work is carried out (or in this case where the scientific team is based), the discipline of the work in question, and a number of other agendas and external factors. Nevertheless a citations-based approach gives the impression of objectivity, and as above, attempts to clearly and objectively quantify the value of the programme. The number of publications and citations are key elements of understanding the impact, or perceived impact, of scientific missions in the space sector. In turn, the promise of citations and publications is a strong driver for those promising primarily scientific benefits from high-risk development, as within the space industry the concept of 'science' has become 'enshrined in papers' (Balmer & Sharp, 1993:474) whose eventual quantity is considered an important measurement of programme desirability. By the conclusion of the roadmap for a finite future narrative the predicted approximate volume of publications should have been met, and these promised publications promise significant value for promoting careers, future missions and future lines of scientific enquiry. The promise of publications and citations is thus a core promise for the development of certain high-risk technologies, and a way by which the value of the programme may subsequently be 'measured'.

However, *qualifying* the value of scientific output was also found to be important. A key method for describing key events in science, the 'breakthrough motif' is used to lend a level of importance, credibility and lasting impact to a particular scientific development or discovery (Brown, 2000:88-89). Along with citations, it forms the second method identified in the research that is used to define the impacts of space science. However, to understand breakthrough and examine the interview data that supported this analysis of the *qualification* of scientific data, it must first be positioned in contrast to the 'discovery'. Woolgar (1976:400,414-419) argues that a 'discovery' contains a level of uncertainty about the narrative of what actually took place – who was responsible? How was it 'discovered'? Was it luck, skill, some combination, and were external factors involved? The concept of the breakthrough, by contrast, is implicitly problematized (Brown, 2000). It posits a particular challenge that was known beforehand – a problem that needed a solution – and that one was subsequently found. It presents nature as not something that is unknown and needs to be explored in order to discover how it functions, but rather emphasizes the role of human agency. For a high-risk technological programme, breakthrough is presented in this way: those supporting the programme have identified a problem, and identified how to deal with the problem. The objective and the way to reach that objective are both carefully planned, examined, and *finite*. It lacks the uncertainty of the 'discovery' which may have been accidental or tangential to ongoing research, or the result of a more abstract, unfocused investigation (which, as we have seen, have fallen out of favour with the increasing need to justify the societal and economic value to high-risk technology development). As Brown puts it:

> '[Breakthrough is] probably the most powerfully future oriented metaphor within the current disclosure repertoire of science and science journalism. In other words, it lends itself to the construction of a future in a way that other forms of disclosure representation, particularly the 'discovery' motif, do not.' (Brown, 2000:89)

The breakthrough motif proposes a distinct single point in the future which will herald a significant change or development, rather than the more nebulous promises of a predicted discovery. Breakthroughs also tie easily into grander and broader narratives (Lyotard, 1984) of societal progress and advancement and serve to signify disjuncture – these are not just the normal gradual, iterative development of science nor the uncertain exploration that may lead to a 'discovery', but rather demonstrate either a move forward that was greater than usual, or a move into an entirely new area of scientific enquiry. The appeal of this is clear – actors may seek to become the first to take advantage of a breakthrough, to exploit its financial potential, or be best positioned to carry out subsequent development of the technology in question once it is considered viable. These are all highly compelling promises for actors considering supporting the development of a high-risk technology.

When considering the role of breakthroughs within high-risk industries, one interviewee closely involved with the technologies involved in science missions (though who did not self-define as being involved with 'space science') made a number of comments stressing the importance and place of breakthroughs in space science missions, also specifically using the word 'breakthrough' multiple times:

> *'They are breakthroughs, scientifically, they are breakthrough missions, and very important, we can build new applications.'*
> (006, [Public, EO, Technology])

> *'Because each science satellite has got a very specific mission that's never been done before, you expect a level of breakthrough.'*
> (006, [Public, EO, Technology])

> *'From a science perspective [space science] has given us significant scientific breakthrough, and that's recognized.'*
> (006, [Public, EO, Technology])

Each of these quotes expresses the idea of the breakthrough and its relation to the mission slightly differently. The first quote of the above three stresses the perceived importance of these missions, suggesting these breakthroughs are not just abstract ones, but that they were presumably breakthroughs *directed* towards 'new applications' – a distinct and finite objective. They are missions upon which new applications can be built, once the appropriate breakthrough has been achieved. The second goes further and argues that not just are scientific missions generally pursuing a breakthrough, but that one is actively *expected*. By this rationale, a space science mission that did not produce a breakthrough would be considered a failure. Space programmes of this sort must both promise breakthrough, and then position their outcomes as a breakthrough in order to show the accuracy of the initial prediction. In turn, the third quote emphasizes the recognition of the value of prior space science; this can produce a strong historical narrative for use in justifying future missions. This was a concept another interviewee concurred with when considering the historical precedents for space science:

> *'In terms of trying to persuade people of the longer-term benefits, you really have to review what's happened over the last ten to twenty years.'*
> (001, [Public, Engagement])

The scientific breakthroughs of previous missions can be pointed to in order to show the value of the planned scientific mission – the logic being that because past scientific missions are seen as having achieved so highly, one can safely assume this mission will too. By ordering history (Deuten & Rip, 2000; Law, 2002; Elzinga, 2004) in this way and proposing an understanding of the past (Michael, 2000:22) within which breakthroughs were achieved regularly via the use of space science, these quotes suggest that the *future* outcomes of space science can be predicted (Williams, 2006) to be in line with past outcomes, namely the generation of breakthrough that is 'expected' to come with science missions. The finite narrative states: fund and support the mission, and by its conclusion, you will have a breakthrough (just like all other space science missions in the past).

However, despite these assumptions a breakthrough is obviously not an objective measure, whether defined by the number of publications (how many is enough?) or by some other means (how significant must new knowledge be to be a breakthrough?). Merely claiming that a breakthrough will occur is not sufficient, whether backed up by past examples or not; the claim of the promised breakthrough must be compelling, and convincing, otherwise the endpoint of the finite future narrative falls away.

To understand how *convincing* breakthrough narratives are created, Brown (2000:103) suggests seeing scientists as 'authors of breakthrough'. This argument posits that knowledge gains the moniker of the 'breakthrough' only due to the work of scientists who produce a narrative in which the new knowledge merits the term. This understanding appeared appropriate to the space industry based on comments from two other interviewees:

> *'How does science come to be defined as cutting edge? It's the networks. The TSB, us [the UKSA], people in the research councils.'*
> (008, [Public, 'Growth'])

> *'You have to remember people are devoting their lives to some of this, and they would not do that if they weren't passionate, and we see that in all walks of life, passionate people are right, sometimes*

> *they're wrong, but it's what drives them forward. And that's a good thing. The ones that succeed just play the politics right.'*
> (019, [Public, Science])

The first of these two quotes is the clearest – this interviewee was asked about the nature of cutting edge science, and replied as above. This answer emphasized the people involved – the Technology Strategy Board, the UK Space Agency, and people within research councils. All these organizations are heavily involved in science missions, and this interviewee argued that it is the people within those institutions who go about identifying and *defining* cutting-edge and breakthrough science. The second quote, however, also supports this perspective. This interviewee was discussing the long timescales of space science missions which may take up to a decade or more, and explaining why people are willing to devote so many years to these endeavours. They stated that those who are successful in these long-term missions are those who *play the politics right* – is *all* scientific data that comes back from space science therefore truly fundamentally new, or has this impression been created by those with interests in the mission results being seen as such? It seems clear from the quotes in this section that the latter is the more accurate interpretation, and that assigning such value to space science is a social and political process (Shapin, 1995). This may be carried out by the individuals in relevant organizations, or by the individual scientists who have committed large volumes of time and effort to space science missions.

There is also a further point worth making about the legitimizing work the breakthrough motif does, not just for the specific mission and the value of space science but also for wider discourses of scientific knowledge. In relating the outcomes of space science to the concept of the breakthrough it serves to further stress the concept of science as an activity fundamentally focused around the *solving of problems* (Gibbons, 1994). Whereas the rhetoric of the discovery is something much more idealist –

that something brand new has been 'uncovered' – the idea of the *breakthrough* reads as the struggle of the scientist or technologist to make progress against the hidden nature of the natural world. The term almost implies that the natural world rallies against the scientist, who is forced to work at their peak to 'break through' its defences and uncover the truth within. Shown in this way as an instrumental activity, it also serves to legitimize and justify the scientific process; scientists are not always seeking 'discoveries' that may be 'blue-skies' (Brown, 2000:104) and with little practical applications, but rather they are seeking breakthroughs in specific areas with clear, applicable goals, and to overcome limitations to current scientific understanding. This therefore once more emphasizes the appropriateness of the *finite* term for this kind of future narrative – a breakthrough is a single distinct acquisition of new knowledge, compared to the much more ambiguous and temporally uncertain 'discovery'.

Scientific benefits are strong and compelling promised outcomes for a high-risk finite future narrative. These benefits can be of two sorts – that the science developed will be quantifiable by a significant number of publications produced, or that the science will be of 'breakthrough' quality. In contrast to the more open idea of the 'discovery', each of these puts forward a predicted and finite end-point for the programme. The conclusion of the programme comes when sufficient papers have been published or the promised breakthrough has been reached. They both offer carefully-defined finite conclusions to the programme – it cannot stretch on into perpetuity and the goals are clear from the outset. Although scientific benefit in both of these forms is a core promise for many high-risk technological development programmes, there are many other predicted outcomes which can be coupled with these, or used in place of these, to contribute to the finite future narrative and sell the value of the programme.

4.3.3. Inspiration

Scientific outcomes are not the only promises offered in finite future narratives. Whether in its nature as a breakthrough or its number of citations, scientific excellence is commonly no longer enough by itself to justify the development of high-risk technologies (Whitten, 1996; Kauffman, 1997). As Behn (1995) somewhat sardonically notes when discussing the value of this 'abstract' scientific research:

> 'Experimental physicists need high-speed accelerators to break down stable particles into these predicted elementary particles so that they can be observed (or so that some phenomena predicted by their existence can be observed) and thus verified. In this time of budget deficits, a lot of us, and particularly those of us in the U.S. House of Representatives, did not think that answering this question warranted building the Superconducting Supercollider.' (Behn, 1995:314).

Chapter 1 covered some of the changes in technological funding in recent decades away from the purely scientific promises of 'Big Science' (Kinsella, 1996) and towards goals that enlist and interest a wider range of actors (Autio *et al,* 1996; Wall & Wood, 2005; Vuola & Hameri, 2006) – as this chapter has shown, some of the goals in high-risk industries do still remain entirely 'scientific' in nature, but others also exist. Within the space industry there is a lot of evidence to support this assertion. Outcomes other than scientific excellence are known to be highly valued in many space programmes (Cornelius, 2005; Goehlich *et al*, 2005; Jakhu, 2006), and another major justification for space technology is the idea of *inspiration*. This outcome is seen as having value to the wider public rather than the scientific or technical community. There was a very common perspective amongst those interviewed that space programmes had many other benefits, one of which was the ability to inspire people in a number of different ways. Interviewees stated the following about the inspirational value of space programmes in general, and space science specifically:

> *'You have to trace it back and say we're going to get people interested in science and inspire people, give people something to hope for. […] I've seen a study that said Apollo has more than paid for itself from the benefits to the economy.'*
> (009, [Public])

> *'I think you only have to see the fascination that young people have for space exploration, or going to Mars or whatever, or looking at pictures of the Hubble Space Telescope to see that it has an inspirational benefit.'*
> (002, [Public, Science])

> *'The general population is enthused by exploring the solar system and studying the universe.'*
> (019, [Public, Science])

> *'The only bit of data out there is the surge in doctoral applications in space sciences that tracks […] a generation from the moon landing. There is an effect there and everyone admits it.'*
> (003, [Public, Technology])

From the comments of these four interviewees, it appears the inspirational argument for the development of high-risk technologies takes three interrelated forms. Firstly, that it raises the visibility of such programmes and increases public interest; secondly that this increased public interest has significant educational value; and thirdly that in turn this education translates into a higher number of school pupils and students pursuing the physical sciences as careers (with attendant economic benefits). Let us first examine the issue of visibility. Ocampo *et al* (1998:137) argue that the world's 'attention, interest and imagination' is focused on space-based technologies more than perhaps any other, although other comparable technology programmes like the Large Hadron Collider (the world's most powerful particle collider at time of writing) or Fermilab (another very large particle accelerator) also garner significant public interest and their proponents argue that the high visibility of such programmes leads to greater public engagement with science and technology (CERN, 2014). The programmes that will get people interested in science, so the argument goes, are those which push the barriers of knowledge or technological capability, not directed research which may only have immediate short-term value for human comfort.

This brings us to the second claim – within the space industry many propose that this visibility and public interest in space technology correlates with technical education in members of the public (Cornelius, 2005), and that it also improves general scientific literacy (Crawford, 2001). In turn, the claimed direct benefit of this kind of education is the idea that space technology can encourage people into jobs in science and technology. Ocampo *et al* (1998) argue that knowledge gained from a space programme – such as learning about Jupiter's atmosphere – may not generate income or help towards alleviating economic austerity, but it has a significant educational value, specifically for motivating students towards achievement. This is the transition from the second into the third inspirational claim identified in the above quotes – that not just do *visible* high-risk technologies generate interest in and understanding of science and technology, but that this leads to more students pursuing Science, Technology, Engineering and Mathematics (STEM) subjects. Such pursuits are conceived as being an inherently desirable outcome, for the promise is potentially economic in nature (cf. Sclove, 1995). It posits that by pursuing such high-risk technologies, citizens will be inspired into STEM subjects, and thus towards greater economic productivity (Elzinga & Jamison, 1995). By this rationale, programmes that promise this inspirational benefit are economic investments for the future. For space science specifically, the Apollo landings are often cited as instrumental in inspiring a generation of space scientists and technologists (Jones *et al,* 2007) who have since ‘paid for’ the Apollo landings via their economic contributions, and the first and fourth above quotes make explicit reference to this commonly-held notion.

However, a question remains about the temporal dimension to these promises – at what point are people ‘inspired’? Is it the single event of the breakthrough or the landing on another world, or is it all that leads up to the development of the technology that interests people? I argue it is the conclusion that is seen as providing the public interest, not necessarily the ‘lead-up’ – in this way although it may take many years for effects akin to Apollo rekindling interest in STEM subjects to be felt, the outcome ‘begins’ at the moment that the programme ‘ends’ and achieves its objective. The outcome is not ‘instantaneous’ like a breakthrough (Brown, 2003), but nevertheless has a distinct beginning. The promise of public impact and inspiration is thus not something that is generated immediately, but starts accruing – if the predicted breakthrough or achievement comes to pass – from the moment the programme is concluded (or perhaps a week or two in advance when news outlets begin to run stories about an impending landing on Mars, for example). In this way it can contribute to a finite future narrative: although the inspirational benefits are not necessarily time-limited, the programme remains finite and promises that such benefits will begin when the programme itself ends. Inspiration is thus a potentially valuable promise for a high-risk technology to make during its development (cf. Ocampo *et al*, 1998; Crawford, 2001), and one that appeals to many actors *outside* scientific communities, focusing especially on the pedagogic benefits to education and public awareness and the potential longer-term financial benefits of encouraging STEM education (cf. Sclove, 1995).

4.3.4. National Pride

Connected to the inspirational value of space programmes is the claim that as well as inspiring citizens in certain ways, they also generate pride and interest on an international level. To understand the claimed international benefit of a nation possessing the clear ability to carry out high-risk technological developments, we can look to Bourdieu's (1975:19) understanding of 'symbolic capital'. He identifies scientific and technical work as generating symbolic capital – resources based on prestige and recognition – and argues that scientific authority is 'defined inseparably as technical capacity and social power'. This kind of symbolic capital is what the national pride argument proposes may be gained by supporting high-risk technologies – upon the completion of the programme, a key beneficial outcome of the programme will be an improvement in international standing, increased respect for a nation's domestic science and technology capabilities, and potentially future investment and interest based on this demonstration of capability. Several interviewees argued that increasing national pride via the accumulation of this symbolic capital was a third major promised outcome of finite future narratives within the space industry:

> *'So there is a prestige factor that comes into space activities, specifically the human space activities. […] There is often a national flag element.'*
> (002, [Public, Science])

> *'Some states that probably can't afford space see [owning a satellite] as a statement of national prestige. […] 'There's always a*

> *huge prestige value in having up stream capability*[3]*. It's sexy and people like it.'*
>
> (003, [Public, Technology])

The generation of this kind of pride is intricately tied to the way in which pursuing high-risk technologies is presented to the public. Much like some interviewees quoted in the previous section argued that the specifics of a programme were almost secondary to the promise of inspiration it could bring, one interviewee suggested a similar trend for the generation of prestige – that the specifics of the programme did not matter as long as it was 'grand':

> *'These are grand projects – it doesn't matter what they do. The politicians in Brussels just want a project, a grand project, so they can say 'We're finishing Galil*eo'[4]*.'*
>
> (019, [Public, Science])

A sense of pride in space programmes – or at least the belief that space programmes generate pride – remains even fifty years after the Apollo programme. From these comments it appears that despite the shift towards more pragmatic or instrumental forms of space technology (such as communications satellites), many nations – especially those developing early space capabilities (Peter, 2006:109) – have either adopted the concept of space as symbolic, or that the symbolism of space technology has simply never left. The ability to 'do space' is therefore perceived to be a signifier, much akin to the possession of nuclear weapons, of importance upon the international stage (cf. Launius, 2000). Within the EU context which the UK operates in, this is a federal formulation of national pride –

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[3] This means the ability to launch and develop space technology; 'downstream' space technology refers to the services and uses of space hardware from the ground.

[4] European counterpart to the US-owned GPS system.

some international standing from successful programmes goes to ESA as a whole, but also to individual nations who may have contributed components or capabilities to a broader mission. Indeed, for nations with existing spaceflight experience, space technology is increasingly collaborative (Peter, 2006), and such a sense of internationalism and international achievement is particularly strong in Europe’s space programmes (Horneck *et al*, 2010).

However, there will be fallout from this kind of objective if unsuccessful. Just as a successful programme designed to showcase national technological capabilities may bolster position on the world stage, a failed programme will not have a neutral outcome whereby the promise merely didn’t occur, but rather a negative one – it will show a technical inability to complete space technology, or a flaw or weakness within the economic or bureaucratic structures behind the programme. The promise of international prestige is thus something of a double-edged sword for high-risk technologies, but remains a key promised outcome from high-risk technology identified by the research (cf. Lakoff & York, 1989; Mackenzie, 1990; Mort, 2008). This promise is not directly related to the roadmap or plan that comes with the programme; there will be no steps in the roadmap that explicitly denote the generation of national prestige (if such a thing could even be defined or measured), but the promised prestige will supposedly accrue at the conclusion of the development. This is once more a promise that is distinct from the roadmap that will lead to it, and further shows the importance of proposing the finite future narrative as a way to acknowledge both the separation of the roadmap and the eventual objective in high-risk technologies, but also the importance that *both* aspects play in their development.

4.3.5. Spin-off Benefits

We have thus far looked at three categories of promise identified within the space industry – scientific benefits, inspirational benefits, and the generation of national pride. Each of these is understood as taking place at the end of the roadmap, and we have noted that the roadmap, focusing on technical, institutional and organizational factors, does not necessarily ‘display’ the benefits which are promised upon the end of the programme. It is focused upon the path, not the destination, even though the desire to reach the destination is what necessitates the creation of the roadmap. In this way the roadmap and the promise(s) at its conclusion are two distinct factors, and brought together under the concept of the finite future narrative, showing that both the eventual promise and the gradual steps to reach that promise are equally important for high-risk technologies. There is one further type of promised benefit identified in the research data for space programmes, which is similarly explicitly positioned as only ‘starting’ upon the conclusion of the roadmap and the completion of the programme.

The fourth form of promise is the concept of the ‘spin-off’. This is a common goal proposed within finite future narratives and the programmes they support, although it is never the sole promise. Spin-off refers to a particular technology or process that has an original purpose in a high-risk development programme, but can later be ‘spun off’ into other applications or other markets. Within the space sector this means taking technologies from esoteric space programmes, predominantly space science, into terrestrial consumer markets. One oft-cited example of spin-off is that of the satellite TV business:

> *‘Satellite TV and things like that have all come because space tech has taken steps and gone into commercial, but it’s on the ground you get the real spin-offs of satellite dishes.’*

> (023, [Private, Science])

Whilst another interviewee expounded at length on what they argued was the origin of modern camera technology, in this case from spy satellites in the early days of the Space Race:

> *'Say you're ESA. I'm bidding to put a scientific piece of equipment on your satellite. Part of that bid would include a section on potential exploitation beyond the mission. Obviously you would look to exploit that on future missions, and I would attempt to say there would be spin-out apps for terrestrial use. As an example, the camera technology we have on mobile phones was a space technology. The reason we now have quite cheap CCD cameras, they only came about because of satellite technology, it was the Russians that did this. They wanted to spy on the US, early spy satellites were film-based, and we had the crazy situation of satellites de-orbiting, parachuting to earth with canisters of film in them, and the Russians had to intercept these parachuting satellites with aircraft to collect the film, because if it touched the ground it could be intercepted. This was seen as an unrealistic and crazy situation so they needed a camera that doesn't rely on film… so there's an example of how we massively benefit from original satellite technology.'*
> (025, [Private, Technology])

In the case of spin-off any *science* the mission does is not the aspect which provides this benefit (nor the concomitant inspiration or pride), but rather the *technologies or processes* involved in creating the new mission. In this way a mission to another world might pioneer a new form of high-resolution camera, and that technology could then gain an application in the consumer market or for other technologies that were not originally envisaged in its manufacture. In this way the space industry understands spin-off from a theoretical orientation of 'basic science'. In turn it is only by emphasizing this orientation that spin-off may be considered a valuable promise for space programmes focused on the acquisition of scientific knowledge, not the development of terrestrial or consumer technology.

The concept of ‘basic science’ posits that ‘doing science’ has value even if no specific purpose for it yet exists (Blume, 1974:276), either because scientific knowledge is considered inherently valuable or because there is an unproblematic assumption that scientific knowledge will one day ‘trickle-down’ into longer-term instrumental or practical benefits. Basic science is therefore generally expressed as the assumption that all scientific research will one day have a use, even if that use is not initially or readily apparent. In turn, therefore, new scientific knowledge will be able to create economic benefits for the country that has invested sufficiently heavily in basic science. Despite having been in decline for several decades (Salomon, 1996; Baskaran & Boden, 2004) basic science continues to be relevant within the space industry (Jasentuliyana, 1995; Ocampo et al, 1998; Cornelius, 2005; Davila et al, 2007). Just as the *specifics* of science missions were shown in this chapter to be only semi-relevant when considering their perceived potential inspirational and prestige value, a similar motif that ‘basic science’ automatically generates benefits regardless of the specific research is strongly apparent here in the comments from one particular interviewee:

> *‘It actually doesn’t really matter what you’re doing – as long as you’re pushing the boundaries – to get economic benefits.’*
> (019, [Public, Science])

> *‘The scientific questions are getting harder and harder, and so the technical challenges are harder and harder, and that creates capability which then has, you know, multiple applications in broader areas.’*
> (019, [Public, Science])

> *‘The cutting-edge instrument to get the signal from the furthest reach of the universe […] that’s an advance in technology that will then spill over into other areas.’*
> (019, [Public, Science])

As all these quotes show, the promise of spin-off is tied most closely to scientific missions. Programmes led by space scientists often conduct ‘basic science’ (Jasentuliyana, 1995; Ocampo *et al*, 1998; Cornelius, 2005; Davila *et al*, 2007) and interview data demonstrates that these missions are seen as having spin-off potential. In some cases this is made codified and explicit – for example, ‘first-class science’ in the European Space programme is touted as essential to European interests because it imparts ‘drive’ to developing technology and industry via spin-off (Worms & Haerendel, 2004:73). In this model any new technologies or processes developed in a space programme are seen as a method for producing other products or services (Walsh, 2004) after the mission’s completion. These products are understood as having clear economic benefit, and it is here that the value of space science missions to private actors becomes clear.

Ordinarily space science missions may not appear to have significant economic return (Schwarz, 1979). However, the idea of spin-off is that technologies developed or processes mastered during a science mission may have subsequent unanticipated economic and consumer value beyond the confines of their original mission. Private actors are concerned about the return on investment when committing to the development of any new technology (Petrik & Echols, 2004), and so making the promise of spin-offs is designed to encourage commercial and private finance into high-risk developments. Natural science and technological research is often subsumed into economic imperatives (Elzinga, 2004) – in this case business and industry may not be especially interested by the main objectives of the dominant frames of these programmes, but are interested in turning a profit from the technologies or processes developed along the way (Autio *et al,* 1996; Elhefnawy, 2004). Within the space industry this comes as a result of the 'increasing commercialisation' (Swaminathan, 2005:256) of the space sector as covered in the first chapter. Interviewees who put forward this benefit argue that missions can bring the countries or companies that build them direct economic advantages in addition to whatever the 'core' promise of the programme may be. However, unlike the quantification of anticipated journal articles in science missions, these space programmes do not explicitly state what spin-offs are anticipated. Interviewees argued this was instead a rather more organic process, and spin-off promises were defined in terms of the *potential* for spin-off into certain areas, rather than explicitly codifying any specific anticipated spin-offs:

> *'Missions are a good pathfinder for technology – they force the engineers to do things they haven't done before.'*
> (002, [Public, Science])

> *'Say we want to go to Jupiter. There's a huge amount of technical challenges to be resolved in that. […] Once you've got all that and you've got the technology you've developed, you say 'Actually, I can use that somewhere else', and technology transfers within the sector start coming.'*
> (011, [Public, Technology])

> *'It makes investors feel good that there are clearly spin-off to what we are doing.'*
> (015, [Private, Technology])

> *'People have to aspire to [spin-off]. You have to build a business case, and you can't build a business case on a circular argument*

> *saying 'If you invest in this for space it will give me the money to do something else for space!'. That won't work.'*
>
> (023, [Private, Science])

This is therefore similar to the future-proofing explored in the first half of this chapter in relation to anticipated future technologies. The above quotes show that spin-off is never expressed in terms of specific predictions (cf. Worms & Haerendel, 2004), instead emphasizing a public image of space science as an area ripe with spin-off *potential*. If no spin-off occurs, it was simply a science mission which failed to produce potential spin-off, a situation which is sometimes to be expected; if spin-off does occur, this reinforces the perception of 'basic science' within the space industry, a perception which will be leveraged in future space science programmes. Spin-off is therefore another promise that is not explicitly codified into a space programme's objectives, but one which has potential to bring in a significant amount of private money and interest from commercial actors who identify potential overlap with their own interests and the technologies being developed for a space science mission (Goehlick *et al*, 2005). Those who may know little about the intricacies of the space sector can be recruited into space programmes not by stressing the *space-based* benefits of that programme, but by emphasizing potential terrestrial technological benefits that the programme might yield.

However, one query remains about the value of spin-off. If those supporting a mission are seeking subsequent development of a technology for terrestrial or 'downstream' (Carayannis & Alexander, 2001; Kleeschulte & Büttner, 2008) applications, this raises an obvious question – why would they develop it via a method as expensive and lengthy as space technology? Why support a programme that promises spin-off technologies down the line rather than simply developing the potential new technology itself? Whilst it may seem strange to prototype a technology in such a way, there is a significant benefit to it. The stresses of the space environment –

such as high radiation, extreme ranges of temperatures, pressure and vibration during launch – set a very high bar for a technology (Underwood, 2003; cf. Chapter 6). If the technology or component can survive in the difficult environment of space it should be well-developed and 'mature' enough to survive without difficulty in a far kinder terrestrial environment (Bach *et al*, 2002). This is particularly the case for new technologies whose developers might be worried about its survival under vibration or impact. If a new camera technology can survive the shaking of a rocket launch, the logic goes, it can surely survive being dropped on the floor when it later becomes part of a new mobile phone. This process allows spin-off to yield not just a new process or technology, but its reliability and quality as well; the challenging requirements for the technology in its original high-risk context will lend credibility to its use outside that context. Additionally, private companies may lack the resources to prototype new technologies, but by supporting a space programme that needs to develop that technology, significant support will be committed to the programme from other sources in addition to their own (Peeters, 2002). Spin-off is therefore the fourth of the promises identified in the research data that are used to support finite future narratives. It is designed to encourage private actors into long-term and high-risk programmes by promising potential for rigorously-tested and cutting-edge technology which may, after the conclusion of the space programme, find application as 'mundane' commercial technology on the ground.

4.4. Conclusion

'Finite future narratives' are one of the three forms of future narrative proposed by this thesis. They consist of two elements – roadmaps, and a selection of promises. Both of these were examined within the social constructivist framework of this research, seeking to examine how these roadmaps and promises are constructed by those within high-risk industries and how they are utilized as the constituents of future narratives. The chapter began by exploring the discursive construct of the roadmap, which is designed to trace out the process for a given programme from inception until completion. The chapter showed that roadmaps were considered vital to high-risk technological developments, and yet many of those interviewees acknowledged that roadmaps could be at best uncertain, and at worst entirely inaccurate, whilst still stressing their importance. To explain this apparent contradiction the chapter explored in depth the four ways in which roadmaps are used as identified from the interview data.

The first of these was as a tool for ‘understanding’, whereby roadmaps are used in order to ensure a wide range of actors – private, public, academic, industrial, state, military – share a single image of the programme’s goals. In this way a roadmap also ties all these disparate actors into the programme by distributing appropriate roles and tying them all into its success or failure (Brown, 2003; Smith *et al,* 2005). The second was the use of roadmaps to generate a sense of ‘proximity’ across the lengthy development times of high-risk programmes by stating a series of interim steps (cf. Wynne, 1983) that both give meaning to the years or decades of development, and allow regular ‘feedback’ to actors who may be unused to working across such timescales. The third use of roadmaps was as ‘direction’ – roadmaps also allocate room within a programme for technologies or processes which have not yet been developed, but will be needed further down the line in the programme's development. These other technologies are then worked towards. By outlining future technologies or processes that will be used in the programme’s development, the potential lack of direction or certainty over a long timescale (Adam, 2004; Nordlund, 2012) is rationalized, quantified, and made into an understandable and relatable part of the programme. Rather than leaving the future of the programme open if a technology which doesn’t yet exist will be required, roadmaps make judgements about when such technologies will be available and how they will be used in the program. This was connected to the fourth purpose of roadmaps – creating a sense of 'certainty' within the programme. This was achieved by making some of these future steps of the roadmaps more flexible by proposing a *range* of potential future technologies or processes the programme can meet up with, not just one. This 'future-proofing' (Woolley, 2003; Anderson, 2008; Lucquiaud *et al*, 2011) acknowledges uncertainty on one level, admitting that future contexts are not easily predictable, but then circumscribes the space of possibilities by trying to account for them all. To outside actors, therefore, this aspect of the roadmap makes it appear as if the programme has considered all appropriate future possibilities and made allowances for them. Roadmaps are therefore able to reduce the perceived temporal uncertainty of a high-risk programme, create a consensus for different actors to align themselves with, and present a plan which appears to lack any of the uncertainty expected from such long-term programmes.

The other constituent of the finite future narrative is the range of promises made for the conclusion of the programme. Whereas a roadmap traces an ongoing future between the start- and end-points of a programme, these futures are only positioned at the *completion* of a programme. Four different forms of promise were identified for high-risk technologies. The first of these was the scientific, which broke down into two categories – a measurable number of publications derived from a programme and the claim of anticipated 'breakthrough'. This pairing of scientific benefits fundamentally underpins the continued existence of many space programmes without immediate economic outcomes (by contrast with, for example, communications satellites). These two forms of scientific promise are potentially applicable to other high-risk sectors, especially those focused on the pursuit of 'abstract' science which may struggle to sell their practical value (Behn, 1995; Whitten, 1996; Kauffman, 1997). The emphases on the quality and especially the quantity of science produced are highly effective methods for presenting the value of high-risk science and technology.

The second type of promise proposed in finite future narratives is that of inspiration. The chapter explored the claim that high-risk technologies can inspire citizens, and identified a three-part logic to this argument: that high-risk programmes raise public interest in science and technology, that this increased interest leads to more educated citizens, and that this in turn leads to a higher number of those citizens pursuing careers in the natural sciences or engineering (cf. Elzinga & Jamison, 1995; Jones *et al*, 2007). This promise is designed for different actors – those in policy, government or education. These promises operated within a framework of perceived economic benefit from directing students and employees into science and technology: that such jobs inherently benefit the economy, and therefore encouraging citizens towards them is a desirable policy decision. Interviewees mentioned the belief that the Apollo programme had 'paid for itself' in this way due to the inspirational value of the moon landings, and used this is an exemplar of the inspirational value such programmes could generate. Related to the idea of inspiration was the third benefit, the generation of national pride. National pride is best understood here as symbolic capital (Bourdieu, 1975), and interviewees argued that by supporting high-risk technologies, a key outcome of the programme would be a boost to international standing (Peter, 2006) and potentially increase potential for future collaborative technology developments (Horneck *et al*, 2010). The ability to take part in space programmes or other high-risk programmes is seen as a signifier of both international stature and domestic technological skill, and national pride must thus be understood as the third category of promise offered by such development programmes.

The fourth type of promise was the spin-off. This posits that high-risk technology developments often develop technologies or processes that can later be used in other applications. In this way some programmes are conceptualized by those within the space industry as being within the theoretical framework of 'basic science' (cf. Blume, 1974) where the programme *itself* is not the objective (for some actors), but rather the technologies and capabilities that will be developed under the challenging environment of a space programme (Walsh, 2004). High-risk technology programmes were thus seen as promising ways to pursue potential spin-off technologies before attempting to sell them on the market. In these ways high-risk developments promise the potential for spin-off outcomes that may not be the programme's primary objective, but appeal to a range of private and commercial actors who may seize upon this perceived opportunity (Autio *et al,* 1996; Elhefnawy, 2004).

The analytic concept of the 'finite future narrative' is thus now clear. A finite future narrative consists of these two elements – the promises of desirable outcomes at the conclusion of a lengthy and high-risk programme, and a roadmap that proposed a sequence of steps and interim objectives towards reaching the eventual goals. These combine to create a form of narrative that promises enough to bring actors into a programme, and has sufficient detail to reassure those same actors and keep them committed for years or decades into the future. In this way, as with the other two forms of future narrative explored in the next two chapters, the finite future narrative draws on both our understandings of 'futures' and of narratives. Much like traditional narratives it is a story, a set of steps and statements about the state of a programme and the steps towards its completion. Finite future narratives tell a story of a programme that has been carefully planned, that is able to overcome any stumbling blocks in its path (for these have already been predicted), and that will offer rewards to all actors involved. This narrative is just as specific and codified as any retrospective narrative, but instead presents conclusions about the future of the programme and the most efficient way to reach that outcome.

Essentially, by promising post-roadmap objectives that appeal to a wide range of actors, it imbues what might otherwise be a purely technical and scientific programme with a sense of *meaning* relevant to those on the outside. This is important for high-risk programmes with dominant frames that emphasize objectives which may be considered important only within specific communities (Behn, 1995). From the interview data that emphasized this range of benefits it is clear what type of high-risk programme that the careful roadmaps and broad promises of finite future narratives are designed to support – programmes seen as being focused on scientific research, not technological development. These are close to the cutting-edge 'Big Science' missions of the Space Race era, but distinct due to all the new interests and agendas explored in this chapter. Pure science is no longer sufficiently compelling for many high-risk programmes (Whitten, 1996; Kauffman, 1997) and instead a wider range of actors must be promised valuable outcomes in order to enlist their support into high-risk programmes (Autio *et al,* 1996; Wall & Wood, 2005; Vuola & Hameri, 2006) across the long timescales they require for development (Lakoff & York, 1989; Kinsella, 1996; Galison, 1997; Knorr-Cetina, 1999; etc). This form of narrative and the analysis proposed here have significant potential applicability outside the space industry to other lengthy science-orientated programmes such as supercolliders and particle accelerators (Galison, 1997; Knorr-Cetina, 1999), nuclear fusion research (Kinsella, 1996, 1999), and indeed the ongoing contemporary research at CERN. Finite future narratives support science-orientated high-risk programmes via a focus on overcoming the negative aspects of long-term developments – noted in Chapter 2 as being explicit, though rarely explored, in previous work on high-risk sectors. As such the finite future narrative is proposed as an analytic tool that foregrounds the importance of this temporal dimension, explains the socially constructed future narratives that support a significant number of contemporary high-risk programmes, and demonstrates the ability for high-risk industries to convince outside actors and the general public of the broader value and feasibility of lengthy scientific research.

Chapter Five: Normalized Future Narratives: Conservatism and Risk Reduction

5.1. Introduction

The previous chapter introduced and explored the finite future narrative, one of a three-part typology of 'future narratives' designed to elucidate the development processes of high-risk technologies. It consisted of two parts – a set of objectives to be met by the completion of the development programme, and a detailed plan or 'roadmap' that lists a step-by-step process for reaching those objectives. The finite future narrative serves to make promises that will entice a wide range of potential stakeholders and keep already-committed actors in the programme until its completion. Those promises go beyond the purely scientific benefits for space technology, emphasizing the potential for inspiration and national pride, and the possibility of spin-off. This chapter introduces *normalized future narratives* which are also designed to recruit and retain non-scientific actors into the contemporary space industry, but go about this in the opposite way. Whereas finite future narratives displayed continuity with the public image of the space industry as a sector concerned with the pursuit of *scientific* research (Ocampo *et al*, 1998; Cornelius, 2005; Swaminathan, 2005; Entradas, 2011) – albeit research that can now benefit a wider range of actors – normalized future narratives are specifically designed to challenge and change this image, and move the perception of the space sector towards that of an ordinary, mundane and normalized technological industry.

Finite future narratives are designed primarily to manage and reduce negative connotations of their temporal length of long-term development programmes. By contrast, normalized future narratives were found to be focused on the mitigation of *risk*. To do this, normalized future narratives are positioned as promises that are explicitly *not* seeking to generate breakthrough technology, inspiration, national pride or spin-off technologies. Instead these future narratives try to present space technology as a part of everyday life: as something increasingly ordinary, expected, integrated into social life, and therefore normalized. ‘Mundanity’ was identified as one of the three high-level codes present in the research data, and this chapter is drawn from the data assigned to that code, and the case study of the ‘Skylon’ spaceplane that was integral to bringing that data together. These future narratives present their technologies as either ordinary in their own right, or as instrumental ways to provide ordinary services such as broadband, mobile phone communications, and television signals.

The finite future narrative discussed in the previous chapter is codified into roadmaps and written objectives. The normalized future narrative embodies a different approach, is a more abstract concept, and relates to the overall choices of language, terminology and image through which space programmes present themselves. Within these service-orientated programmes any claims about radical or innovative new technologies are routinely toned down or edited out altogether, an unusual trend when most technological industries hold innovation to be an essential mandate (Feenberg, 1999; van Lente, 2000:56). A normalized future narrative will be shown to emphasize low levels of risk, the age and tried-and-tested nature of components, confidence in service provision, and minor iterative improvements from previous programmes. Normalized programmes are presented as being mundane, predictable, and in line with existing expectations for the technology in question.

To understand these narratives the chapter begins by examining the relationship between risk and reliability within the space sector. This is a theme that a large number of interviewees discussed in detail, and is integral to the analysis of the reasons identified in the research for the greater contemporary emphasis placed on safety and reliability of space technology. The space industry has always been risky, but the specifically *contemporary* and post-Space Race disinclination to engage in riskier programmes and preference for mundane and ordinary (predictable and reliable) programmes was found to stem from three sources. These are the changing customer base of the space industry and the growing importance of service provision; the strong preference for the use of older components, reinforced by long-established employees of the space industry; and a three-part concern focused on the cost of satellite launch, the inability to retrieve satellites, and the required length of survival for modern satellites. The chapter explores each of these in turn, drawing heavily upon interview data to analyze the causes behind this increased concern with risk, reliability, and the subsequent necessity for the creation of normalized future narratives.

Having discussed the three themes identified in the research that encourage risk-reduction in the space sector, the chapter then examines how normalized future narratives are used as a method for overcoming (or acquiescing to) this conservatism, and ensuring the continued success of high-risk programmes in the space industry. It summarizes the impacts of these conservative tendencies and considers the implications of defining technology within existing norms rather than as disjuncture from the past. The chapter does so using the case study of the Skylon spaceplane, showing how interviewees ascribe the programme's success to its ability to define itself and its benefits within existing industry parameters; how the future narrative for the Skylon programme has been normalized, despite its apparent status as a potentially groundbreaking technology; and how this normalization is used to support a high-risk technological development programme. The chapter concludes with a summary of the analysis presented here and the concept of the normalized future narrative.

5.2. Risk and Reliability in the Space Industry

The focus of this thesis is not on the quantification of 'risk', for that is an academic field in its own right, and it is instead concerned with narratives and futures. However, in keeping with grounded theory, interview data showed that the understanding of risk shared by *those within the space sector* should be a core element on which to build our understanding of the industry's conservatism and the need for normalized future narratives. The traditional definition of 'high-risk' technologies stems from Perrow (1999). His work on such technologies – Normal Accidents: Living with High Risk Technologies – includes air and marine traffic, nuclear power, dams, and chemical plants within this definition. Perrow's definition focuses on a particular type of risk: to individuals or the public. This definition therefore includes manned spaceflight, but this is due to the loss of life that may occur rather than any particular analytic focus upon the space industry.

By contrast, the types of risk identified by interviewees that the contemporary space industry is concerned with are not primarily risks to life or public, but technical and financial risk. Risk to the *public* is considered negligible within the UK space industry, lacking as it does a human spaceflight element (British Interplanetary Society, 2014). Interviewees understood risk as something that limited and 'restricted' the potential of the space industry to support riskier programmes:

> *'The problem is that because the cost of access to space is so high it tends to drive everything towards high reliability and conservatism, because it's an attempt to try and minimize the risk.'*
> (016, [Private, Technology])

> *‘The cost and risk definitely. [Although] the biggest operators may have 20 or 30 satellites, small operators may have just one or two, and there’s an awful lot at stake.’*
> (022, [Private, Technology, Comms])

> *‘[The] risk aversion trickles back down to the space platform builders, you are very restricted in your ability to take risk.’*
> (025, [Private, Technology])

Each of these three quotes identifies a slightly different perspective on this very conservative attitude towards risk. The first quote argues that ‘access to space’ is the primary issue (which will be explored later in this chapter) and that the difficulty in actually getting a satellite deployed means that once it is deployed, actors want to feel confident in its efficacy; the second quote argues that the ‘cost and risk’ (cf. Ancarani, 1995:661) of the space programme is the primary issue, which is to say the cost drives the perceived risk up because of the amount of investment at stake; whilst the third quote expresses an understanding of the connectivity between different space sector actors, and argues that a disinclination towards even small risks from those in control of space programmes will then ‘trickle down’ to other actors involved in a programme.

However, the space industry has always been a sector producing high-risk technology (Elhefnawy, 2004; Sadeh, 2005; Handberg, 2011:171). The early Sputnik and Apollo programmes were explicitly positioned as the cutting-edge of technology whose success was not guaranteed, whilst space disasters (Perrow, 1999) only strengthened this impression. As for reliability, many early space programmes were one-offs without much long-term thinking behind them (Ellul, 1964), focused instead upon scoring regular geopolitical victories (Ehrenfreund & Peter, 2009) instead of the creation of service infrastructure. Nevertheless, this did not prevent the overwhelming majority of space programmes being focused around scientific or technical objectives, and accepting high risk and low reliability as the price that had to be paid. What, therefore, has changed? Interviewee comments fell into three broad themes about the changing nature of the contemporary space industry, and why this changing nature has led to a far greater conservatism than was present in the early days of the space industry (and in turn led to the new-found necessity for normalized future narratives). Each of these themes will now be explored.

5.3. Themes in Space Industry Conservatism

5.3.1. A Changing Customer Base and the Importance of Service Provision

The first major theme identified from the research data was the changing customer base of the space industry, and the desire of that customer base for low-risk, high-reliability space technology. The economic and financial liberalization of the past decades (de Montluc, 2009) combined with the growth of global communications (Slotten, 2002; Sadeh, 2005) and the decline of Cold War competition (Salomon, 1996) has resulted in an increasingly privatized space sector. Private expenditure on spaceflight is now significantly greater than that of governments (Vedda, 2002:201), and several interviewees argued that this shift in the customer base was a central cause behind the increased conservatism and risk aversion of the sector as a whole:

> *'The risk aversion comes from the customer. Commercial customers like telecoms operators, they don't buy technology, they buy a service, [or] a product that gives me a service. 'I'm not interested in you flying your latest fancy chipset, your latest computers or your latest exotic solar panels. I'm buying from you a reliable platform and you will sign a warranty saying that if your platform doesn't work for 15 years, I will sue you'. So that stifles the technology, and*

> *unfortunately it's just a function of the brutal commercial world we live in.'*
> (025, [Private, Technology])

> *'[Space has] a customer base that has been quite conservative.'*
> (022, [Private, Technology, Comms])

> *'Basically the customers want exactly the same spacecraft they had the last ten times, and it's very hard to get new tech.'*
> (021, [Public, Science])

These quotes suggest that the contemporary risk aversion stems at least in part from the nature of the current customer base that much of the space industry now serves. Taking a historical perspective and drawing once more on the literature explored in Chapter 1, we can see that the space industry's customers have changed very significantly over the last half a century. Originally they consisted primarily of state actors and bodies associated with them – this led to a significant role for both the military and air force in the US space programme, for example, due to both the overlap in some areas of technical expertise and the fact that space was tied to military and geopolitical goals (Ehrenfreund & Peter, 2009). The other customer was the state, and early spacefaring states tended to recognize that any space technology whatsoever was a very new and very problematic technology, and expectations were low. This meant that any space technology that could be deployed would be a victory, irrespective of the quality of the hardware or the time and cost involved, and the sense of satellites as a *futuristic* technology contributed much to this perspective (Huntley *et al*, 2010). These were therefore customers who were both able to invest large resources in space technology with (relatively) low expectations on the outcomes; who were able to think in long timespans rather than immediate cost/profit considerations; and who recognized that the kinds of space programme they were promoting were novel and highly innovative.

The contemporary change in the space industry's customer base away from the state and towards the private sector highlights space technology as what scholars have termed a 'dual-use' technology (Mackenzie, 1990:24; Jarritt *et al*, 2010). This is traditionally a term used for technologies that have both a civilian and a military application, and is a term used particularly often in research relevant to chemical or biological research (Balmer, 2006:693). Although in the early decades of the space industry militaries and governments were overwhelmingly dominant actors (Lakoff & York, 2006:5; Siddiqi, 2010), since then the sector has opened up to a wide range of customers. Some of those may be actors who desire the type of finite future narrative discussed in the previous chapter or the adaptive future narratives explored in the next chapter, but many instead desire the provision of services that were unknown when space technology's development began but which have since become every-day expectations. Space technology's distinct role as a dual-use technology means that a range of new customers have emerged driven by profit, service provision and the private market, and this changing customer base has been one factor behind many of the conservative changes in this chapter. This difference between the customers of finite and normalized future narratives is comparable to the distinction Balmer and Sharp (1993) draw between a 'scientific' paradigm and its 'technological' equivalent in their study of 1980s biotechnology in Britain. They argue that compared to a scientific paradigm, a technological paradigm involves a range of industry actors, many of whom were closely interconnected, and that the role of market forces was considered especially important, rather than the pursuit of 'pure' unfettered scientific research. New customers from private actors and industry have caused a shift within the space industry towards a technological paradigm, which in this instance means a reorientation towards what the technology offers, rather than what the technology *is*.

One of the causes of the space industry’s increasing conservatism is therefore these new private actors who are concerned with reducing risk and promoting reliability and predictability. Elhefnawy (2004) suggests that private satellites of the sort that provide communications or broadband are seen as routine, and a routine mission is never going to be one that is expected to bring with it a high level of risk, in contrast to ‘breakthrough’ missions that public bodies might fund where a high(er) level of risk is more acceptable. In addition to highlighting the effects and implications of this changing customer base, a number of interviews delved deeper into the nature of this change, and explained that the concepts of the ‘failure rate’ and the attendant sense of ‘reliability’ that went with a low failure rate were integral metrics for this new low-risk perspective. Interviewees emphasized the need for reliable space technology rather than scientific advance given the shift in focus towards service provision:

> *‘There’s a clear cost/reliability relationship – as things become more reliable, the cost has to go up, which is why aeroplanes are so much more expensive than cars, because they’re so much more reliable.’*
> (017, [Private, Technology])

> *‘Space has to be very conservative in its use of technology and materials because of the need for reliability. For example the electrical system in a spacecraft tends to be quite primitive and uses components that are not by any means state of the art because they have to have proven reliability, be radiation-hardened, et cetera.’*
> (016, [Private, Technology])

> *‘We’re in a bit of a vicious circle at the moment. We have a question about reliability because even though they are very reliable, we still have quite large failure rates. Something like one in fifty. So one in fifty is still not particularly good, and basically what happens is that*

> *you make sure you over-engineer, so that when it goes up, if it gets up fine, it's going to work.'*
> (021, [Public, Science])

A programme with a low failure rate will be perceived as reliable, and a programme with a high failure rate will be perceived as risky. This failure rate is presented numerically – as the third of the above quotes states, the generally-agreed average figure for the space industry is 1/50. This denotes the portion of all space launches which are expected to fail, whether due to an unsuccessful launch where the satellite is destroyed in the process, a failed deployment once in space, a technical fault after deployment, or a satellite which ceases to function before its intended lifespan has concluded. Defining a failure rate and thereby making a statement about future reliability is one strategy among many for constructing a successful programme (Sørensen & Levold, 1992). This is not just presented as an analysis of the viability of the programme but also crucially as an aid for actors to make informed judgements about the future. A reliable satellite will be able to continue the provision of services into the future, whilst a satellite with a high failure rate lacks the potential for confidence and reliability that private space actors require.

In this way we can also identify the particular form of failure that the failure rate reflects. Failure within the science-orientated missions of the previous chapter can be understood as 'heroic failure', a phrase familiar to those who followed the aftermath of the failed Beagle II Mars landings (Jeffries, 2003; Briggs, 2004). This is a type of failure where the mission was very specifically striving (or presented as striving) for a goal that was conceived as inherently risky, distant, and at the cutting edge: a failure is therefore clearly not desired, but if it takes place it is quickly defined as the type of failure necessary for science and technology to advance[5]. This is similar, for example, to Richard Nixon's undelivered speech for a scenario in which the Apollo 11 astronauts did not survive the journey (Redd, 2014) which emphasizes the 'nobility' of failure, and the risk of death, in order to attempt bold scientific advance. By contrast, the failure for these more conservative missions is merely 'service failure' – not that the programme was aiming to do something new and fell tragically short, but that a service might cease to be available, or that a service might not function at the quality expected for the duration of time expected. It is a form of failure only relevant to the space industry in recent decades as a result of this shift towards increasing privatization and the provision of services. This shift has been explored here as the first of the three identified themes behind the increasing conservatism of the industry, and in turn the necessity of creating normalized future narratives.

5.3.2. Old Components and Established Employees

The second major theme identified for the growing conservatism of the space industry was the importance of older components, and the related role of long-established employees within space companies and space agencies. This section explores these two issues and shows that whilst the changing customer base is an 'external' pressure upon the space industry, these two issues have a significant 'internal' dimension to them, and are related to both the unique nature of space-based technologies and the personal preferences of those within the space industry.

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[5] Interestingly, the recent discovery of Beagle II's remains in January 2015 has led to it being rebranded as a 'great success' (Kelland, 2015) due to the fact it landed on Mars (although it was too badly damaged in the process to function). Within a framework of necessary or sometimes 'expected' failure, this has been touted as the programme's success 'in getting to its target, landing, and inspiring scientists', and that Beagle's status does not represent a complete failure of the mission as a whole.

Interviewees described a strong preference for using older components rather than allowing new components to be flown. They argued that the reliability described above can stem from the deliberate use of older components rather than newer, and that the risk involved in a programme may be reduced by the use of components that are *not* at the cutting-edge of space technology:

> *'[Space programmes generally use] old-fashioned technology which you know to be reliable rather than cutting-edge tech, and deliberately so.'*
> (019, [Public, Science])

> *'Generally the chips used on satellites are really antiquated compared to what's used in your phone, and the reason for that is that they've had to undergo a lot of space qualifications, so they know their responses to space radiation and things like that.'*
> (017, [Private, Technology])

This does not mean there have been no 'new' components in the space sector for years or decades and thus they are forced to rely on older parts – there have of course been developments, iterative improvements and entirely new components – but that those are generally very deliberately not chosen for these types of programme. Instead, older and well-trusted components are selected in their place. This is common to other high-risk sectors. Failures in nuclear technology, for example, are often attributed to failure of *new* technologies – that recent technologies are either not sufficiently tested, or the human personnel in question are inadequately experienced with them (Sovacool, 2010). Similarly, Mackenzie (1990:238) notes that despite the pressure to use 'the latest thing' in high-risk technologies purely *because* it is cutting-edge and new, it is not always appropriate to the context. Just as there were niches where 'less advanced' mechanical gyros remained more useful for nuclear missile guidance despite the development of more complex equipment, so too have older components remained highly relevant in the space industry. Newer components bring both a level of technical uncertainty and the requirement of extra learning for those who staff the technologies, whilst older technologies are seen to be easier to use because of the experience already gathered on their operation and use. Interviewees agreed on this extra level of trust granted to older components due to their 'proven' reliability:

> *'For example, the electrical system in a spacecraft tends to be quite primitive and uses components that are not by any means state of the art because they have to have proven reliability, be radiation-hardened, etc. So it takes a lot of time and is quite expensive to demonstrate this, so for example with computer chips and things like that you tend to find very old versions of computer chips.'*
> (016, [Private, Technology])

> *'Most of the big space observatories and big space missions are using, for example, processor technology that is at least ten years old, as it takes you ten years to develop it, and also it's something that's robust, tested, you know for sure how it's going to act. It might not give you the cutting edge performance, but that's less important than it working.'*
> (019, [Public, Science])

This claim is therefore that older components are trusted above newer equivalents both due to whatever testing they may have undergone (see Chapter 6), but also due to the mere fact of the temporal distance involved. The first interviewee's statement that 'it takes a lot of time [...] to demonstrate this' suggests a level of perceived inevitability to the process. A component needs time to be tested and proven, so by giving it that time, it will emerge from the process reliable and trusted. The second quote agrees by stating it takes ‘ten years to develop [a component]’, and then it becomes something that is ‘robust, tested, you know for sure it’s going to act’. These quotes show that *time* serves as an important method and concept for getting a component widely accepted – newer components which may simply be an ‘upgrade’ of the original, rather than entirely new, can still struggle to find acceptance against their well-tested predecessors.

Crucially this means that the *time* committed to the development and prior use of a component becomes a method to *reduce the perception of risk* in a later programme that subsequently uses it. It is a trade-off – the more time that went into the components before any given programme begins its development, the lower the perceived risk of that programme. ‘Degrees of danger are socially mediated’ (Balmer, 2006:693) and the time spent developing the component in the past is thus mobilized to sell its low risk in the present day. The claim of increased reliability and reduced risk comes from the time that has gone into the programme’s components, and by using components which already exist, the programme both appears more reliable and does not have to spend any time developing those components itself. By emphasizing this separation between the components and the eventual programme, the development of the components is discursively positioned outside and prior to a particular programme, and thus is not considered within the timescale of the programme. This is another reason why normalized future narratives are primarily concerned with the mitigation of risk, not the management of negative perceptions of temporally lengthy programmes: service-led programmes take less time because they will primarily, or sometimes exclusively, use hardware that has already been developed.

What this illustrates is that wherever possible ‘off-the-shelf’ technology is preferred for as many of the components of a given mission as possible. Using such ‘ordinary’ components helps a future narrative to appear normalized and mundane, and therefore low-risk and high-reliability. Off-the-shelf technology is a term used to denote components that are designed with ideals in mind of 'low cost, ready availability, high performance [and] low power [demands]' (Underwood, 2003:193). It is the second of these to which we look for understanding of this use of older hardware in such missions – the ready availability. The development of normalized space programmes does not have to include the time, resources or expertise required to develop new components; instead such programmes are able to utilize components that have already been developed, and due to having been developed and used before the programme begins, are likely to be well-trusted within the sector. The emphasis within the sector on older components being inherently more desirable encourages the sector towards their use, whilst this very use of older components can then be used as a method for demonstrating the reliability and low-risk of a normalized programme as we shall see in the examination of Skylon later in this chapter. Skylon uses many components the sector has used before which have become normalized (whilst playing down the role of its major new and 'innovative' companies), and this use epitomises this more conservative preference for the choice of utilized components. Creating such 'off-the-shelf' components will be explored in depth as the primary focus of the next chapter on adaptive future narratives.

There was also a second reason I identified behind the strong preference for older components, which was a technical factor unique to the space industry. This was the claim that using older circuitry in space technologies is preferable due to the effects of extra-atmospheric radiation. In addition to preferring tried-and-tested hardware for all the rationales already explored, this interviewee suggested that even if modern space-based technology was as normalized and trusted as older components, they *still* would not be as desirable due to a quirk of the space medium and what makes for reliable technology within that environment:

> *'In the space scenario where you have charged particles flying around without the atmosphere to protect you, the very high velocity particles can go straight through a circuit board, and if the tracks are close together… whereas big technology with big old-fashioned boards, with tracks further apart, it's actually more robust.'*
>
> (022, [Private, Technology, Comms])

This interviewee was one of the last interviewed so the potential to pursue this avenue further with other respondents was limited, but it does raise interesting questions about both the future of the space sector and the position of advancing technology within it. According to this interviewee the sophistication of space technology for certain components may be limited due to the nature of the space environment, much as airspace or aquatic environments will impose limits and requirements upon their equivalent high-risk technologies. This claim therefore undermines traditional technologically determinist assumptions (cf. Williams, 2006) about the 'progression' and 'improvement' of technology as being inherently, and universally, desirable. However, it is worth noting that the above comment refers only to circuitry, not any of the other components of a satellite or other space technology. Whilst this impacts upon the uptake of new components, I believe this space-specific issue for circuitry remains a small concern. There was only a single interviewee who mentioned it, and the comment said little about the simultaneous development of other space technologies – for example those which may *protect* against radiation and particle damage – which could be coupled with improved circuits to offset the issue with smaller circuit tracks.

In summary, the preference for older technology – primarily due to the social construction of older technology as reliable and well-trusted (but also the claimed circuitry issue for space components) – is a form of trade-off between the high-risk and long-term natures of the space industry. I propose that this trade-off can be expressed as a rule:

> *The longer the development that went into the components before the start of a programme, the lower the perceived risk of the programme itself.*

However, these two reasons – both of which draw upon the temporal distance of the component's development as a way to sell its value for normalized service provision – were accompanied by a third factor relating to the use of older components. This was the decision-making process of long-established space sector employees who give preference to these components for their own reasons, rather than only considering the value of presented trusted and normalized programmes to service-orientated private actors. Two interviewees argued that the sector's conservatism was in part due to most of the influential individuals within the space industry originating from one generation of scientists and engineers, and that this generation had become predisposed to supporting conservative programmes. This was one of the only pieces of data acquired which focused specifically on the individual *human* actors rather than the interrelation of many different actors involved in the contemporary space industry. The two interviewees who raised this topic were both amongst the older interviewees in the research, worked in the private sector, and raised several interrelated points about the role of human actors with particular experiences and histories within the space sector:

> *'I think it's going to change as our generation, if you can call it that, retires. Everyone in this industry knows everyone else… and since we all started at the same time and everyone knows everyone, there's a bit of a comfort zone thing. I suspect in the next few years that will change. Because one big problem we have in our industry is that…*

> *there's not a new field of people coming through. We all came out of the big Marconis [a British space electronics company].'*
> (024, [Private, Comms])

> *'So it's very much that there are built in ways of thinking, people are used to handling them, people are used to working with them and they know how it works.'*
> (023, [Private, Science])

In these quotes the interviewees argued that the group to which they themselves belonged – of older space scientists and technologists – discouraged the space sector from pursuing programmes outside a certain sort. The idea of the 'comfort zone' in the first quote is much the same as the conservatism described in this chapter, but in describing it in this way the interviewee sought to argue this was more due to preferences and opinions amongst space engineers, not a function of minimizing quantified risk and maximizing reliability in order to recruit external support for the programme. Although these two are very 'personal' perspectives on the nature of space sector conservatism that emphasizes the human actors and de-emphasizes the interactions between corporate or technological actors in the industry, such a concept is not without prior scholarly work to support it.

In his study of the subatomic particles known as quarks, Pickering (1984:10-12) coined the term 'opportunism in context', arguing that scientific careers can be significantly advanced by taking advantage of certain contexts – in this case, the massive state funding that the early space industry was granted (Fisk, 2008; Hill, 2012). The careers of many scientists, technologists and engineers were enhanced significantly by the emphasis and support many states placed on the space industry during its first few decades, a context specific to a particular 'time and place' (Hermanowicz, 2007:629). These quotes support the assertion that many of the higher echelons of the sector contain a specific ‘generation’ of individuals who saw significant potential in the early space industry, and whose perspectives are strongly determined by what the space sector was when their careers began. These interviewees were the only ones to mention this perspective on the people involved in the space industry (and acknowledged that they were part of this generation themselves) rather than citing the other rationales in this chapter for the normalization of much of the space industry. Whilst the sample size of the interviewee set was too small to draw any such demographic conclusion, the average time spent within the industry of those who worked within well-established parts of the space industry tended to be high in comparison to those working in more innovative technologies. This is not to say that youth guarantees innovation (nor that age is a guarantee of conservatism) but rather that the development of the space industry over the last fifty years may have led to a level of socialization within its human actors. Socialization is a phenomenon by which those within organizations and other social settings ‘commit themselves to a distinct way of life’ (van Maanen & Schein, 1977:209) according to the unwritten and learned rules of that setting. For the space industry’s senior staff, this assertion of socialization from these two interviewees is supported by the work of King and Sethi (1992) who describe the creation of a ‘custodial’ role that employees within high-technology industries can take on, focused around the maintaining of the status quo. As these individuals are more likely to be in senior positions – the longer the employment, the higher the likely rank and the higher the likely degree of socialization – this leads towards a preference for programmes using older and safer components. In this chapter’s later discussion of chemical rockets (5.3.3) we shall see another way in which norms and routines within the space industry from its early days have become ‘entrenched’ and enforce their continued relevance upon the sector as a whole.

This is therefore a push towards conservatism and the mitigation of perceived risks that is entirely ‘internal’ to the space industry. This preference away from innovation is driven by those who are well-established within the industry, not by a deliberate and planned agenda focused on recruiting outside actors. According to these interviewees normalized future narratives may be preferred by those who are secure within the space industry and see little value in disrupting the status quo too far. As well as the concept of socialization, we can look to the work of Wynne (1983) to understand the importance of this human element in high-risk development programmes as a whole. Wynne argues that commitment to a technological development programme is as much personal and intellectual as it is material. Wynne stresses the importance of producing ‘taken-for-granted’ frameworks for human actors within a programme (Ibid:15), and those within a programme may wish to push for a more conservative outcome that can use such frameworks, rather than the development of new rationales to go with new and innovative programmes. An internal working culture (cf. Chompalov & Shrum, 1999) within the space industry or any high-risk sector may be one that values job security, reliability and ease of programme development over pushing the boundaries of the technology with the attendant risk.

It is also interesting to note that what these actors may support now, currently considered conservative, would at some point in the past of the space industry have been perceived as deeply innovative. This therefore points towards potential future research into the extent to which human actors within high-risk sectors come to regard what was once bold and innovative research as normalized, and what drives this reorientation of interest from the new and untested to the older and trusted. A more mundane, normalized narrative for a programme’s development may be promoted as much for the comfort and preference of those inside the space sector as to promote interest and investment from those outside, and due to the age of the space industry such a preference for older components could only have arisen within the past decade or two – immediately after the Second World War there were, by definition, no well-established and well-trusted space components. The older generation may remember that these components were the result of more risk-laden innovative or experimental work in that era, but they have now become normalized and ordinary, and therefore safe for regular use.

This four-fold preference for older components is thereby the second of the three themes identified for the growing conservatism in the space sector. Older components are strongly preferred due to their perceived reliability and low-failure rate; their development times in the past being seen as desirable characteristics for a contemporary programme; the claim that older circuitry may be more desirable in a space environment; and because long-established members of the space industry promote, deliberately or otherwise, an institutional culture that privileges the classic over the contemporary.

5.3.3. Satellite Launch, Retrieval, and Lifespan

The third major theme identified in the interview data for increasing space sector conservatism also consisted of three interrelated issues. These three issues are the high cost of launch via chemical rockets, the impossibility of retrieving or altering a satellite once it has been launched, and the subsequent required length of satellite survival in the space environment given these restrictions on satellite technology. This section will explore each of these three issues in turn, and then summarize the interrelation between them and why they too encourage a more conservative space industry.

The first of these issues is the high cost of launching satellites via chemical rockets. Two interviewees stressed the high cost of launching satellites as the price for launch by chemical rocket remains relatively inflexible, and down to a price-per-kilogram calculation:

> *'Getting something into space, the price per kilogram is huge, and in terms of innovation that's now become the main barrier. So if you have someone like SSTL saying we can produce you a reliable, cheap satellite around the £20m mark but it costs £50m to launch it… it's not worth you going much smaller than that until it becomes cheaper to stick something into space.'*
> (007, [Public, EO])

> *'Launching space assets, they're expensive, you need them to work, and that drives conservatism.'*
> (010, [Public, Technology])

At the time of writing the only reliable and regular method for launching satellites remains the chemical rocket (Spaceflightnow, 2015). Such rockets are iconic primarily for launching the Space Shuttle, but they remain the only means of ground-to-space conveyance for any space programme. These are rockets powered by the chemical reactions of propellant fuel, producing thrust which carries the rocket and whatever cargo it contains from the launchpad. Existing chemical rockets must be booked well in advance, are extremely expensive, cannot normally be reused and require significant resources to build (e.g. Walker, 1993). These quotes argue that the high cost which comes with chemical rockets encourages the space sector towards more conservative programmes that are seen as having a higher chance of success, in order to minimize the chance that the cost and effort of investing in the launch will have been wasted.

Just as we saw that several interviewees emphasized the importance of the preferences of space sector incumbents in the use of older components, similar comments were made about the history of the space industry being an important factor for understanding the chemical rocket monopoly and the high costs of launch that come with it. Two interviewees particularly stressed this historical dimension to understanding space industry launch vehicles:

> *'What Apollo did was to commit to a single short-term objective which was put a man on the Moon. It didn't worry about the cost, or create infrastructure. It didn't worry about follow-on technology, and essentially what we're got now is a consequence of those things. Because when you start off you can do anything, but when you've been through a generation you tend to do things that logically follow on from what you've done before.'*
> (020, [Public, Private, Science])

> *'That sort of evolution to gradually get into space with reusable aircraft never happened, and instead we got into space very quickly, but with these expendable rockets. And it's been very hard to – I think people have written alternate histories for this in science fiction – imagine an alternative line of development. It's very hard to change the direction and everyone's still stuck on these expendable rockets.'*
> (002, [Public, Science])

From these comments we can see that the launcher industry is perceived as having unintentionally become a black box. Black boxing is a social process by which a particular technology becomes standardized in a particular form, and is subsequently unquestioned and unchallenged (Rammert, 1997). Interviewees argued that the black box of the launcher industry, having been the staple launch solution for so long, will actively resist changes to launchers (cf. Winner, 1977:244). Those outside the space industry who purchase the use of launchers will also be uninterested in a potentially more complex technology, and will prefer instead the black boxed launchers they have become comfortable with regularly using. The black box of the existing launcher paradigm thereby restricts the types of space programme that may be launched. Due to the price of this ubiquitous launcher paradigm it is the most reliable, trusted and conservative satellites and components that stand by far the best chance of making it onto the launchpad. However, this high cost of launch and the resulting conservatism is only one issue of three interrelated concerns raised in the interview data.

The second issue of the triumvirate explored in this section is the inability to retrieve satellites. Although chemical rockets are currently the only method by which satellites may be regularly and reliably launched, retrieval is significantly beyond their current remit. The impossibility of repairing or otherwise physically accessing satellites after launch was identified by a number of interviewees as a concern for the space industry, and one that in turn is driving its contemporary conservatism:

> *'One of the features of launching something into space is that rarely can you go up and fix it when something happens to it, so generally space instrumentation does have an inherent level of conservatism.'*
> (019, [Public, Science])

> *'Space is certainly very technically conservative, and the reason for that is that if something goes wrong out there, you can't do anything about that.'*
> (017, [Private, Technology])

> *'It just has to work. Once it's up there, you can't say 'Bugger, I forgot to tighten up that nut', it just has to work. And so the degree of product assurance, QA, testing, retesting, recording, provenance of components, it's a very high level, it's just inherent in the business.'*
> (013, [Public, Private, Technology, Comms])

The use of the word ‘inherent’ in the first and final quotes is interesting because it shows a high level of acceptance in the familiar procedures of the space industry and, crucially, a conflation of ‘this is how things are’ with ‘this is how things have to be’. These procedures have become *normalized*, and in turn high levels of reliability have become a key part of normalized future narratives which succeed or fail on their ability to demonstrate the ordinariness and trustworthiness of the programme. This space industry framework where satellites cannot be retrieved and therefore a high level of engineering diligence is required has become a taken-for-granted understanding which both acts as the foundation for rules and practices (Wynne, 1983) and is further strengthened by continued adherence to these norms (King and Sethi, 1992; cf. Chompalov & Shrum, 1999).

This returns us to the concept of reliability – a satellite must be reliable precisely because once launched it cannot be fixed. This places space technology into a unique category of products and components. Other high-technology industries such as nuclear power are able to replace components despite containing sophisticated and risky technologies, whilst other industries where components have to work in extreme or unusual conditions, such as submarines, are equally able to return to be refitted and modified as long as they do not suffer a critical destructive failure. Although the managerial structures surrounding these technologies may also be categorized as ‘High-Reliability Organizations’ (Weick *et al*, 1999; Boin & Schulman, 2008), space stands on its own as an industry with a *point of no return* for any given product. This point of no return is the launch, and it was identified in the research as a significant driver towards space industry conservatism. Whilst a vehicle like the Space Shuttle is unique in this regard in that the same physical craft may have been reused multiple times, with that exception the space industry never uses the same physical pieces more than once. A satellite is launched, it (hopefully) completes its mission and survives in space for the intended length of time, and then it is either abandoned or de-orbited, subsequently burning up in the atmosphere. If it fails to meet that goal, however, there is little that can be done other than cutting losses and moving on. Since the losses may be quite substantial, interviewees argued that this generates a high level of conservatism in what is launched, selecting components which are well-trusted (and therefore have a lower level of perceived risk) than any potentially ‘better’ but riskier counterparts.

We have therefore now seen two issues raised in the research data – the high cost of chemical rocket launch, and the observation that such launches are also points of no return, beyond which a satellite cannot be altered or repaired. The third is the *length of required survival* for satellites, which is closely related to these above two issues. As discussed earlier in this chapter, conservative programmes are often those which aim to reproduce and improve a service for which components already exist – television, radio, broadband, and other communications. It is the provision of a long and reliable service that matters for many space programmes, not the technologies which provide and produce that service. Two interviewees discussed why the length of survival of satellites has become paramount for large numbers of commercial actors. They argued that satellite manufacturers tend towards components which can give long-term signal reliability rather than potentially more ‘advanced’ technology that may run the risk of lasting a shorter length of time in space:

> *‘Right now if you put a satellite in orbit it has to last 10-15 years, so you plan for very high reliability parts because of that, the cost of putting the sat in orbit, whereas if the cost of putting it in orbit was much less you would not necessarily require a very high reliability of the component.’*
>
> (016, [Private, Technology])

> *‘Spacecraft are expensive and they take a long time to build and launch, [so] there is actually a great reluctance to use untried, untested new technology. Although space is often seen as cutting edge and in many ways it is, it also can be incredibly conservative because if you’re building something that has to operate for the next five, ten, maybe fifteen years, the last thing you want to do is to have a new dodgy bit of technology that breaks down on day one.’*
> (002, [Public, Science])

Whereas half a century ago merely launching a satellite was a great victory (Ellul, 1964:145; cf. Jones *et al*, 2007), the desired survivability of satellites has undergone a distinct discursive shift. The repositioning of many space programmes towards providing services instead of science or international pride has been accompanied by a shift to satellites needing to survive for longer and longer periods of time in space. The first quote shows the importance for the commercial sector of considering the length of time a satellite must survive for. In this way many satellites have become less and less akin to impressive symbols and more akin to normalized pieces of infrastructure (Levine, 1986) that merit a normalized future narrative. The second quote also emphasizes once more that the satellite *itself* is neither the mission nor the selling point, but rather the service it can offer is what sells it. A greater predicted length of survival is more appealing to commercial actors than a shorter one, and this in turn requires the use of well-trusted components, encouraging the industry towards this conservative outlook and the normalization of its future narratives.

We can now identify the relationship between these three issues – costly launch, irretrievable satellites, and long-term satellite functioning. If launches were cheaper or satellites could be retrieved and repaired, long-term functioning would be far less important. If launches were carried out via a different form of vehicle – such as a spaceplane – satellites could perhaps be retrieved. As it stands, however, the financial risk of launching a satellite is significant, and the satellite cannot be repaired, resulting in a situation where communication and service satellites are only acceptable if they can be trusted to provide a lengthy and successful period of service. The moment the satellite fails to function is the moment the service the satellite provides ceases to be, and since it cannot be fixed and failure is permanent, it must be made as reliable and trusted as possible prior to launch. These three interrelated factors form the third and final rationale for conservatism identified in the space sector.

Having explored these three drivers towards conservatism within the space industry – the changing customer base, the value of old components and the three-part problem explored in this section – this chapter will now explore a case study that illustrates these three themes and how they have altered the future narratives proposed by the space industry. This case study is the ‘Skylon’ spaceplane. The next section examines Skylon and shows how the normalization of space industry future narratives is designed to work around this new conservatism, mitigate the perception of risk, bolster the perception of reliability, and ensure that space programmes remain viable even when faced with the many conservative inclinations identified here.

5.4. Defining New Technology within Existing Norms: The Skylon Spaceplane

Skylon is a spaceplane currently being developed by *Reaction Engines Limited* which is designed with the intention of providing a new form of launcher for the space industry. Instead of the current norm of chemical rockets which can only be used once, must be launched from a specialized launch-pad, are very expensive, potentially risky and have ‘slots’ that must be booked months or often years in advance, Skylon aims to change all of these assumptions. Designed as a craft which takes off and lands in the manner of a plane but enters space (hence 'spaceplane'), Skylon seeks to be reusable, able to be launched from existing airstrips rather than specialized launch pad infrastructures, significantly cheaper than chemical rockets (because it does not have to be built anew after each use), and can potentially be booked only months or even weeks in advance of a required launch (Reaction Engines, 2010).

Skylon could understandably therefore be seen as heralding a major change within the space industry in terms of many of the themes explored in this chapter. It is technologically unlike existing chemical rockets, and it would also cause a total reorganization of a number of assumptions within the space sector to do with risk, time frames and launch expenses, and the amount of forward planning required for any given satellite. However, much to my surprise it rapidly became clear that the ways the Skylon programme are presented and sold to other actors actually *play down* both the technologies involved, the hype and ambition of the programme (Launius, 2003), and the changes this would make to the space industry.

Rather than promising such changes, the future narrative for Skylon's development and potential benefits has been normalized. One interviewee involved in the programme (though not directly a *Reaction Engines* employee) had the following to say about Skylon's normalized presentation:

> *'The cultural outcrop… you come up against is the mad inventor motif. It's a potent symbol and everyone talks about it. And if you go too far in that direction most people and socialization dismisses you as a mad inventor. So you've got to present it as something that makes a significant change but not a change that takes it beyond the pale of existing space economics. So Skylon, the guys behind Skylon, sell it as something that is effectively the next generation*

> *launcher, or a competitor to current-generation launchers, in that it has significant cost savings.'*
> (003, [Public, Technology])

Although used somewhat flippantly in the above quote, what the interviewee terms the 'mad inventor motif' is actually highly relevant to the space industry. When trying to sell service satellites, the existing cultural assumptions about the scientific innovation of the space industry leads space technologists to avoid selling service-orientated programmes as heralding a new age of spaceflight, transport or communications. Instead they are presented as being in a clear historical continuity with *services* which have gone before. Skylon has to present a normalized future that, as the above quote states, denotes a gradual or iterative improvement over existing launchers and presents Skylon within currently normal space industry expectations, rather than something that is 'beyond the pale' of what the space industry expects. Even if Skylon can be seen as a shift that could potentially affect the entire sector, it is presented in mundane and normalized terms – it can make launches a bit cheaper, a bit safer, a bit faster – rather than as something which will fundamentally alter the space industry. Skylon in this way is not depicted as a new service in its own right, but as only a gradual improvement over the technologies that have provided that service in the past (i.e. chemical rockets). The technological specifics of the programme are edited out of the language used to describe it (or at the very least, toned down). As one interviewee put it:

> *'Many people tend to be conservative because they have a solid business case and don't want to risk the credibility of that business stuff by introducing all this airy-fairy stuff.'*
> (019, [Public, Science])

Were Skylon presented using the tools of the finite future narrative of the previous chapter – emphasizing disjuncture, new technology, innovation –

it would not appeal as a *service* for launching satellites. The risk of its failure would be considered too high to justify any investment or support. Just as the scientific advancement of early spaceflight has now taken second-place to the variety of service uses of modern space technology (Slotten, 2002; Vedda, 2002; Elhefnawy, 2004; Sadeh, 2005) and the wider range of actors space programmes are accountable to (Ocampo *et al,* 1998; Cornelius, 2005; Goehlich *et al*, 2005), so too has the 'science fiction wonderment' of early spaceflight (Huntley *et al*, 2010:25) largely faded (or been deliberately removed) to be replaced by the much tougher and tighter assessments of risk, reward and reliability shown in this chapter. Indeed, although Skylon is defined in *technical* literature as being a 'spaceplane' (e.g. Varvill & Bond, 2004), this quote suggests that it is generally termed in sales pitches and when trying to recruit others as simply a new type of 'launcher'. This word signals consistency with the space sector's current reliance on 'launchers', and thus reduces the amount of change denoted by the Skylon programme.

This rhetorical strategy is important to analyze – even though its mode of operation is utterly different to chemical rockets, the use of the term *launcher* places it discursively within existing models of the launcher industry. It downplays the level of change in the components and technologies at play – and also, crucially, downplays whatever future changes in the space industry it would cause were it to be fully adopted – and presents it as simply something which *launches satellites*, the same job chemical rockets do now. In this way it is presented as something that does the *old task better* and maintains a service of satellite-launching. The term *spaceplane* is seen to represent too much of a discontinuity with that which has gone before, and hints more explicitly towards the changes it would herald than the term *new launcher*. Other interviewees concurred about the importance of describing new space technologies within the discursive frames that had come before:

> *'One of the sales points we're having to make with Skylon – and this in certain quarters is a very strong selling point – is how much it's like existing launchers. The thing that really works isn't us showing delivering 24 people to the International Space Station, it's us showing a communications satellite being launched into Geo-Synchronous Orbit and does exactly the same thing and looks the same.'*
> (015, [Private, Technology])

> *'For Skylon… the marketing pitch should not be technology-led, it's 'I can give you a far more reliable, risk-averse, [system]'. You're dumbing down your fantastic scientific breakthroughs because your end customers, frankly, don't give a toss [laugh]. They're buying a service, and they want it to be reliable. You don't sell technology, you're selling a service.'*
> (025, [Private, Technology])

Rather than leading with the technology, they lead with the service. Private actors have no particular interest in the technical or engineering specifics – in this case a new form of launch vehicle – but rather in the outcomes and the services it can provide (Jørgensen *et al*, 2009). Instead of terming Skylon as an innovative new launch vehicle that tests certain technologies or new components – an objective only of primary interest to the engineers working on it – Skylon instead defines itself within the objectives that outside actors will recognize, which is to say cheaper, faster and more reliable launches, as well as a longer-term objective to potentially make satellites retrievable once in orbit. These have all been identified in this chapter as issues that encourage a more conservative outlook in the space sector, and these methods recruit actors without *appearing* to upset the standards and norms of the industry too much.

This form of expressing a programme's objectives is therefore a fundamental method by which programmes which are not focused around 'science' are able to recruit actors into supporting new high-risk technologies and developments. Normalizing the future intentions of a programme allows for some gradual technological development and change because the final product is defined within specific boundaries that emphasize its practical benefits, not its new technologies. *Reaction Engines*' objective to develop new propulsion technology and revolutionize the launch industry is, despite the apparent promise of such an idea, not what commercial space actors are interested in, and thus it is normalized into merely representing an improvement over the status quo in terms of quantities – time, cost, risk, etc – that commercial actors are familiar with. Skylon is promising significant upheavals, but presents these upheavals in terms that actors who *do not desire upheavals* are also willing to support. This creates a juxtaposition of equivalences (Callon *et al*, 1986a, 1986b) between the two actors where the technological innovations of one have been presented as service potential for the other, and thus the programme is strengthened by the shared interest in Skylon's success, even if private and engineering actors' reasons for supporting Skylon are entirely unalike.

To return to the three themes of this chapter, it is clear that the Skylon programme includes them all. Firstly, Skylon is designed to appeal to a wide range of private actors newly investing in the space sector by promising improvements in satellite launch services. These affect all commercial space actors irrespective of the specific services their satellites provide. Secondly, although much of Skylon's success or failure is believed to come down to the viability of one essential new component (Reaction Engines, 2012), the majority of the spaceplane consists of old components used in new ways (Hempsel, 2010) – clear recourse to tried and trusted components already used in the space industry. Third and most interesting is its relationship to the issues of launch vehicles, satellite survival and satellite retrieval. These assumptions have become so ingrained within the space industry that it does not seek to explicitly challenge them, but rather to emphasize that it can offer slight, gradual improvement in those fields. This is presented as a small development that will improve the space industry for all satellite manufacturers rather than a major change which will require significant upheaval and re-thinking. *Reaction Engines* has normalized the future narrative for Skylon's planned development by promising improved reliability, speed and safety, and a service-led promise, rather than emphasizing bold claims and clear changes from the space industry norm. As mentioned at the start of the chapter (and covered in more depth below), a normalized future narrative is fundamentally terminological in nature. Skylon has produced a successful normalized future by acknowledging the three core reasons for the space sector's increased conservatism, and altering the language of its promises to meet these new expectations.

5.5. Conclusion

This research project considers technological development in high-risk and long-term technological industries. Where a finite future narrative as analyzed in the previous chapter is designed to manage long timescales, the normalized future narrative proposed in this chapter is specifically designed to mitigate the perceived risk of such programmes, and has little to do with their normally significant temporal dimension. As defined in the introduction, a normalized future narrative is a less codified or distinct structure than a finite future narrative (or the adaptive future narratives of the next chapter), but rather refers to a future narrative for a programme's intended development and objectives which *has been normalized*. By this I mean that the terminology describing every aspect of the programme – the planned objectives, funding proposals, media appearances, internal working documents, government or policy documents – has been altered and designed in order to account for the three new conservative impetuses identified in this chapter from the interview data. This conservatism has led to the creation of normalized future narratives which emphasize regularity, mundanity and ordinariness, designed specifically to reassure potential stakeholders about the reliability and low-risk of a given programme.

The first of the three themes was the increasingly commercial and privatized customer base of the space industry. Linked to the issues explored in Chapter 1 (Sadeh, 2005; de Montluc, 2009; etc), a significant number of important actors relevant to the contemporary space industry are private and commercial actors, rather than the states and militaries of the Space Race era. Just as some private actors in the space industry now engage with space science missions in order to pursue spin-off (Bach *et al*, 2002; Worms & Haerendel, 2004; Chapter 4), many private actors are also now turning to the space industry as a method for service provision. This higher number of commercial interests within the space sector means that the customer base for the space industry has shifted towards being more interested in technical reliability than the generation of new scientific knowledge (e.g. Greenberg, 1993; Vedda, 2002; von der Dunk, 2011), and the interview data showed that a large portion of the space industry has therefore reorientated itself towards the service-led programmes that risk-averse private actors are more interested in supporting.

The second was the observation that the space industry has existed long enough to build up a repertoire of trusted and well-used components. The research showed that older components are used because they are considered a step ‘apart’ from the rest of a given programme. Whereas new and innovative components would require time to be developed and tested, components developed *before* the start of a programme have a multitude of benefits. Their development time is separated from that of a space programme that will eventually use them, making the temporal dimension of normalized space programmes appear far less; they are components that have already undergone extensive testing and are therefore considered reliable; and the mere fact of the temporal distance between their development and their eventual use is itself sufficient to lend them a reduced sense of risk compared to new components. This is coupled with the preferences of the human actors long-established within the space industry, identifying the importance of interpersonal aspects of technology programmes (Wynne, 1983) and internal working cultures (Chompalov & Shrum, 1999) that may tend towards the conservative use of older components. One interviewee also suggested the older components are preferable due to a quirk of the space environment resulting in ‘less advanced’ circuits being less prone to radiation damage.

The third consisted of three interrelated issues – the high cost of launch, the risk of launching a satellite which cannot be repaired or replaced once in space, and the subsequent need for satellites with long lifespans in as a response to these other two issues. The very high cost of launch for space programmes encourages a level of testing and diligence in order to ensure that the satellite in question gives as much value as possible per launch, whilst the inability to retrieve satellites means that it is considered paramount that they have the highest chance of success once launched. These both create the need for satellites that last a long time within the space environment, encouraging a preference for only launching tried and trusted satellites rather than more innovative alternatives.

These three themes towards conservatism and the subsequent need to normalize the future narratives of high-risk technologies were examined via the case study of the Skylon spaceplane. In contrast to chemical rockets, Skylon is designed to be reused, launched from airstrips instead of special launch pads, far cheaper than chemical rockets, and able to have a very rapid turn-around time from booking a launch to the launch itself. The examination showed that due to the new conservatism and the normalization of future narratives, Skylon is presented and sold in a specific way. Rather than emphasizing the new technologies and components involved (see Chapter 4) and the disjuncture with present-day launch vehicles, Skylon is depicted as being a cheaper, safer and faster *type of launcher*, rather than an entirely new technology. It is presented as something that simply launches satellites, which is a task that chemical rockets already perform and external actors are used to. Although the technical definition of Skylon is a 'spaceplane' this term was rarely used by interviewees involved in the Skylon programme, who both emphasized in the interview situation that it should be thought of as a launcher, and that using this definition was itself an important discursive choice as part of normalizing the programme. Any sense of major technological change within Skylon is played down and replaced by pragmatic assessments of its benefits. By using a normalized future narrative Skylon is able to present its technical innovation as merely a slight – but still very desirable – improvement in service normality.

To conclude, a normative future narrative is highly distinct from the finite future narrative of the previous chapter. Instead of providing a story that is different from what has come before, normalized future narratives reuse and iterate upon past stories of successful service provision. Rather than emphasizing the step-by-step process towards its completion and the newness and value of its objectives, the normalization of future narratives instead seeks to make the programme appear as ordinary, mundane, reliable and realistic as possible, and proposes outcomes that are a continuation of the services that have come before. Where finite future narratives emphasize new technologies and processes as a means to generating new scientific knowledge or spin-off products, normalized future narratives *de-emphasize* any new technology in the programme and stress that many of the components are old, reliable, and unproblematic. In contrast to emphasizing what high-risk technologies can do for national pride or citizen inspiration, normalized future narratives reposition high-risk technologies as being as close to mundane and everyday technologies as possible. Any risk, even risk that brings with it a potentially greater reward, is downplayed in favour of reliability of the components and confidence in the programme. The normalized future narrative is therefore best understood as an attempt to *reposition* a high-risk industry seeking to remain viable and fundable in an era of privatization and reduced state funding. Instead of presenting space technology as the end-goal, the technology becomes an artefact which is ‘bought and sold in an economic system’ (Balmer & Sharp, 1993:474). For much of the space industry the future narratives of a past era are no longer appropriate, so new normalized narratives for the new range of actors and customers relevant to the sector have been created which reposition space technology in this manner.

Beyond the space industry the concept of the normalized future narrative stands as an analytic tool for potentially examining other industries or technologies that have undergone a similar discursive shift from state and military funding into a market environment. Sectors of this sort include the Internet, which shifted from a high-reliability organization (Boin & Schulman, 2008) designed to ensure communication in a time of nuclear war to a public and private marketplace of immense size, no longer controlled by a single state (Abbate, 1999); the shift within the aerospace industry from military development (Futrell, 1989) into commercial air travel (Alic *et al*, 1992); and nuclear power’s discursive move from military-scientific research (Rosenberg, 1983; Sagan, 1995) into a leading source of global energy production and consumption (Winner, 1986). These are presented as ‘services’ – air travel provides a transit service, nuclear power an energy service, the Internet a service for information exchange – and the technologies which underpin them are toned down or simply excluded from the presentation of the service altogether. All the language used within these programmes is designed to reflect this new requirement for high-reliability and low-risk, and to describe the programme in terms of the service it offers, rather than focusing on the method by which that service is provided. In doing so a normalized future narrative attempts to make these high-risk technologies appear akin to the bikes and bulbs which SCOT has studied in the past, and present them as part of the quotidian technological milieu.

Chapter Six: Adaptive Future Narratives: Credibility, Testing, and Qualification

6.1. Introduction

This chapter is the third and final analysis chapter in this thesis, and proposes the concept of the 'adaptive' future narrative to conclude the proposed typology. The previous two chapters have covered the first two of the three distinct narrative types that emerged via coding and analysis of my research data. The first of these was the finite future narrative. This is a future narrative with two elements: a detailed plan or 'roadmap' which lays out a step-by-step process by which the space programme may be completed, and a clear temporal end-point beyond which the programme will not continue (and at which point it will therefore cease to demand time, money, expertise, commitment, etc). The development times of such programmes are often many years or sometimes even several decades, and when considered as tool for use within high-risk industries it was identified as being a future narrative focused on the temporal dimension, not upon risk. The second future narrative was that of the normalized future narrative, which seeks to present the space industry as something ordinary and mundane. They do this in order to negotiate the many drivers towards conservatism within the space industry identified in Chapter 5, including the growing presence of private and commercial actors in the space industry. This was explored in particular detail using the case study of the 'Skylon' spaceplane, which plays down the new technologies and processes going into its development and instead plays up the *service* potential of the spaceplane for faster, cheaper and more reliable satellite launches. In this way these future narratives are used to present the space industry as an ordinary technological industry which private actors might be keen to invest in. This was a future narrative that dealt primarily with lessening the perception of risk, rather than negotiating the timescales of lengthy development.

This chapter explores the third future narrative identified by this study – what I term an *adaptive* future narrative. Whereas finite and normalized future narratives apply to ‘programmes’ that are seeking to develop space science missions, satellites, or fleets of satellites, adaptive future narratives are instead designed to aid in the construction and future use of space *components*. This chapter will thus use the term ‘component development’ in lieu of the term ‘programme’ to describe the creation and subsequent deployment of a component, rather than the equivalent process for an entire space programme (which may consist of many thousands of components). A small number of interviewees quoted in this chapter did use the term ‘programme’ to refer to component development, but I am selecting a different term here for the sake of clarity and to aid in distinguishing between the creation of ‘programmes’ and ‘components’. No particular analytic importance was found in the research data in relation to the use of the term ‘programme’, so a minor rephrasing to aid understanding is acceptable in this context.

Space components may be circuit boards, solar panels, communication equipment, or anything else flown on a large number of satellites. They may be designed for initial use on a specific satellite which will be followed by wider use, or designed for immediate market distribution without an initial mission in mind. Although only relevant to components, this future narrative was found to be just as important as the other two in this thesis – in some ways more so, since there may be thousands of components for any one satellite. Such a future narrative is designed to convey the impression that the component being produced may not be used for any specific programme or set of programmes, but rather that upon completion of the development of the component, it can then be used in *any* subsequent satellite or space programme which requires a component of that sort. It is termed ‘adaptive’ due to the claim that the technical output of a component development can be adapted to the needs of any potential programme, and because such component developments propose that this adaptability and concurrent applicability will be the case for an indefinitely long time into the future. A successful adaptive future narrative will be used to ‘prove’ that a component is a well-trusted piece of hardware that will work reliably and safely when put to any use, and an unsuccessful one will leave a piece of hardware appearing unsafe, unreliable, or outdated.

The most important code that emerged in my interview data which pointed towards adaptive future narratives was that of ‘Credibility’. Whereas the cores of the finite future narrative are the roadmap and its promised objectives, and normalized future narratives are focused on recognizing emerged and emerging conservative tendencies and demonstrating the low risks of the programme, adaptive future narratives live or die on the strength of the forms of *credibility* associated with them. An adaptive future narrative consists of a lengthy *retrospective* narrative about all the forms of credibility a component has attained throughout its technological development, and then leverages this past to make claims that emphasize the component’s universal applicability to *future* space programmes. Components that deploy successful adaptive future narratives are therefore readily identifiable as the preferred type of component for service-led space programmes, as explored in Chapter 5.

In order to make clear the functioning of the adaptive future narrative, this chapter will first explore how interviewees explained the acquisition of ‘credibility’ for new component developments. The interview data showed that credibility may be acquired at three stages: when the component is deemed to be in its early or formative phase, when the component is in what I will term ‘technical development’ (this period was described as taking a component from a ‘concept’ into a completed ‘product’), and when many of the technical aspects of the component are complete and there is a planned launch of a satellite using that component. The chapter will first examine how credibility is gained in the early stages of a component development – this is achieved primarily through accreditation by a trusted space body like ESA, or by acquiring government funding and interest.

Subsequently the chapter will explore how credibility is managed in the 'technical development' stage of a component development. This is done primarily through two methods – the concept of the 'Technology Readiness Level' (TRL), and the use of complex testing regimes. The chapter will consider the TRL system and how each level is used to further lend respectability and viability to a component development, a system which was found to be comparable to what Balmer and Sharp identify as the concept of the 'technological trajectory' (1993:473) – a heuristic framework which 'forms the basis for the development of the technology' and along which the developing technology is expected to progress. The chapter then explores the crucial roles played by discursive concepts of objectivity, neutrality and linearity within this framework, and how these are used to bolster the impact of the TRL system. It will then look in more depth at testing regimes (which are a key part of mid-range TRLs) and how financial investment, the testing processes themselves, and the ideas of standards and acceptable margins are used to manage actors outside the space industry itself. Although all levels of the TRL system were found to be relevant to the accumulation of credibility, the interview data gathered on testing and standardization was far greater than that acquired on the 'early' or 'late' TRLs, and these processes were found to be integral to component credibility.

Lastly the chapter analyses the final part of the credibility process which occurs long after testing. This final stage consists of the twin concepts of 'qualifying' a component or technology for launch, and the concept of 'flight heritage' and the issues it poses for new components. The chapter will then contain a summary of how these concepts of credibility are then deployed ‘retrospectively’ after the technical development phase of the component development concludes, and therefore how they therefore contribute to the construction of adaptive future narratives, and the contrasts and relationships between adaptive future narratives and the other two forms proposed in this work.

6.2. Early Credibility

6.2.1. Third-Party Accreditation

Analysis of the interview data showed that there were two ways for credibility to be ‘gained’ in the early stages of a component’s development. This section explores these and how they begin to lay the groundwork for the construction of adaptive future narratives. Interviewees argued that credibility may be attained via being positively assessed by a large space body such as ESA, or by gaining government funding at an early stage. ESA was found to be an important contributor to the creation of credibility for component developments in the UK. Interviewees explained that ESA offers a variety of methods – workshops, exercises and assessments – which can be used to enhance the credibility of that component. For example, when speaking about attempting to enhance the early credibility of one particular component, an interviewee stated the following:

> *‘We invited people from all over the world to come and hear [about the component]. People from NASA, from ESA, from Russia, Japan, and allow them to ask any questions they liked. Because a lot of it is about giving and enhancing their credibility and allowing peer group review, if you like, to challenge, question, allow them to answer, and that process gives everyone more confidence. It gives us more confidence that if they’re able to answer the questions these guys*

> *are asking, they know what they're talking about, as with any new technology there's a credibility issue.'*
>
> (002, [Public, Science])

Components for space programmes (being high-risk, high-cost and high-time) may struggle to look like credible investments, particularly given public associations with the space industry explored earlier in this thesis, and ESA seeks to enhance the credibility of early-stage components that it deems appropriate to support. Once this topic became apparent, a significant number of interviewees explored the reasons they understood as being behind the importance of ESA-granted credibility, the value that this credibility had, and the processes behind the creation of that credibility. Three interviewees offered summaries of the uses of ESA in this regard:

> *'Ultimately things like the ESA science programme are a way of developing capability in ESA member states and de-risking developing technology.'*
>
> (019, [Public, Science])

> *'You get a level of credibility by going through the ESA process, and the qualification process is really rigorous, so to some extent you position the technology at a point where it's considered to be credible, and then your next step is how you transition that into the commercial world.'*
>
> (023, [Private, Science])

> *'If you do some technology and ESA thinks it's good, then the world will say it's good. Whereas if a country does it, they might say well, are they just saying that?'*
>
> (004, [Public])

These quotes show that there are a number of perceived benefits to accreditation from a body such as ESA. The first interviewee describes ESA's role as 'developing capability' in member states, i.e. assisting in the creation of components that can perform important roles in space missions by reducing the perception of risk around these new technologies. The second suggests that the importance of credibility in the space sector is more to do with 'position[ing] the technology' – removing a technology or component from blue skies research or the realm of possibility, and towards a more practical and factual suggestion that will result in use within an eventual programme. However, it is the third which points towards an important issue about the nature of authority in the space industry which is worth exploring in more depth.

Space agencies – especially multinational ones – were seen by interviewees as having the capability to make neutral assessments about space technologies, and were perceived as arbiters who can assess the purely technical aspects of space components without any political sheen. As we have seen, the ontology of outer space has shifted – at least publicly – towards one of common heritage and cooperation (Peterson, 1997) rather than competition (Ehrenfreund & Peter, 2009), and the perception of space agencies has followed suit with this change. Space agencies can no longer count on automatic, politically-backed support from state governments (Salomon, 1996) – this has led to them being seen as comparatively apolitical actors, and therefore a good source of knowledge and judgement that will not be biased by nations standing behind their own components and programmes. Equally, the loss of political influence in space agencies leaves them perceived as organizations consisting of only natural scientists and engineers free of political oversight. This gives space agencies significant discursive power to lend credibility to new components in a seemingly neutral manner. One example of the effectiveness of gaining credibility via ESA was the Skylon spaceplane programme explored in the previous chapter. During the research I interviewed a number of people responsible for the development of the components used in the programme, and they identified a number of positive outcomes that going through the ESA process had generated. One had the following to say:

> *'We've worked with ESA to commission a technology review of what [Skylon] are doing. So a two or three day engineering review, world-class experts got together under appropriate non-disclosure agreements and so on and did an assessment of the technology, and the report at the end said 'Yes, this is feasible, we can see no reason why this shouldn't work'. Now that piece of paper is worth a huge amount when you go and talk to a bank or an investor, and say the ESA – you might want one that says NASA instead because an investor might have heard of NASA [laughter] – but a global authority has said that our system makes sense, and is worthwhile, so that endorsement is worth a lot more than the money because it enables you to unlock other relationships in other directions.'*
> (011, [Public, Technology])

The quote from this interviewee identifies a number of benefits of the process and also shows several unquestioned assumptions inherent in this same process. This interviewee mentions the acquisition of 'world-class experts' who would be the ones who would get together and establish the viability or otherwise of Skylon. This lends credibility to the judgements of these bodies (Rip, 2003) by deploying claims of the expertise and experience of those carrying out the judgements (French & Raven, 1960; Hilgartner, 1990) within the apparently depoliticized space agencies. Other interviewees as well as the one quoted above said that deferring to 'expert' judgement was a key part of the early credibility process (the first part of forming an adaptive future narrative). Upon being questioned many of the interviewees dismissed the possibility of entertaining any alternatives; experts must be involved, and if not, then national preferences would be referred to instead of scientific judgement:

> *We can’t possibly be experts on everything. But what we can do is provide a link. If it’s something serious [we can] involve experts at one of our national labs, or in ESA to bring their expertise to bear on something to evaluate it, the technical credibility of something.’*
> (002, [Public, Science])
>
> *‘If you disagree with the scientific recommendation, then each and every one of us will be bringing in their national wants.’*
> (006, [Public, EO, Technology])

After this process is complete, the opinions of the *experts* become the assessment that is given out by the *body* as a whole. Although depicted as technical, the process remains firmly social (Shapin, 1995; Rammert, 1997) and generated via the interplay between the experts rallied to the consultation. The social process of deciding on the feasibility of the component amongst the experts becomes quickly inseparable from the mark of quality that the space agency as an institution gives the component, and this mark of quality is presented subsequently as a purely technical outcome. In this case the institution is ESA, but other national space agencies with equal global prestige are able to carry out the same procedure. The endorsement from a trusted and seemingly impartial authority helps to achieve a strong seal of approval that can be used by proponents of the component.

This kind of third-party accreditation was found to be an important first step in generating a compelling credibility narrative. It relies on the perception of neutrality and objectivity on the part of the agencies doing the assessing, a perception which flows from the overall depoliticizing of the space industry and the loss of unquestioned national funding for space technology. However, outside actors are not only recruited through a mark of quality from known and trusted space industry actors. Those outside the space industry may not be aware of the significance of such bodies, nor fully understand the process behind the endorsement. A key second method for recruiting those outside the space industry comes from a different form of credibility. Rather than a 'technical' assessment by a trusted industry expert body, governments – which is to say, governmental scientists and technologists – are able to lend credibility to a component themselves, a form of credibility which is focused somewhat more upon finance than technical feasibility.

6.2.2. Government Investment

The interview data showed that confidence within government circles was another important method to acquire credibility for the early stages of a component's development, and in turn contribute to that component's adaptive future narrative. Sans-Menéndez and Cabello (2000) argue that future predictions strongly influence policy choices, in this case the choice to support a component or to choose another. Interviewees echoed this perspective, stating that initial government funding and policy interest in the outcomes of a component development were important ways to attain initial credibility, instead of or as well as the use of space agency interest described in the previous section.

> *'Government investment… tends to give authority to the technology and validity to the technology that perhaps is not so prevalent in the private sector, so it's important to have the government saying basically 'Yes, we think this is a good idea and we're prepared to put some of our money into it'.'*
> (016, [Private, Technology])

> *'That argument about the confidence that the public sector getting involved gives the private sector to get involved, especially if it's risky or long-term.'*
>
> (002, [Public, Science])

These quotes suggest that government interest gives 'authority' to the technology – which is to say, a government endorsing a technology gives the technology a level of credibility as something worth taking seriously. As we shall see this form of government-given credibility is focused on a belief that funding will continue once the component has a governmental 'anchor tenant'. The interview data yielded a perception that government money signals a level of commitment that will not be suddenly withdrawn (Balogh *et al*, 2010; Balogh, 2011; etc). Such funding is seen as less reliant on 'the market' and therefore less variable or capricious. A number of interviewees elaborated upon this role that government investment makes and why it is seen as so significant. Two interviewees linked it explicitly to private money, and that government money was merely seen as a stepping stone to enable the acquisition of private finance:

> *'It's important that the public side makes a clear commitment to provide that baseline investment, because that could be used to get the private investment from the banks that you can then leverage and gear up and be able to make the later investments in the programme.'*
>
> (011, [Public, Technology])

> *'The function of state funding is to de-risk stuff to the point where the private sector can take over.'*
>
> (019, [Public, Science])

There was therefore a strong level of agreement between interviewees that some credibility for a component must be attained from elsewhere first, and this could be via state funding. Such credibility ‘de-risks’ the component and encourages private actors to invest (cf. Collins, 1998:39,42,67). However, this highlighted an uncertainty within the sector about the continuing appropriate role of the state in non-scientific space technology, and what exactly the state’s value is (Lambright, 1994) when seeking to attain credibility. All interviewees agreed the state still has a role in lending early credibility to a component or programme and potentially serving as an aid to secure further funding, but there was uncertainty over where the line should or could be drawn between government and private money:

> *‘There’s always going to be a role for the state in there, but it’s hard to understand when that role finishes… and [when to] be good capitalists and know when to give it over to the market.’*
> (011, [Public, Technology])

Interviewees argued that space technology benefits from early governmental funding or endorsement, but there was an assumption that at the first possible moment the state could ‘pull out’ from the component or programme and allow it to be fully commercialized, it should do so. No longer is the state praised as the source of near-unlimited funding, but rather merely tolerated as a necessary method by which early credibility may be attained. Even this instrumental role of government (Collins, 1998:41) in the space industry has not just declined, but in some cases may be actively positioned as undesirable. Interviewees had little to say on whether government interest was used instead of third-party accreditation from bodies such as ESA or in addition to that accreditation, but it is likely that most components will pursue both routes, especially given that both appeared well-established within the space sector as equally valuable methods to acquire early credibility. Irrespective of the different values interviewees placed on the role of the state and how welcome the state was within the space industry, all nevertheless agreed that a major practical benefit of government money at an early stage in a component development was to ‘unlock’ significant quantities of private money down the line:

> *‘Once you have government investment, the cost of borrowing and the risk associated with it disappears. This is a safe bet, this is as good as a government bond, and suddenly you can borrow money at a much better rate than if you said 'I’ve got this long-term procurement contract which might work out', so at that point you can re-finance and get a much better deal.’*
> (011, [Public, Technology])

> *‘[Government investment] provides a signal to other investors that this is a technology we need to look at.’*
> (016, [Private, Technology])

> *‘Quite often government coming in at an early stage of a project and funding maybe 20% of it just gives huge amounts of credibility. There have been other cases where the government has been the anchor tenant, and [the project would not] have been viable otherwise because that level of investment could not have happened without an anchor tenant.’*
> (019, [Public, Science])

A clear network of credibility creation emerges here. A government may commission an organization (or use an internal government equivalent) to carry out an assessment, which is then endorsed by that government as its opinion, and this endorsement is then used as credibility to show other actors (e.g. Bonometti *et al*, 1991). In this model the actors subsequently brought into the component development will presumably check over the results of whatever initial study was carried out by the government, but it remains the *government’s* faith in the assessment which recruits them, not the actual assessment itself. This merits a little clarification. This is *not* to imply that governments have not carried out the same level of assessment as a space agency might and that they are simply investing or supporting something for political reasons, but rather that it is the government support – crucially perceived as being one step removed from any initial scientific/technological assessment – which lends credibility. Outside actors assume that the government(s) in question will have carried out their own internal assessment and vetting process, and it is this belief that *governments* will not invest in hopeless technologies which lends the credibility. The government's word is what matters, not the specifics of the test that gave the government the confidence to give their word. The belief in the government's *ability* to carry out a good assessment is what is trusted rather than the assessment itself. As two interviewees put it:

> *'A bit of overnight investment will encourage the private sector because it will give them confidence because the private sector know the government's not going to put money into projects that just won't work, as we don't have money like that at the moment.'*
> (001, [Public, Engagement])

> *'[The TSB is] traditionally I guess a little bit wary of endorsing people necessarily, particularly new people, but we can make a big difference if we do that.'*
> (011, [Public, Technology])

The opinion in the first quote above that the current era of austerity has an impact on space funding (Sheldon, 2010; Akiwate *et al*, 2012) is interesting to note in several ways. It ties into the discourse apparent throughout this section that much of the space industry is now seen as depoliticized (Salomon, 1996; de Montluc, 2009) and standing on its own merits. As there is no longer an expectation of government financial backing for space technology, this reinforces the belief that all space technology which receives funding and interest must have demonstrated its technical, scientific or financial merit, rather than meeting social or political goals. In turn this lends more credence to any component that gets past its earliest stages.

Thus, the data pointed towards two methods for attaining credibility in the early stages of a component development, which will later be used to construct an adaptive future narrative. Interviewees argued that credibility may be attained via a seal of approval from an acknowledged body, generally a space agency; or by getting a government to invest some early money which will then reassure private investors – some of whom may not know much about the space sector – about the viability of the proposed component. However, this early credibility is not sufficient to see a component through from inception to completion, nor enough to support an adaptive future narrative on its own. As the introduction to this chapter noted, an adaptive future narrative relies on many 'layers' of credibility, of which this early interest in a component is only the first. As the research progressed it became clear that there were a number of other systems in place to ensure that credibility was maintained throughout a component development. As we shall see, upon completing the technical parts of the development, these forms of credibility then add up to support an adaptive future narrative. Whereas these early forms of credibility make a space component appear viable in its earliest stages and thereby help to build the necessary support base, other forms later in the process were found to be designed for different purposes.

These later types of credibility were identified in the research data as belonging to two other 'phases' of attaining credibility. 'Technical Development' credibility is created by the use of 'Technology Readiness Levels', or TRLs, a structure of discursive statements designed to unambiguously quantify the 'stage' a technology is at, in keeping with a linear model of technological development (cf. Bijker & Law, 1997:17). This is related to the creation of tests and standardized testing regimes in the space industry. Subsequently, the final stage of ‘launch credibility’ consists of two parts – ‘qualification’, which is a similar process to the attainment of early credibility described here, and the subsequent acquisition of ‘flight heritage’. Many companies who engage in space programmes refuse to use equipment or satellites which have not already been tested in space, leading to the obvious question – how is anything new ever launched? To answer this question there is a complex selection of processes which qualify new equipment for flight that will be assessed towards the end of this chapter. The next section will therefore explore technical development credibility, the second of these three ‘phases’ of credibility used in an adaptive future narrative.

6.3. Technical Development Credibility

6.3.1. Technology Readiness Levels 1-3

Early on in the research a number of interviewees introduced the concept of the ‘TRL’ – the *Technology Readiness Level* – which is a model of technology development used in a number of high-risk industries (Krois *et al,* 2003; Sanchez, 2011). This section explores this concept and the work it does to generate a narrative of credibility after the initial acquisition of government or agency support described in the previous section. TRLs are numbers assigned by the component’s developers (not by outside bodies) to their components, and are designed to describe what ‘stage’ in development a component is at. This is a system that assigns credibility throughout a component’s development, and the evidence of carrying out this process is later used to create adaptive future narratives. As we will see, it became clear from the interview data that these serve a large number of rhetorical goals throughout the process of a technology’s development, and depending on what the assigned number is they are used to recruit a range of different actors at different stages in the process. Upon the component's conclusion, they are then used to help form an adaptive future narrative by presenting a strong credibility narrative for the quality and oversight of the component's development. The relative positions of the nine TRL levels within this system were described as follows by one interviewee:

> *'TRL 1 is when you're sat in the bath and have an idea, and TRL 9 is when the thing is wheeled out and flown.'*
> (014, [Private, Technology])

Within this TRLs break down into a number of categories which adhere to a very linear model of technological progression. As we shall see, the concept of TRLs rest upon a number of assumptions which themselves do significant work in convincing others about the accuracy (and efficacy) of the TRL system. Foremost amongst these assumptions are the beliefs that technological development is linear, and does not go 'backwards' at any point; that there are no social influences in the progression of a technology; that the points between the conception of a technology and its deployment in a working satellite or other technology can be quantified; and lastly that a given point (on the 1-9 scale) can be usefully compared between wholly disparate technologies or systems.

Interviewees argued that TRLs 1-3 are roughly akin to 'research' and 'creating plausibility' for a component (Collins, 1992:150), 4-6 are 'testing', and whilst there is no single word that best describes the concepts interviewees described to me as being appropriate to 7-9, 'optimization', 'taking to market' or 'implementation' all describe aspects of the final three TRL levels. Before looking at the kind of work that the TRL concept does, it is first important to establish what exactly each of these categories entails and how the external presentation of the component changes significantly as it 'progresses' through TRLs. A significant number of interviewees gave their definitions of each of the three categories of TRL levels (1-3, 4-6, 7-9) and the outcomes of these discussions are summarized here and in the following two sections. To begin with, the levels of 1 to 3 are best summarized as being ‘research’, or proof of concept.

> *‘1-3 [are] for initial ideas and you just want to produce that first proof of concept, generally that can be a lot cheaper, so you tend to find quite a bit of money around for those early-stage projects.’*
> (025, [Private, Technology])

> *‘If it’s 1-3 its ready in the design bread-boarding phase, basic research.’*
> (004, [Public])

> *‘TRLs 2-3-4 you’re clearly still establishing the principles of how to make the thing or establish it works.’*
> (014, [Private, Technology])

The three above show a broad level of agreement across my interviewees about the role of the early TRL levels, although the third interviewee defines these stages slightly differently. The first interviewee states there is ‘quite a bit of money’ at these early stages where the component is largely hypothetical, although this comment does seem to contrast somewhat with the earlier comments about acquiring early-stage component investment. This chapter has showed that such money is primarily from governments for the majority of space components and programmes (bodies that accredit, like ESA, do not necessarily always fund), though it will also be from private actors for more commercial technologies such as the creation of routine satellite components. A component development at this point will only be able to recruit very specific kinds of actor and in very certain ways – industries putting in small investments in the hopes of large returns, or government agencies wanting to push new components. Assigning TRL numbers at this stage means denoting that a component is at a very early stage, and should be treated by other actors as such. Too high a TRL number at this point may generate false hope, but a low TRL assessment at this stage fails to convey a level of credibility and trust that the component is viable to subsequent development.

6.3.2. Technology Readiness Levels 4-6

Interviewees contended that the area between TRLs 4 and 6 is seen as the point at which most of the 'testing' of a component takes place. One interviewee broke this down into two different categories that applied for different kinds of technologies - it was either a matter of moving abstract 'research' into the market and ensuring it will work, or taking a 'good idea' into a real-world application, albeit not necessarily a commercial one:

> *'[TRL] 4-5-6 [is] where we're trying to get people to either take blue sky research into the commercial environment, or take what's been demonstrated as a good idea and the feasibility level into real-world application.'*
> (011, [Public, Technology])

> *'If it's 4-6 it's proven but needs to be developed into a mission.'*
> (004, [Public])

From these two quotes the question of what exactly has 'been proven' or 'demonstrated' is a difficult one to isolate. As we shall see shortly, those interviewed about TRLs 7-9 suggested that 4-6 was the point at which the component was 'proven', but in these examples it is levels 1-3 which were supposedly concerned with the matter of proof and the viability of the component. This highlights a vagueness inherent in these levels – different actors, even within the space industry, have differing understandings of what each bracket of levels is actually for. When viewed from the perspective of the adaptive future narratives created afterwards, it is the traversing of the TRL process that is retrospectively more important than ensuring all relevant actors agree on what precisely each level actually meant during the process itself. Between TRLs 4 and 6, the best way to present how most interviewees understood these levels is as an intensive testing regime:

> *'TRL 4-5-6 is designed to take up to that qualified engineering, equipment you know will survive and do the job.'*
> (022, [Private, Technology, Comms])

> *'[During TRL 4] you're looking at £1000, £1500 a day, and your test campaign may last a week. But of course things will go wrong, you have to tweak, go back, then thermal vacuum chamber, radiation chamber… so it's not unusual to have a six-figure cost for your testing campaign. It is a very expensive build to get across that nasty bit.'*
> (025, [Private, Technology])

This emphasis on *testing* will be returned to shortly. Whereas TRLs 1-3 are used to group what many consider to be 'blue skies' research, initial experiments or brainstorming, these TRLs in the 4-6 range are used to quantify the point in the testing regime the component is at. Although one might think that assignment of TRLs happens after testing – as testing continues and the component gathers credibility, the TRL level will rise – in some ways the reverse is true. As TRLs go up different forms of testing are required, and upon leaving TRL 6 a minimum of further testing is expected. Although TRLs were presented by interviewees as being entirely *responsive* to the linear development of a component, there is actually a reciprocal relationship between the two. Several forms of test explored later in this chapter can sometimes be less 'rational' than the discourse of TRL development might suggest, and when seen in this light this period serves to *define the limits on testing* as well as being responsive to the outcomes of those tests. Those behind a component know that if a testing regime in this segment lasts too long it will raise questions about the credibility of the component, for the TRL model itself assumes unproblematic linear progress, so there is a driver for TRLs to advance irrespective of the level of success seen in the testing regime. This is not to imply the two are not related, for they undoubtedly are, but that there is an inevitable level of ambiguity in the way social actors – engineers, technologists, or managers – choose when to 'advance' a component along the TRL spectrum. As with testing more generally, the movement along the quantified chart of TRLs serves many goals of reassurance and a clear signal of progress, and this is an additional pressure to the component development. A clear narrative of progression must be present for the successful creation of an adaptive future narrative – a component that was effectively and cleanly developed will be more appealing than one which encountered multiple issues during the TRL process.

In testing something is at stake – the claims that the component in question will work, and therefore the funding, jobs or prestige of those bound up with that component – so expectations are built around certain outcomes expected from that test (Pinch, 1993). As a technology proceeds through the Technology Readiness Levels, between 4-6 more than between 1-3, the component appears increasingly *credible* as tests are passed or TRLs are advanced. This both continues the component and continues to lay the groundwork for the adaptive future narrative that will be developed upon concluding the TRL system. When the component has reached the ninth TRL, the evidence of its passing through the prior levels will be seen to form an important and integral part of the adaptive future narrative its designers will later propose.

6.3.3. Technology Readiness Levels 7-9

TRLs 7-9 are those that interviewees seemed to find hardest to describe. It seemed to consist of everything between 'testing' (TRLs 4-6) and the preparation for launch of the actual component on-board a satellite. In many ways compressing the social and political dynamics inherent in such a process to a numerical signifier is an even greater feat of reductionism than earlier TRLs. The TRL number becomes an object that does not require constant maintenance or upkeep, and in this case those who control it are managing how the component is presented to those outside the component development. The use of this is particularly apparent when one considers the requisite political interactions behind securing launch; the national or international dimensions to any space programme the component might be launched as a part of; questions over subsequent financial investment or insurance; and much more (Walker, 1993; Sadeh, 2005; Spaceflightnow, 2015). The TRL stages prior to this point may have kept the technology broadly confined to the lab or the testing arena – although many external non-technical actors will have been involved – but from this point onwards a wide range of non-technical actors come to occupy the foreground, for whom the space industry will strive to present clear reductionist numerical categorizations rather than contested technologies. In the case of these final stages in the TRL system, these numerical categorizations meant improving and optimizing the component:

> *'TRL 6-7-8-9 you're clearly in those sort of areas where what you're investigating is a better design.'*
> (014, [Private, Technology])

> *'7 onwards you know it can be done quite easily.'*
> (004, [Public])

These two quotes both give a similar understanding – that these final TRLs are about refining and improving the system or technology once one ‘knows’ that it will work (as a result of passing successfully through the middle TRLs). The fragility of this supposed certainty will be returned to shortly, but it is interesting to note the position these levels occupy in terms of knowledge. In some ways these levels thus present the most linear and most simplistic part of the TRL process – there is no suggestion of further obstacles to overcome, but rather merely things to be improved and built up within a clear framework of linear technological improvement. The suggestion that these levels are concerned just with improving and optimizing the system points to a belief that the component could actually be used at *any point from the end of TRL 6 onwards*. It might not be optimized, but it will be functional.

By placing TRL 6 point at two-thirds of the way through the process, rather than at the end, it implies that optimizing and improving is an equally *inevitable* part of the development of any given component. Making the ‘improvement’ part of this linear technological process simply part of the main body of the development process, rather than a different or subsequent process, is an interesting and clever discursive move by engineers who have developed the TRL model to boost the subsequent perception of credibility. It also ensures the existence of a lengthier credibility narrative. Were the TRL process one that concluded upon getting a workable version of the technology (at around TRL 6), it may be trickier to persuade outside actors to continue investment and support whilst engineers optimize and improve the product (up to TRL 9). It would also reduce the length of employment for any engineers taking part in the component’s development. However, by placing optimization as part of the TRL system it makes this process (TRLs 7-9) appear to be an integral part – who would be willing to launch a high-risk high-cost product when it does not seem to be ‘finished’? Launching at ‘TRL 6’ appears eminently risky when that is only two-thirds of the way up the scale that all actors adhere to, whereas were TRL 6 the highest TRL, launch at that point might seem quite reasonable. In presenting the TRL model in this way the concept of the ‘finished product’ is renegotiated in a manner which assists with maintaining funding and support for a much longer period. It also creates a longer narrative which will be used to support the adaptive future narrative that these systems of credibility support, emphasizing in more detail the lengths to which the component was not just tested, but improved and optimized.

6.3.4. Technology Readiness Level Objectivity and Linearity

Having established what the different groups of TRLs were, and the kinds of ‘stages’ in which they categorized technologies, I asked my interviewees questions about what the functions of TRLs were and how they were utilized. The below quote from interviewee #013 answers both of these questions clearly, and highlights the two important factors for the subsequent discussion – the claimed use of TRLs as methods to convey information about components between different actors who may not speak the same technical language or have the same understanding of the technology, and as seemingly objective metrics that are simple to apply and simple to understand. This section will explore a number of comments from interviewees on these two themes, and the uses to which TRLs are put in the formation of a credible adaptive future narrative for the component.

> *‘If somebody comes to me with a project or a piece of technology, straight away I can say ‘Well, what TRL is it?’, and there are comprehensive definitions of TRLs on the web so you can see all that, so you can determine it, then depending on what the TRL is… it lets you know where you are on the development scale as well, so what your challenges are.’*
>
> (013, [Public, Private, Technology, Comms])

One particular sentence of this quote is very important to show the kinds of rhetoric that have built up around the use of TRLs. #013 stated that 'comprehensive definitions of TRLs [are] on the web so you can see all that, *so you can determine it*'. There is actually no mention of expertise here (though presumably a basic level of familiarity with the technology is assumed) – rather this posits a simple two-stage process where someone aiming to assess a technology consults the guidelines, looks at the technology, and thus comes to the *only appropriate conclusion* about the level of the technology. Those from communication or broadcast companies, for example, who are unaware of the internal workings of a technology, are instead presented with a simplified version of the technology where all its complexities or uncertainties (Wynne, 2002) are reduced down to a single number. They trust in the black box handed to them due to it being a simplified quantitative assessment; due to it being measured by scientists and engineers with a close knowledge of the component in question; and due to the presentation of TRLs as clearly defined intervals in the formalized temporal process of a component's development.

Actors external to the space industry are thus unlikely to challenge this assessment. Even if they would wish to, the blackness of the black box – an entire technology or component reduced to a single number – makes it very difficult to unpick, given the degree of trust given to the 'objective' assessments of those who assign the TRL numbers. This simplification thus meets a simple political goal (cf. Hilgartner, 1990) – in this case recruiting actors into a component development. Future predictions that promise technological development are difficult to reject if actors operate within an ontological framework where such development is an unproblematic and linear task (van Lente, 2000), such as the TRL system, and where any social complexity or conflict within development is well-hidden (Borup *et al*, 2006:292). This promotion of a deterministic model of technology is part of the ‘repertoire of promises and expectations and strategies’ (Jørgensen *et al*, 2009:84) for actors wishing to promote the success of their components. The TRL level thus acts as a system for compressing a complex piece of contested technology-in-development into a simple numerical figure. This quantification was something mentioned by a number of other interviewees who also elaborated on the process of assigning TRLs to technologies and the effect that assigning a TRL can have to close off debate:

> *‘TRLs are a great way to quantify and communicate in an engineering term exactly the status of your product development, otherwise how can I tell you how mature my technology is? How can you take away an understanding from me of where I am in my development cycle? So it’s a great way of quantifying exactly and unambiguously the state of my technology.’*
> (025, [Private, Technology])

> *‘It’s well-defined, you’ve been on the Internet, you’ve seen it, it’s well-defined, I mean, nothing’s black and white – you might get people saying 'Well, we’re half-way between 4 and 5’ – but that’s ok.’*
> (013, [Public, Private, Technology, Comms])

> *‘If we start getting a disagreement over whether it’s 3 or 4, let’s end the discussion and look at the ESA definition. It’s very clear and very simple to follow.’*
> (025, [Private, Technology])

This is a crucial point. There is nothing mentioned in these descriptions about interpreting the TRL definitions, or doing a thorough assessment of the technology or system to decide what level it lies at – rather, the definition of TRLs is ‘clear’, ‘simple’, ‘exact’, ‘unambiguous’ and ‘well-defined', and will immediately 'end the discussion' if any debate over a TRL level threatens to upset a component's development. The complexity of the technology is reduced to the straightforward act of reading some guidelines and quickly and easily applying them. Interestingly, some examples of the TRL process are actually carried out in a way specifically designed to seemingly remove any social interaction. The version used by the US Air Force includes a 'TRL Calculator' – this is a set of questions implemented in Microsoft Excel which, when filled in, 'outputs' the TRL of the technology according to the answers given to the questions (Nolte, 2003). This once more hides the social aspects that went into the creation of the software package, leaving instead just a selection of inputs (the answers to the questions) and a single output (the TRL number).

Additionally, the first quote by #025 raised another important issue when they asked 'otherwise how I can tell you how *mature* my technology is?'. The use of the term *mature* is a clear connection to the linear temporal model of technology progression that TRLs reflect, but the question they posed nevertheless shows awareness of the difficulty in changing tacit knowledge into a language that those outside the space industry have experience with. Tacit knowledge is 'practical intuition and a developed 'engineering gaze'' (Sørensen & Levold, 1992:20) which exists within technological industries (Hamlin, 1992). This consists of information, concepts and understandings of a technology that have been accrued and developed over time within the industry in question. What distinguishes tacit knowledge from more codified forms of knowledge is that tacit knowledge is difficult to transfer outside an industry no matter how accurate and detailed an account is given to external actors (Kenney & Patton, 2005). The seminal study of this phenomenon is that of Collins (1974), who explored the difficulty in spreading the knowledge of how to construct 'TEA lasers' outside the epistemic community that originally developed them. Tacit knowledge can make it challenging to convey an understanding of a sophisticated technology between technical and non-technical actors (Rosenberg *et al*, 1992:4), and the associated technical knowledge splits those 'who speak the language of machinery' (Redfield, 1996:267) from those who don't, and is hard to acquire without any previous familiarity with the area.

It has been argued that tacit knowledge may be higher in more complex and sophisticated technologies (like the space industry) than in more ordinary and mundane equivalents (Burgel & Murray, 2000). Those in the UKSA and other institutions whose employees were interviewed will presumably possess such knowledge, whilst those outside the space industry will not. From this perspective we can see that TRLs are also designed to quantify this seemingly unquantifiable concept. They seek to translate tacit knowledge of 'engineering judgements' and the like into a figure, which – to return to the above quotes – demonstrates the 'maturity' of a component. Actors must be convinced of both the accuracy of the TRL system in assessing this concept of 'maturity', and in turn trust that this is a reasonable and accurate translation of tacit knowledge for consumers beyond the space industry. A component which is classified as TRL 9 is conveying that the technical opinion of the space industry is that this component is ready for use, and therefore credible. TRLs are *presented* as a method of translating tacit knowledge into a form which other actors can use – 'how I can tell you how *mature* my technology is?' (my emphasis) – and in doing so only offer these other actors a black boxed perspective of the technology. Figure 1, below, shows an example of such a black-boxing TRL system:

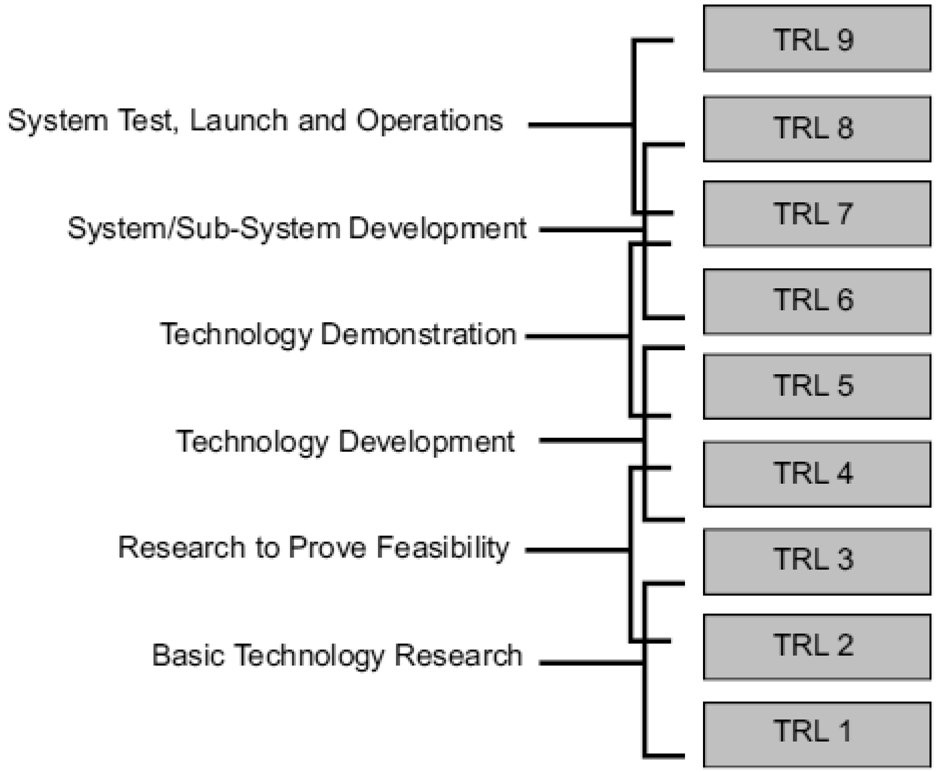

Figure 1. Illustrative Chart of Technology Readiness Levels. Example produced by Parliament.uk, available at http://www.publications.parliament.uk/pa/ld200910/ldselect/ldsctech/104/9121507.htm.

To summarize: TRLs offer a linear and unproblematic model of technological development as a method for making a new component appear credible. They are designed to redefine a component from an abstract concept which has gained interest from governments or third-party bodies, into a technology which is tested, trusted, and has been improved and optimized to a high standard. TRLs are not open to debate from outside the space industry and are presented as being a clear and obvious translation of technical and tacit knowledge. Any component which achieves the highest TRL level will be one that is then considered highly credible, having passed all the tests and trials that were required for it to reach that point. TRL 9 conveys a message that a component is 'ready to use', and that is the core of what an adaptive future narrative claims: that the component is immediately, and *always*, ready for use. As with all the forms of credibility explored in this chapter, a component being at TRL 9 combined with the evidence of that component having climbed up the TRL scale are both important for creating a narrative that sells the long-term value of that component.

6.3.5. The Testing Process

We should at this point return to the middle TRLs (4-6) to examine more closely the processes of testing and the 'sub-industry' within the space industry that has arisen to test space components. Whilst the examination of TRLs 1-3 showed that these levels are designed to denote the shift from 'research' towards a component that merits testing, and TRLs 7-9 were found to be concerned with optimization and iterative improvement on a component that has been 'proven' to work, far more data was gathered from interviewees on these middle levels which are focused around the concept of testing. A range of interviewees commented in detail about the processes of testing when exploring these central TRLs (4-6), and described testing as an integral and constitutive part of creating successful components. As such this section will explore the use of testing as a method of credibility attainment and therefore its subsequent contribution to a successful adaptive future narrative, and examine the difference identified in the research between 'internal' and 'external' debates over testing regimes.

To begin, one interviewee emphasized the importance in the space industry of 'proving' that a component will work after launch:

> *'If you think about it it's quite logical. Fundamentally the [large space companies] deliver to operators and operators provide a service, so the last thing operators want is to put something up that*

> *will fail. So they will only work with things that are proven, so the Catch 22 is: how do you ever prove something is going to provide the reliability?'*
> (023, [Private, Science])

The primary way in which this is 'proven' was found to be via the use of testing. Much like other parts of the space industry, testing to generate credibility also requires significant investment, albeit in a different model from that seen before. Much of the financial investment that goes into testing will have been acquired via earlier systems of credibility-acquisition explored earlier in this chapter. As with other steps in the process, testing and examination regimes are required in order to move the component 'forward' and subsequently attain further financial investment by displaying the results of successful tests. Three interviewees argued that the testing process itself, which happens mainly in the central TRLs, is a very expensive process, significantly more so than the actual manufacturing costs behind whatever components are being tested:

> *'[The] James Webb [Telescope] is the perfect example where it has so many different mechanisms and devices that have not been done before, that's what drives the cost up because you have to test it and test it and test it.'*
> (002, [Public, Science])

> *'You put vast amounts of money into designing it so it doesn't go wrong when it's up there.'*
> (003, [Public, Technology])

> *'The fundamental cost of those components is very cheap, but as I say it's all the qualification and testing that really drives the cost up.'*
> (017, [Private, Technology])

As we have seen in the previous chapter of this thesis (5.3.3), the inability to test a component or satellite in a space-like environment is a serious issue for the space sector. As it cannot be tested in a space environment beforehand, the argument goes, and since it cannot be retrieved, it must be tested to as high a level as possible before launch, and this is a costly process:

> *'It's a bit like Boeing building the 787, rolling it out, putting it to the end of the runway, and taking it to Tokyo on the first flight. Every time you're with a spacecraft you do that – every time it's impossible to test the whole thing on the ground because it's such a different environment. So the building, testing, building, testing you do with spacecraft is what costs the money.'*
> (002, [Public, Science])

> *'You can buy a lot of the parts you need to make a satellite out of a Radio Spares catalogue, and to take them all up it wouldn't cost that much, but in reality to make them space qualified the cost goes up by about a factor of a thousand, literally.'*
> (017, [Private, Technology])

These costs may be met by government (Vedda, 2002), by private industry such as the communications sector (Slotten, 2002), 'private spaceflight' initiatives (von der Dunk, 2011) or scientific bodies (Elzinga, 2004). Components which lack an appropriate level of testing will likely never be flown, but any process of testing them is still lengthy and expensive. However, regardless of how much money is spent or where the money is sourced, there is nevertheless a point beyond which a space technology cannot be fully tested (and therefore fully 'proven') before it is launched and used *in situ*. At some point the testing regime must end, and trust must be placed in the component to work once deployed in the space environment. In order to mitigate this issue of residual uncertainty, the processes of testing that have been developed for the space industry are designed to ‘mirror’ the conditions a satellite or component will experience during launch and once in space.

Data from a number of interviewees suggested that this attempted mirroring of space conditions can be isolated into three central components, all of which are required for a credible testing regime. The first is testing in vacuum conditions; the second is testing for the potentially high temperatures of launch and the guaranteed low temperatures of being deployed in space; and the third is the ‘vibration and shock’, as in one of the quotes below, that will be experienced during launch. Several interviewees called this three-part testing regime the ‘shake-and-bake’ tests, and explained that although the instrumentation with which the results are measured may have become more accurate or refined, the ‘fundamental’ test has not been altered significantly since the early days of the space industry. In this way rules have emerged from practices and assumptions which have later been codified (Wynne, 1988) into assumptions of what a thorough testing regime should look like, and therefore what an interested customer will look for in an adaptive future narrative for a credible component:

> *‘You go through an extensive test regime anyway so all of our equipment is temperature cycled in vacuum, it goes through a simulated launch environment in terms of vibration and shock, and it goes through the same at a satellite level before it’s launched.’*
> (026, [Private])

> *‘We’ve got better at testing and controlling the test environment, but the fundamental test of shaking something vigorously hasn’t changed [laugh].’*
> (025, [Private, Technology])

These shake-and-bake tests are an example of what Trevor Pinch (1993:29) identifies as the establishment of a 'similarity relationship' – that the state of affairs surrounding a test is identical in all important ways to the state of affairs surrounding the use of the technology *in situ*. The dominant discourse around testing is that a satellite in space will undergo *a, b* and *c,* and therefore we must test for these things. Pinch argues instead that this relationship of similarity is not something which is inherently 'out there', but rather that it rests upon a social convention which agrees these two things are similar. Testing is therefore not designed to develop the fundamentals of the technology nor to pay for the launch itself, but in effect to pay for the component to be redefined from one that is new and unknown to one that is known, quantified and well-tested. It changes the component from something that *might* work into something that *will* work. The component cannot be tested in space beforehand, so a claim must be *socially constructed* that the testing done on the ground is equivalent to that which it will encounter after launch – a claim which will be essential to the construction of its adaptive future narrative, and to it progressing through the TRL system. After this redefinition is complete, the component is then 'proven'.

Other interviewees, although agreeing that the shake-and-bake tests are appropriate and relevant for the space industry, did however acknowledge a change in the *specifics* of the tests or the possibility for testing regimes to be debated:

> *'We have a lot of standards we work to in the industry, and these standards are viewed from time to time by panels of experts, but we have a standard we apply. The process is rigorous and pretty constant. The technology may shift and the requirements may change, but the methodology stays the same.'*
> (021, [Public, Science])

> *'Has testing stayed the same? It tends to have evolved relatively slowly.'*
>
> (026, [Private])

> *'The fundamental shake-and-bake tests haven't changed, but the way we test them has been refined now we understand the space environment a bit better. So the battle of any customer is that they say we want this product with all these tests, but we only want to pay x. And we say, 'Fascinating, but you can't afford that. What you'll get for x is a much reduced test campaign'. Then you argue different models for testing.'*
>
> (025, [Private, Technology])

> *'A customer might say we'll want a 50% margin on the vibration campaign, but it passed at 40%, and we know the actual launch will be 40% below that. So we say 'Ok, it failed the original test, but maybe we're being overzealous. Let's scale back and revise that test limit and it still passes and we've still got a margin.' Was it the margin we were originally looking for? No. Is it still good enough? Probably.'*
>
> (025, [Private, Technology])

These quotes identify two related but distinct points. The first and second state that the standards *within* the space industry have shifted over time, whilst the third and fourth state that debate over testing between the space industry and those *outside* is debated. This difference is important to explore. For those within the space industry standards are expected to 'evolve' and change over time, but maintain the same basic 'methodology' – which is to say, 'shake-and-bake' remains the dominant paradigm but the exact methods by which this is performed, and measured, may shift over time. The use of the terms 'refined' and 'evolved', and the claim that such refinement is due to ‘understand[ing] the space environment better’, make it clear this development of testing regimes is not seen as something that demonstrates a level of uncertainty or debate in testing, but rather a linear and unproblematic model where testing regimes are constantly *improved* as more is learned about space and the space industry develops.

External to the space industry, meanwhile, these quotes show that the process of *agreeing on the severity of the test* – even if the testing itself remains within the shake-and-bake regime – is a social process. The nature of the test (vibration, temperature, and also vacuum) is seen as relatively fixed (albeit ‘evolving’) but the intensity of the testing regime is one that is contested according to cost, time, requirements and a number of other metrics. This draws a line between two aspects of the testing regime – the methodology, and the intensity – which is a socially produced distinction. It is considered acceptable to reduce the intensity of a testing regime in debate with a particular customer, but it is not acceptable to change the method of the testing regime, so ingrained have the shake-and-bake tests become. The specifics of given testing regimes are therefore determined by humans, not technical necessities (Douglas, 2010). This creates ‘overall’ testing concepts whose nature and meaning gradually shift as time passes, and also results in specific testing regimes being based upon the requirements and expectations of the users (Pinch, 1993), which will consequently affect the ‘level of testing’ given to the eventual product (Sismondo, 2010:10).

We can therefore see that the nature of the test is socially contested, and the claim that the test is ‘similar’ to the space environment is *also* socially constructed. Space industry testing regimes are constructed both to emphasize that the test has been appropriate and diligent, and to give confidence that diligently conducted test will deliver a component which will function correctly in the space environment. Despite this established similarity relationship, testing ‘methods’ change over time and testing ‘intensities’ are debatable between involved actors. On the one hand the assessments are believed to be non-social procedures that follow a clear set of guidelines and are only ever ‘improved’ as time goes by, but on the other hand those within the space industry accept that the *specific* set of standards applied for a given test are debated and contested for each individual component and gradually shift as a whole. The discursive separation between the two reflects the way in which the space industry is structured; those *within* the space sector are able to adjust and refine the testing criteria, whilst those *outside* the space sector are presented with just the most contemporary up-to-date regimes, reassurances that different levels of regime are equally valid (for different components), and a belief that as testing regimes ‘improve’ they do so linearly towards ‘better’ testing regimes, a process which masks whatever debates go on within the space sector about these testing regimes. These debates are only visible within the space industry, and when testing debates occur outside the space industry, the debate is presented in a very specific way. Testing debates with outside actors (as #025 states) are presented as a debate over a ‘greater’ or ‘lesser’ testing regime, *not* as a debate over the *nature* of the testing regime itself. In this way the internal evolution of testing regimes is understood as being logical and scientific, whilst in debates with outside actors the testing regimes are presented as being fixed and unchanging, and outside actors simply debate how much they are willing to pay for. No outside actor debates the nature of the regimes (as the internal actors seemingly do).

Such rules for testing and accruing credibility in this phase are therefore socially constructed by the experts who define them. As Law (1987:120) puts it, testing involves the ‘construction of a background against which to measure success’. Both the background and the metrics of the test are negotiated to reflect the individual customer’s requirements whilst also ensuring that testing diligence is visible as ‘evidence’ to support the component’s future use. The component will only ever be said to function correctly when it behaves 'according to the rules' set out for its functionality (Rammert, 1997:176), rules which are socially determined according to the space industry's internal testing outlook combined with the external needs of any non-space actors. Collins & Pinch (1998, 7-29) echo this, arguing via their examination of Patriot missile batteries in the 1991 Gulf War that any effort at measuring effectiveness is a social activity. Any arbitration on the successful or failed functioning of a technology is firmly social, and this social activity is carried out entirely *within* the space sector in order to enhance component credibility to those viewing from the outside. Debates with those outside the space industry are only about how 'much' testing should be done, not 'what' form of testing is appropriate.

However, a few interviewees also argued that these internal debates over testing are not just a linear progression towards 'refined' testing, but that even internal space industry testing regimes could be deeply arbitrary, and designed more to meet an expectation of testing standards for external actors than improve the space industry's own technical diligence. It is this *expectation* of standards which we next examine in the final section on TRLs and testing regimes, in order to understand how standards combine with testing to socially construct strong claims of credibility.

6.3.6. Standards and Margins

We have now examined much of what interviewees understood as taking place within the 'technical development' stage of a component – initial investment has been acquired and the component is deemed credible for this early investment, and the component is progressing up the TRL scale. As we have seen, much of this is reliant on the testing regime carried out in the centre of this process. However, a test requires a standard to test against. Several interviewees commented on the creation and management of these standards. In addition to those in the previous section who acknowledged that the metrics by which testing is carried out have changed as time has passed, and that the use of these metrics is debated between relevant actors, other interviewees went further and argued that the nature of the tests may be quite arbitrary even within the space industry, or that testing standards are more concerned with meeting the *expectation* of a good test than an actual metric of technical performance. This section explores the variation within standards and margins discovered in the research, and the use of standards as a 'public act' to maintain the perception of objectivity that testing regimes provide, and therefore the credibility they can bestow.

One interviewee acknowledged the fluidity of testing standards when discussing 'ECSS', and another mentioned the nature of the *expectations* attached to this testing regime. ECSS is the 'European Cooperation for Space Standardization', an organization which works to create and improve standards in the space sector, and publishes documents which outline standards that ESA contractors and associated actors are expected to adhere to. Talking about ECSS, one interviewee offered a comment close to the official line and another emphasized the importance of ECSS:

> *'There's something called ECSS which is component standardization and is used to define how a particular electronic component might go through a certain level of testing.'*
> (026, [Private])

> *'Invariably you make reference to ECSS, and customers will expect you to mention ECSS as the test standard.'*
> (025, [Private, Technology])

However, another hinted towards the level of debate, confusion and uncertainty involved in this same standardization:

> *'I had the misfortune to be involved in the European Standards debate over ECSS. A truly mind-boggling exercise.'*
> (019, [Public, Science])

As interviewee #025 stated, 'customers will expect you to mention ECSS as the 'test standard'', whilst #026 emphasizes the use of ECSS for 'component standardization' in relation to testing regimes. However, the candid quote from #019 rather undermines this emphasis on the use of ECSS as a *standard*, suggesting that the process of developing it was far from the simple and scientized step-by-step 'refinement' of a testing regime that earlier interviewees mentioned. It clearly highlights that setting standards is not the straightforward process that most other interviewees described. This allows us to see that ECSS and other similar testing standards are *expectations* (as noted explicitly by #025) – customers expect a space-ready component to adhere to industry standards. In their examination of the 'sociology of expectations', Borup *et al* (2006:289) argue that expectations are 'constitutive' or 'performative' in that they are able to attract the interest of useful allies and 'broker relations'. A space component that meets the requirements of a well-known and well-used standard (irrespective of whatever debate went into that standard) will meet the expectations of private actors for a credible space component, as their trust is placed in the standard itself rather than the process that led to the creation of that standard, and thereby reassure them about the credibility of the planned component. Although what goes on will be defined as simply 'carrying out the test according to the appropriate standards' – akin to 'assigning a TRL' – it will gloss over what actually goes on during the test, who arbitrates on the interpretation of the test results, and by what *changing* and contested standards the tests are run, transforming the outcome of the test into neutral knowledge (Slayton, 2007). It is clear from the interview data that external actors take their lead from those within the space industry when it comes to testing standardization; long-accepted and normalized testing regimes from within the space industry are unlikely to be challenged from without.

To take this even further, another interviewee stepped outside even this emphasis on the (albeit sometimes heavily debated) level of diligence in space testing, instead describing a vagueness and sometimes arbitrariness they saw as inherent in the process:

> *'They tend to be sensible boxes [that need ticking]. Some of them aren't – aeronautics tend to, if they can't think of a better thing to do, say 'Well, we want to see it run for 10 hours or a thousand hours or a hundred thousand hours', or whatever.'*
> (003, [Public, Technology])

This suggests that several of the quotes in this section and the previous (those from #021, #025, #026) are akin to the 'official line' of objective standards, whilst that from #003 (and #019) shows a greater willingness to describe the actual experience of the standards-setting process within testing regimes. This thus highlights an interesting point which is unlikely to be visible to those outside the testing sub-industry that has grown up around the space sector – that some aspects of testing may not be all about ticking the 'sensible boxes' but rather just doing *something* that has the appearance of a suitable testing regime and can be used in a subsequent future narrative. As Collins (1992:129) notes, there is an 'algorithmic' quality to testing – experiments are on some level a *formality* following a set of instructions because the instructions have assigned social expectations and value. Carry out the ascribed tests and the component will be considered suitably 'tested'. Some assessment standards within the space industry, therefore, appear to have much more to do with expectation than genuinely stressing the component in question.

The data in this section shows that specific testing standards are often in place simply in order to have *something to show* in an adaptive future narrative based upon the testing of a component. Some interviewees implied that the standards against which to test were designed primarily as part of the public face of a testing regime, and the analysis showed that meeting the standards is often more important than the nature of the standards themselves (in much the same way as carrying out the *process* of testing and 'moving up' in the TRL system appears just as important as the nature of the tests themselves). The standards themselves are sometimes heavily contested, and 'at worst' are sometimes quite arbitrary. To reiterate, this is therefore a question of expectations (Borup *et al*, 2006) – testing is expected to be done according to standards, and non-space actors are not going to closely question the technical standards in question.

In the last two sections we have seen that standards are presented as being things 'out there', and that they are presented as being the only sensible and rational standards for the dominant space industry testing regime – i.e. vacuum, heat, and vibration. This is akin to the presentation of nature in scientific discourse as something 'out there' which scientists examine and uncover information about (cf. Woolgar, 1976:417; Brown, 2000). Standards are presented as being metrics that are so clear that test results only need 'viewing', without acknowledging any debate or work that goes into these standards, and their potentially arbitrary nature. However, the interview data showed two different forms of debate over both the testing, and the standards themselves against which the testing is performed. These two sections identified that debate occurred 'inside' the space industry on the nature of testing standards, which sometimes meant the gradual incrementing of standards, sometimes significant debate, and sometimes entirely arbitrary rules; and debate also occurred 'outside' the space industry between space actors and private actors, in which case debate focused on the *level* of testing required rather than the standards by which testing was performed, despite the internal standards debates within the space industry. Testing and testing standards are therefore used both to form and maintain consensus (Hilgartner, 1990) for space components, and transform the uncertainty of any technical evaluation into a certainty other actors can rely upon. In this way testing is integral to a component's acquisition of credibility – a seemingly objective metric is selected to test against, and that metric is then tested against. If successful (where success, as we have shown, is socially debated), then the component will be considered significantly more credible than when it began 'testing'.

6.4. Launch Credibility

6.4.1. Qualification

The acquisition of component credibility – and a lasting record of the processes associated with this credibility having been carried out – serves two purposes. As the component is developed the credibility acquired helps it to gain more funding and support, whilst afterwards all these forms of credibility are used to create an adaptive future narrative (summarized at the conclusion to this chapter). Thus far we have seen two forms of this credibility that interviewees described: early credibility and the funding that comes with it, and then 'technical development' credibility, created via the negotiation between testing and testing standards, the steady march up the ladder of Technology Readiness Levels, and the transformation from a concept into a physical item. The final type of credibility that a component needs in order to successfully deploy an adaptive future narrative is what I shall term 'launch credibility'. Interviewees identified the constituent parts of this form of credibility as taking place at the end of a component's development, and just before (and to an extent, during) its deployment on working satellites. Launch credibility consists of two distinct but related aspects, and both of these combine to form the final part of a compelling credibility narrative – these are ‘qualification’, and ‘flight heritage’.

This section will first explore qualification. To understand the meaning of qualification we can first look to particular comments from two interviewees. The first of these interviewees spoke of a process of ‘*product* demonstration’, which is to say the component being understood as a product which should be sold and used from that point onwards, rather than as a component still in ‘technical development’:

> *‘In the aerospace aeronautical regime – they are distinctly different between military and civil – but you still have procedures, standards regimes, and behind that you have an accepted path to development and key points in that development are demonstration stages, so you ground-demonstrate things, then you product-demonstrate things, then you flight-demonstrate things, and at each stage you’ve got a varied but closely defined set of boxes you’ve got to tick, really.’*
> (003, [Public, Technology])

This comment makes an interesting point about the visibility of these processes by defining them as ‘demonstrations’. As Trevor Pinch argues, many tests are performances which are ‘witnessed’ by others, either directly or through documents such as reports produced about the test (Pinch, 1993:26) which attach meanings to particular technologies (McBride, 2003), in this case the successful functioning of the space component. In the same way, ‘product demonstrations’ are also designed to be *witnessed* by non-space actors as another stage in the acquisition of credibility, in this case after ‘ground-demonstrat[ing]’ (which is to say, testing). Following on from this first comment, the second interviewee talked instead of an engineering activity known as ‘qualification’, which is concerned, much like the quote above, with the transformation of a single component-in-development into an *entire line* of trusted components:

> *'[Qualification is] very much an engineering activity. The qualification at the parts level you would have to prove you were using parts qualified to the right environment for space. There will be a standard for proving the right component, but then there will be a qualification phase which is developing flight standard equipment.'*
>
> (022, [Private, Technology, Comms])

This quote explicitly defines a separation between 'proving the right component' – the testing regimes and standardization described in the previous sections – and then qualifying it, which transforms a component into 'flight standard equipment'. This is comparable to the first quote which separated ground-demonstration and product-demonstration. These two quotes – speaking of 'flight standard equipment' and of 'product-demonstration' – are clearly discussing one and the same thing, which is to say a process that results in the component being understood at this point as a product, a blueprint or a selection of manufacturing processes, not specific copies of that component which are being trialled in a shake-and-bake testing regime. These are two ways of expressing the same procedure, but from this point onwards I shall use the term 'qualification' due to it being used by several other interviewees as well as the two above, whereas 'product-demonstration' was only used by the first interviewee in this section.

The process of qualification is therefore once more an example of a similarity relationship (Pinch, 1993) which in this case constructs an assumption that all components are effectively indistinguishable from one another. As no physical item can be tested *in space* without launching it (and thereby removing any possibility of getting it back), components are trusted based on the performance that earlier copies of those components were able to achieve. Interestingly, this moves the component back from the technical specifics of the testing regimes towards the more conceptual forms of credibility explored at the start of this chapter with the accreditation from scientific and governmental bodies. Rather than linear progression from a concept of the component to ever more ‘physical’ manifestations of that component, the tested physical copies of the component fade from view at this point and the focus returns to the *idea* of the component. Looking back over this chapter we can therefore see that credibility begins with the concept of the component which must be accredited, proceeds to test *specific* instances of that component, and then once more changes the component back into an abstraction by establishing a similarity relationship between the copies of the component that were tested, and all potential copies which will be launched. This leads to the situation mentioned by another interviewee:

> *‘In many ways it’s what you go through to qualify it ready for flight that does the work. […] There’s a lot of design that’s testing, analysis to prove the lifetime reliability analyses, analysis where all the failure nodes could be, what happens if this bit fails, what’s the knock-on impacts on the next bit of the spacecraft, so that by the time you launch, by definition, you expect it to work, and you don’t expect it to have problems.’*
> (002, [Public, Science])

#002 supports the existence of this similarity relationship by arguing that by the time of launch one simply *expects* the component to work because all the others in the chain (which were tested on the ground) have done so. This is not necessarily an inherently flawed assumption, but it takes us back to the sociology of expectations and predicted futures. The expectation of successful functioning becomes embodied by a qualification (cf. Borup *et al*, 2006:292-3), which is specifically designed to make a future of successful functioning appear realistic and credible (Brown, 2000) by transforming the component into a ‘product’ or a piece of ‘flight standard equipment’. Just as testing regimes were designed to establish a relationship between the outer space environment and the tests being done on the ground, a qualification therefore establishes a second similarity relationship between individual instances of the component and the entire potential run of future copies of that component. Crucially, the combination of these two similarity relationships results in a claim that consistent future *space-based* functioning of *any copy* of a component can be extrapolated from the *ground-based* testing on *specific copies* of a component. Testing and qualification are leveraged to create the component’s future credibility via these two relationships, and the significant extrapolation of similarity involved is hidden within the systems of testing and qualification that only display positive outcomes and official documents and reports to external actors.

This is not the only aspect that qualification and the standardized testing of the previous sections have in common. Just as there are specific codified testing regimes such as ECSS which must be adhered to, so too are there equivalent formalized qualification regimes:

> *‘From a quality side there is a very rigorous progression of reviews. [For example] EQSR [Engineering Qualification Status Review] is an equipment qualification status review which says anything that’s going on the satellite has to be reviewed and a qualified component – qualification against standards being the benchmark all technology is tested against – then dependent on the result of that there could be varying degrees of reviewing.’*
> (022, [Private, Technology, Comms])

Much as test standards and test results result in documents that can be looked back upon as evidence of appropriate testing, so too are qualifications socially-produced documents (Macdonald, 2008:287). Their ‘surface’ content (van Dijk, 1997:ix) may be the extent to which a component met with the qualification standard and should therefore be understood as a product, but the latent content of such qualifications allows it to recruit actors and display the credibility of the component. This latent content (Stephenson, 2012) brings with it a narrative: that the component has been thoroughly tested and examined, by standards all experts agree on, and has met the requirements that ready it for flight. As above, a qualification from a trusted agency is a projection into the future that the component will function as promised for the length of time promised, it will always function *the same way*, and that it can be used in other programmes. By creating a formal qualification system which is the same every time it is applied to a new component (or understood as such), the space industry is able to claim that any component which gets qualified must also, therefore, be equally worthy of qualification as all those which have gone before and will come after, and that qualification is an entirely objective measure of component viability.

In this we begin to see the emergence of the adaptive future narrative as the conclusion of a component’s technological development. Although they are not explicit predictions of a specific outcome, qualifications serve as more general predictions about the future correct functioning of the component being qualified – which are precisely what adaptive future narratives consist of. Qualifications have a strong promissory nature that turns components into objects of ‘shared speculative promise’ (Brown, 2003:16) – even competing actors who support competing programmes will nevertheless agree on the technological validity of a universally-recognized qualification.

To summarize: a component ready for flight has therefore had two similarity relationships constructed around it. An understanding that specific physical components for a given satellite cannot be *directly* tested must be coupled with the claimed strength and diligence of the testing regime and the technologically determinist TRL discourse that surrounds it. The same applies to qualifications, which are used regularly across all components and presented as universal concepts that are applied by rational engineers. It is essential to sell the claim that whatever testing regimes and qualifications were carried out on the line of components, they were sufficiently rigorous. Such claims are developed from a shared agreement that the testing system is *representative* of launch conditions, and in turn that a qualified component is equally representative of future copies of that same component. However, it is interesting to note that even these discursive tools are not always sufficient to get a component accepted. Many companies demand at least three years worth of flight experience for a component – which is to say that copies of that component have been used successfully in space, not just on a test-bed. This therefore brings us to the final form of credibility: flight heritage.

6.4.2. Flight Heritage

'Flight heritage' as used by interviewees is difficult to define, but is an essential final aspect of an adaptive future narrative. It is somewhere between a cumulative measure of the 'flight hours' a component has been flown for, and the period of time throughout which a component has been flown 'regularly'. However, since a flown component will often be flown multiple times as soon as it has gained any flight heritage, stating a component has 'three years flight heritage' will be approximately comparable regardless of which definition is adhered to. Although neither was defined precisely, interviewees seemed to use the two interchangeably – in some examples the regular-use model was simply implied, whilst in others the precise-timing model was used. Either way, flight heritage is a measure of *how much the component has been flown*, and it was presented by interviewees as an indicator of the credibility of that component and how safe it is to assume any subsequent copies of that component will perform correctly (much akin to the above concept of qualification). The assumption that subsequent copies of the component will work correctly is the core of any adaptive future narrative, and what all these concepts of credibility support. To begin exploring this final factor, several interviewees emphasized the importance of heritage:

> *'[Because] once the satellite is up there you can't repair it, heritage and technical confidence are paramount, absolutely fundamental. One of the big challenges for all space companies is if you've developed a new part or component or procedure or software or anything, nobody trusts it until it's got some in-orbit heritage, and people like Astrium will not buy a satellite now unless every element of that satellite has at least 3 years of in orbit heritage. They just won't buy it.'*
> (013, [Public, Private, Technology, Comms])

> *'New technology that has no heritage, that's the issue. That's why we do lots and lots of testing.'*
> (021, [Public, Science])

> *'It's heritage. If Japan or India wanted to buy some satellites from providers, they'll look around to see who has got the heritage – the proven products, got them into space. They're not just going to get somebody in the garage who can do it, it has to have this heritage and that is what ESA gives. ESA is a system that allows people to get heritage and allow new products to come through.'*
> (007, [Public, EO])

Once a technology or component 'has heritage', the acquisition of this heritage transforms a new technology into one that customers may be willing to use, even if the physical aspects of the technology itself may not have changed at all in the process of heritage-acquisition. There is a temporal, rather than technical, aspect in the viability of components due to their ‘heritage’. As we saw in Chapter 5, many successful space components are those which ‘stood the test of time’ irrespective of their original qualifications (5.3.2). As Collins (1992:144) puts it, ‘distance lends enchantment’. Even if the original standards by which a particular piece of equipment was tested might no longer be considered acceptable, the fact it has many years of use acts strongly in its favour. ‘Heritage’ thus acts as a discursive tool in its own right, for it can be used to reassure outside actors that the component is well-used in a space environment and should therefore be unlikely to fail. Interestingly, whereas many other systems described in this chapter serve purposes for those within the space industry as well as those without, the concept of flight heritage is entirely a tool to allow space industry actors to recruit those outside the industry into the development of space components. The technical development of the component is considered ‘complete’ at this point – all that remains is to gain some flight heritage so that the component does not appear to be fresh off the assembly line and therefore unproven within a space environment.

Heritage transforms the technical language of components and testing into a more palatable discourse that shows *experience* with the component, and also crucially a level of ordinariness, predictability and stability (Neyland, 2006). If a component has flight heritage it appears ready for use within the space sector. Flight heritage, like qualification, is therefore a similarity relationship which emphasizes that every component is equally and predictably reliable and effective. The copy of the component that is about to be flown is the same as those which have been flown before, and since all of those functioned correctly, this one is expected to function correctly. After several flights the component subsequently appears trusted due to both the length of time it has been used and (presumably) its lack of failure in that time. At this point a component with flight heritage becomes an ‘off-the-shelf' component – a simple, supposedly guaranteed-to-work purchase that is no longer debated. This is a point of confluence with normalized future narratives that is important to note. In the previous chapter it was shown that a number of space programmes express a clear preference for using older 'trusted' components, and that much of the trust these components possess is due to the temporal distance between their development and whatever programme they are being used within. A component with years or ideally decades of flight heritage will become precisely this kind of component.

We can therefore see that components which have achieved flight heritage are components which more conservative space programmes may seek to include within their own satellites, assuming that component has built up a successful adaptive future narrative that emphasizes its credibility and applicability to any and all relevant future programmes. Such off-the-shelf components are used in all space programmes – adaptive future narratives are not only used to sell the value of components for use in *normalized* programmes – but it is a point of overlap and interrelation. A component with a strong adaptive future narrative will be desired by more conservative and normalized programmes in the future that will see it as an unproblematic and trusted part of a larger and more complex whole. However, this is not to say a component may not be designed at first with a specific satellite in mind, even if the later adaptive future narrative is designed to lend it broad applicability. One interviewee stressed that flight heritage is something designed around the initial customer for a component, not a universal set of rules:

> *'This is normally what people ask for. People ask for the ESA qualification process, [though] most operators will ask for three years of heritage, independently of the qualification. It varies between operators, it varies between customers because there's not only the operator but there's the whole food chain.'*

(012, [Public, Private, Technology, Comms])

Expectations for heritage vary between different actors just as they do for testing regimes. The expectations of the actor(s) originally funding the development of a component may be different from any future actors who might want to use that same component. Some may see it as the means to an end, or a commercial venture, and may differ in terms of the timescales they can accept, and each will have different assumptions about what level of qualification or testing they are willing to fly with, and how much heritage is enough to put to rest any concerns. This means a level of negotiation remains – something which has 'acquired heritage' cannot immediately lend credibility to a programme, but the amount of credibility it lends (and the minimum point at which it lends any credibility whatsoever) will be socially contested each time the component is considered for use in a space programme. Those who push the credibility of a component thus must do work to both give it heritage and to assign *meaning* to that heritage as something actors should understand to be a marker of quality for the component – this meaning comes from the adaptive future narrative constructed at the conclusion of acquiring early, development, and 'launch' credibility.

There are a number of examples which illustrate the above points about qualification and heritage. One interviewee explored at length one method for gaining flight heritage via certain satellites which are specifically designed to be flown as a 'test' of new equipment, whilst another echoed the important role of these satellites. The former was the case of 'TechDemoSat 1' (TDS1), a satellite on which were flown a large number of previously untested components with the sole purpose of testing them and gaining them flight heritage. In this case there were no specific objectives for the satellite beyond checking whether or not these components were able to function in a space environment:

> *'That classic Catch-22: I won't fly it unless you've flown it! The government recognizes this, and we have something called TechDemoSat. So TDS1 is an attempt to break that cycle – let's just fund a satellite that is going to be high-risk, fly these technologies, so we can get past this first barrier of saying 'Yes, we have some flight heritage'. No, it wasn't a commercial app[lication], it wasn't a scientific mission, but you know what? It was in a space environment, it operated for 9 months, it did exactly what we said it was going to do, and then you'll get maybe a science mission or a communications operator saying 'Ok, maybe we'll fly that as a secondary payload. We won't rely on that for the primary mission, but you've convinced me enough that we'll have a secondary payload and operate it, and if you survive that, you know what guys, absolutely, we'll rely on you for the next one'. It's those stepping stones.'*
>
> (025, [Private, Technology])

> *'Every customer would like somebody else to prove it first. Some of our customers even have contractual requirements that they won't take a technology which hasn't been proven in-orbit for 3 years on somebody else's programme. So somebody has to be first.'*
>
> (022, [Private, Technology, Comms])

In this case a way has been found to 'circumvent' the issue of only flying components that have already been flown, via the system of launching satellites with only this purpose. This means a number of things are unique for satellites of this sort. The attitude to risk will be more relaxed both because it has no external objectives, and because part of the mission's objective is to test (or rather, mitigate) risk in the first place. In this way it is almost akin to the early stages of the TRL cycle – it is done as a proof of concept, knowing that it will not have any direct or immediate economic or scientific benefit, but that if successful it will pave the way for such in the future by lending credibility to the components it flew.

In this way the space sector distributes risk in a very unequal way – whereas most missions are launched with an absolute minimum of perceived risk with highly credible components, a very small number are launched deliberately with components that lack flight heritage and the credibility that goes with it. This benefits both actors within the space industry and actors outside. For actors within the space industry they are able to present most missions to outside actors and potential investors as using well-tested and well-proven pieces of equipment – and can present themselves as sensible and rational engineers who would only ever consider using such equipment – whilst they are still internally able to carry out research and development and get new components a little further towards a state where they might later be flown in the ‘safe’ missions. This means that components without flight heritage do not have to be tested on more important missions where the use of such components might push up insurance premiums or become a source of concern for other actors. They therefore deploy ‘proven’ and ‘unproven’ pieces of equipment to different parts of the industry, as ‘applications’ missions for a specific customer and ‘technology’ missions designed for flight heritage (Eurospace, 1994). What this means for actors outside the industry is that they are given a level of confidence knowing that only qualified equipment will be presented to them. This separation serves both actors, internal and external to the space industry, whilst keeping those outside interested by only presenting them with the ‘finished goods’ that have a clear history of being tested, qualified, flown, etc. As we shall see in the chapter conclusion below, this duality between emphasizing the present state of a component – it is ready to be flown – and the past development that went into it is an essential part of adaptive future narratives.

6.5. Conclusion

We can now finally bring together the many forms of credibility examined in the previous sections of this chapter. Space components are not entire space programmes in their own right, which distinguishes them from the scientific missions of Chapter 4 or the service-led programmes of Chapter 5. They are single components that are initially designed either for market distribution or as part of a particular satellite. This chapter has shown that irrespective of this initial objective, the development of the component is aimed at turning it into an ‘off-the-shelf’ component, and that this requires a future narrative as integral to the contemporary space industry as either of those explored in the previous two chapters. Off-the-shelf components are positioned as components that can be easily and trivially used in any future space programme that may have need of such a component – rather than develop another new circuit board, an older one can instead be used. However, that older component will only be viable for use if there is a clear adaptive future narrative with it. That is the term I choose to use to describe the *sum total of all the credibility narratives* outlined here. Whereas the finite future narrative consists of clear documentation and planning, and the normalized future narrative is focused on definition and terminology that create a mundane prediction for a space programme, the actual form of this third future narrative is the *past evidence* of all the forms of credibility the component has accrued, and the use of this evidence to claim the component’s future viability. This will be primarily through documentary evidence, but may also be present within space industry employees who feel confident using the component, and from historical evidence of other missions in which the component has been successfully deployed. The more evidence of that component’s credibility, the stronger the adaptive future narrative, i.e. the more easily the component’s use may be adapted to suit any future programme. Adaptive future narratives create a story of repeatable success and credibility that can be told again and again, but within a new context which is different in every programme the component is used in.

This chapter explored how space components are able to attain credibility at different stages of the process, and how these methods combine into a past narrative of attained credibility to support the future narrative of predicted success. Those within the space industry generally broke this down into three temporal phases – the ‘early’ credibility phase, the ‘technical development’ phase, and then a final phase involving qualifying the technology for flight and subsequent flight testing. Although I do not hold to this linear model of technological development, the grounded theory requirement to use the language of the interviewees has been a deciding factor in structuring the chapter this way. They saw clear distinctions in the ways credibility is attained and managed in these three perceived phases, and that is what is reflected here.

This chapter thus began with the attainment of credibility in the very early phases of a component’s development, which consisted of two methods. The first of these was the value of accreditation by a recognized body – these are primarily bodies connected to (or part of) space agencies which are deemed to meet two requirements: they have the requisite technical knowledge to pass an accurate judgement on the technology, and they are sufficiently neutral to pass an *objective* judgement on it. As well as these bodies, credibility in the early stages of a component development could be acquired from government investment, which in turn often led to private investment. This meant that public money was used as an ‘anchor’ which would convince private actors that if it was good enough for a state to risk public money on (states being seen as having much longer timeframes than commercial space actors) then it was good enough to merit some private investment.

The chapter then moved on to consider how credibility was acquired and managed in the 'middle' stages of a component development. This analysis consisted of a large number of different aspects. Interview data showed that the concept of the Technology Readiness Level is key to the attainment of credibility in this phase. TRLs are a detailed discursive structure consisting of nine numerical 'levels' which denote the 'stage' a technology is at. The first three TRLs (levels 1-3) roughly correlate to design and research, the middle three (4-6) to development and testing, and the last three (7-9) to optimizing, improving and tweaking the technology. This adheres to a linear model of technological development, and much like the above expert opinions for early credibility, the TRL system rests upon the idea that all human actors who assess a technology will come to the same 'correct' conclusion. The TRL system possesses a strong discourse of objectivity, claiming that so long as the person assigning a TRL is knowledgeable and qualified, they will inevitably come to the *correct* conclusion about what number it should be assigned, and this number can in turn be used to communicate with other actors about where the technology currently stands. The belief in TRLs as a system allows them to be used to recruit actors who are not given a complex technology-in-the-making to understand, but rather a single digit to denote the success of the technology to date.

The chapter then examined in more depth the 'testing regimes' within the 4-6 TRLs in order to understand how these tests have been constructed over the past few decades, the ways they are presented, understood, and what work a 'successful test' can do to promote a component. The tests that space components undergo were shown to have socially constructed standards which are interpreted anew for each mission – an actor that needs a launch in a short timescale may be willing to compromise to a reduced testing regime. These standards function for the benefit of both those within the space industry and customers on the outside. They allow space sector actors to sell an 'off-the-shelf' version of a new component which hides the complexity of the technology, whilst it also serves non-space actors by giving them a 'non-technical', easily-understandable and apparently objective and accurate appraisal of the technology. Despite this claimed scientific objectivity the chapter found both testing and the standards of those tests to be highly contested and sometimes even 'arbitrary', and argued that the *visible* or documentary evidence of completing a testing regime to an agreed standard may be just as important as the results of the tests themselves. It also noted a distinction between the 'methodology' of the tests and the 'intensity' of the tests, and that although only the latter was seen as a matter of debate (with those outside the space industry), the former has also gradually shifted over time, but these shifts have remained 'hidden' within the space industry so as not to damage or impair claims of testing objectivity and applicability.

The final part of the chapter assessed how credibility may be gained towards the end of the development of a new component – when it is being considered for launch. It began by exploring the concept of qualification for launch, which is primarily carried out by an established body stating that a *series* of components is ready for flight – which is to say, no physical component which undergoes a testing regime will actually be flown, due to the damage it may sustain in the process, so the qualification process instead denotes that *all copies* are usable, and will work in the same ways as the tested copies. Interviewees defined this process as converting a component into either a 'product' or a piece of 'flight standard equipment'. However, even if a component is successfully redefined as a product, many space actors will only use technologies that have a significant amount of 'flight heritage' – the length of time the line of components has already been flown for. The concept of flight heritage both lends greater viability to older components that have been flown many times, and has also forced the creation of several methods, such as 'technology demonstration' missions, to allow new technologies to get flight heritage and thereby generate documents and experience surrounding them that acknowledge their viability for flight. Upon acquiring flight heritage a component can then finally become an off-the-shelf component whose credibility will only increase with each passing successful flight.

This examination of credibility from the initial accreditation of a concept to the first flights of a newly-developed component therefore allows us to identify and specify three broad forms of component credibility: the early trust placed in the component by an agency or a government, its successful navigation of the TRL system and testing regimes, and then its subsequent qualification and early flights. These are then deployed after the development of the component concludes. By retrospectively emphasizing the level of credibility the component gained, those who have developed the component are able to use this *past* narrative of the attainment of credibility to propose a *future narrative* of perpetual applicability and trust in that component. This past narrative gives credence to the future claims that the component will work well in whatever situation it is placed within. Given this understanding of credibility, at this point it is worth making explicit that the use of the term ‘credibility’ in this thesis is therefore highly distinct from the use of the term ‘reliability’. Whereas reliability in the previous chapter was a question of successful service provision designed to meet the needs of new space customers, credibility is focused on the perceived potential of technical failure. There is naturally an interrelation – lots of credible components will raise the perceived reliability of a programme – but these are two distinct factors.

Components with adaptive future narratives are highly desirable to larger space programmes. Those developing future satellites will of course be aware of the long development times of space technologies, but in a credible component they find a part of their programme that requires *no time investment* whatsoever. It does not need to be invented, funded, ground-tested, developed, qualified or flight-tested, because this has already happened (see 5.3.2). It was not qualified for use within their particular programme, admittedly, but as this chapter has shown, credibility is designed within the space industry to be expansive and easily adaptable – a component becomes credible for a wide range of uses, not just the satellite it was originally built for. This multiplicity of uses turns the component into an off-the-shelf piece of technology and one that needs no time to make, therefore appealing to other programmes. Such components are especially prevalent in programmes using the normalized future narratives in the previous chapter, given the conservative outlook within the space industry that privileges the use of such off-the-shelf hardware. In this way we can perceive that while finite future narratives are concerned with time, and normalized future narratives with risk, adaptive future narratives are located at the intersection of these two variables. A long development time and all the credibility that goes with it leads to a low-risk component – the temporal dimension is leveraged to reduce the perception of risk, and thereby create a component which appeals strongly to future space programmes that may utilize it.

Like the finite and normalized future narratives in the previous chapters, the concept of the adaptive future narrative has extensive potential applicability to other high-risk technological industries which produce significant numbers of technical artefacts all of which share components (as with satellites in the space sector). Sectors of this sort include air traffic control, which has undergone an extensive standardization in recent decades (Wickens *et al*, 1998); chemical plants where trustworthy and well-tested components are seen as essential to prevention of future disasters (Perron & Friedlander, 1996; Perrow, 1999:102); and nuclear weapons which number in their thousands and use a range of standardized components, such as guidance controls (Mackenzie, 1990). The creation and use of adaptive future narratives is designed to make components appear safe and credible for regular and repeated use in these high-risk and high-reliability sectors. With the example of the space industry this chapter has showed the importance of testing and standards to such components as part of their transformation from an uncertain technology into an off-the-shelf component. This creation of regular and credible components is essential for such technologies – focused on both concerns of risk and the navigation of long timescales – by presenting a component that is both de-risked and *already developed*, therefore needing no further development time and being ready for use immediately.

In conclusion, therefore, an adaptive future narrative for a *component* serves to support other *programmes* that will use it in the future. It does this by presenting a component that has no perceived risk and that does not need any further time to develop. These two concerns of high-risk technologies (risk and time) are swiftly countered when presented with a credible off-the-shelf component, and the forms of credibility associated with it are specifically designed to be adaptive, and usable in any future context. Like finite and normalized narratives this is a fundamentally new narrative for the space industry that could only have arisen after many decades of the industry's existence, and one that would make little sense in the prior Space Race understanding which emphasized the uniqueness and cutting-edge nature of all space endeavours.

Chapter Seven: Conclusion

7.1. Introduction

This concluding chapter will summarize the thesis and focus upon its contributions to the field of STS. This thesis asked two interrelated research questions about the role of narratives in the development of high-risk technologies: what roles do future-orientated narratives play within such industries, and how are these narratives subsequently constructed and utilized? This question was developed by summarizing existing STS literature on high-risk technologies, and identifying that the theoretical concepts designed for ‘mundane’ technologies did not necessarily translate well to high-risk development. The thesis proposed that the scholarly understanding of high-risk technology development would be significantly improved by examining the roles of ‘futures’ and narratives in such technologies, and subsequently the space industry was selected as the case study for this work. This goal of furthering understanding of high-risk technology development has been achieved via a three-part typology of ‘future narratives’, which I have termed finite, normalized and adaptive. These future narratives also highlight the importance of the long-term nature of such technologies in addition to their high levels of risk, and demonstrate that a more serious consideration of the temporal dimension within subsequent research into high-risk technologies would be highly valuable to STS.

7.1.1. Research Retrospective

This thesis builds upon the SCOT concept of interpretive flexibility. This term refers to a level of ambiguity in the design of artefacts which undermines claims that the most successful or efficient design is always the one that wins out (Bijker, 1995). Within this model each interpretation of a technology is a ‘frame’, and eventually a ‘dominant frame’ (Bijker, 1993:128) may emerge that determines the understanding of an artefact. Although integral to existing SCOT work, the thesis argued that the process by which a dominant frame emerges implicitly assumes an open market for the circulation of competing frames, whilst existing work on high-risk technologies (e.g. Perrow, 1999; Boin & Schulman, 2008) suggests that an open-market interpretation cannot be supported or substantiated within the high-risk context. A study of the literature also showed that unlike ‘mundane’ technologies where frames constantly compete during the *development* of the technology and promote a new design with each new dominant frame, this was not the case for high-risk technologies. Instead, existing case studies on high-risk technologies (Lakoff & York, 1989; Kinsella, 1999; Knorr-Cetina, 1999; Law, 2002; Mort, 2008; etc) showed a strong level of agreement upon three points – that high-risk technologies are planned within a closed market of powerful and influential actors, that the development of the technology does not (and cannot) begin until the acquisition and commitment of significant financial, technical and political capital has been achieved, and that the objectives of high-risk technology developments rarely change much once the practical development of that technology begins. The literature suggested that the success or failure of such programmes was rather a question of acceptance or rejection of the dominant frame that emerged from the initial closed-market debate on the programme’s objectives, but rarely explored this process. This was thus the initial point of departure for this work: to understand what determines the acceptance or rejection of a dominant frame in high-risk technologies.

The eventual technology has not yet begun any form of manufacture or development and there may be several years until any form of working prototype exists, so any dominant frame must be supported by statements about the technology’s promised *future*, a narrative of how to achieve that future, an emphasis on the value and worth of that future. I selected the term ‘future narratives’ for these concepts that support the dominant frame, which the research into the space industry subsequently showed to consist variously of plans, roadmaps, careful choices of terminology and component use, acquiescence to conservative impetuses, and complex regimes of testing, standardization and qualification. As such the thesis proposed that studying future narratives may be a way to explore how dominant frames vie for acceptance or rejection within high-risk technological industries. How is a future narrative created to support these development programmes, and what makes for a successful one?

The space industry was selected as the case study for this thesis for two reasons. The first was its relative under-examination within sociology, whilst the second was the existence of a clear prior future narrative in the form of the Space Race. The space industry had thereby already demonstrated a willingness to create narratives for high-risk programmes which stretch a considerable distance into the future, but the Space Race narrative appeared to have little contemporary relevance despite the continued growth of the space industry, suggesting that at least one new narrative must have emerged that has not yet been analytically identified (Vedda, 2008). Using a grounded theory approach, the research into the space industry was conducted via 26 semi-structured interviews with those currently working in the space industry. Data analysis and the coding of this data began during the interviewing process and concluded shortly afterwards, resulting in over 100,000 words of transcription within which a range of codes relating to futures and narratives were identified. Upon further examination it became clear that this range of codes could be compressed into three dominant codes: ‘Planning’, ‘Mundanity’, and ‘Credibility’. Each of these then informed one of the three forms of future narrative that form the core of the work’s contribution to our understanding of high-risk industries.

7.1.2. Summary of Findings

STS scholars have sought to demonstrate that narratives and futures are essential to social life and define intended or predicted paths and trajectories (Bruner, 1990; Orbuch, 1997; Brown *et al*, 2000; Elzinga, 2004; Michael, 2000) just as others have explored how high-risk technologies are developed, constructed and managed (Perrow, 1999; Boin & Schulman, 2008), but integration of these two bodies of work had thus far been relatively limited. It is these strands of future and narrative research, combined with high-risk technologies, which this thesis has brought together, and for which the space industry was an ideal case study.

This thesis asked two questions – what role do future orientated narratives play in the development of high-risk technologies, and how are they constructed and utilized? By researching the space industry the thesis has answered these questions. Based on the empirical interview data acquired, I have shown that future narratives serve a wide range of purposes, that they are constructed to assist in every contemporary space programme whether scientific or commercial, and that three types of future narrative have emerged in order to achieve these varied purposes.

The first of these I termed the finite future narrative. This form of narrative consists of two parts – a roadmap which denotes a series of steps or milestones towards reaching a valuable and desirable conclusion, and the conclusion itself. Such roadmaps were found to be designed to recruit and maintain the support of a wide number of actors and reduce the perceived uncertainty of many-year or many-decade programmes, while the promises emphasize a clear end to the programme (beyond which support will no longer be required) and one which is highly valuable to a range of interests. This analysis demonstrated the range of agendas that contemporary scientific high-risk programmes must appeal to, and contributes to the STS understanding of contemporary ‘Big Science’. The second I defined as the normalized future narrative, which was found to emphasize the ordinariness of the contemporary space industry and play down the perception of risk associated with space technologies. It was identified as being a response to growing conservative pressures on the space industry and a shift away from ‘abstract science’ and towards service provision. The analysis demonstrated how a high-risk industry such as the space sector may undergo a reorientation towards such programmes, and how important a low sense of risk and a low chance of ‘service failure’ are seen within such a newly-commercial framework. The third future narrative I termed the adaptive future narrative, which is concerned with the manufacture of components rather than entire space programmes. This future narrative consists of many different forms of credibility and is designed to project the viability of a component indefinitely into the future, emphasizing that a given component will be usable on any future programme. The analysis explored how components are transformed into ‘off-the-shelf’ products that can be used in any number of programmes, developing the STS understanding of standardization and regularity in high-risk programmes which are often perceived as being always esoteric and rarefied. The thesis therefore demonstrates the importance of these new future narratives to the space sector, and analyzes the attendant interplay between risk, time, and prediction, exploring the value of futures and narratives relevant to the space industry’s post-Cold War context.

The profound importance of the temporal dimension to the development and production of high-risk technologies was also identified by this work and heavily informed the analysis of all three forms of narrative. Having identified the crucial impact of the long timescales within which the space industry operates, the work presented here therefore has significant importance for the subsequent study of other high-risk sectors, given the implicit but rarely examined role of the temporal in such industries (as identified in Chapter 2). The three future narratives not only explore the role of ‘high-risk’, but also the role of the long-term within the development of high-risk technologies, and serve as a typology by which STS can understand how these twin concerns are mitigated and negotiated. Rather than relegating the temporal dimension of these technologies to the background, these three future narratives propose bringing this dimension into the foreground, and demonstrate that it should be considered to be just as important as risk for these technologies.

The thesis also marks two other contributions. It has firstly assisted in opening up the space industry as a new field of high-risk technology for sociological examination. Existing scholarly STS work has examined a wide range of related fields such as particle physics (Pickering, 1984), nuclear power (Winner, 1986; Cowan, 1990) and nuclear weapons (Mackenzie, 1990), but the space industry has thus far remained relatively unstudied by sociology (exceptions include Redfield, 1996; Entradas, 2011; Pass, 2011; and to a lesser extent Peterson, 1997; Lester & Robison, 2009; Hill, 2012). By using the space industry as its case study a number of sociological aspects of this industry have been explicitly highlighted, including the interaction between space sector employees and those outside the sector, and the use of complex discursive structures such as the TRL system. Secondly, by utilizing a close study of semi-structured interview data, this thesis also marked a clear divergence from the methodologies of past space research. It was not anchored in fields traditionally associated with the study of the space industry – political science and policy research (cf. Marshall, 2008) – but instead in a sociological and STS analysis of the internal workings of the space sector. It points the way towards viewing the space industry as a technological industry reinventing itself in the wake of the loss of older narratives that justified immense financial investment and unquestioned government support. To carry out this reinvention the space industry has had to create new narratives to continue justification for the science-orientated programmes that still exist (finite future narratives), to broaden its reach into private market areas (normalized future narratives) and to build up a repertoire of off-the-shelf widely usable components to offset the lengthy timescales and financial and technical risk that come with the sector (adaptive future narratives). These three future narratives form the core of the contributions of this thesis to the wider body of STS literature, but also shine new light on the specifics of the space industry as it is currently practised.

7.2. Future Narratives

At this point all three future narrative types proposed by this thesis may be examined together, and the relationships and variation between the three forms can be identified. From the analysis presented in the prior three chapters, we can produce the following table of differences between these three future narratives:

	Finite	**Normalized**	**Adaptive**
Development Length	Long	Medium-Short	Short
Impact Length	Short	Long	'Infinite'
Perceived Innovation	High-Medium	Low	Low
Future Narrative Focus	Temporality	Risk	Both

Table 2: The typology of future narratives proposed by this thesis.

There are several important things to take away from this table. Firstly, there were no space industry programmes (or component developments) identified in the research which do not fit into one or more of these categories – regardless of the level of innovation of a programme, or its length, or whether the programme struggles to negotiate its risk or its timescale, all programmes are contained within the above three-part typology. Secondly, only one of the future narratives has a significant level of perceived innovation: finite future narratives, which were identified in Chapter 4 as possessing the highest level of similarity to the prior Space Race narratives within the industry. Both normalized and adaptive future narratives support programmes which aim at minimal and iterative change, and these programmes along with component development dominate the contemporary space industry after the loss of military and state support. Thirdly and lastly, the table above highlights again the importance of the temporal dimension. The future narratives varied widely in terms of the length of high-risk development they were designed to negotiate, and in terms of the timescale of the promises they heralded. Also, an equal number of future narratives were concerned with time as well as with risk. One future narrative focused upon risk, one upon temporality, and one upon both, showing that the temporal dimension is just as crucial as risk to this 'high-risk' industry.

This chapter now summarizes in more detail this three-part typology of future narratives and the contributions it makes to STS. This begins with finite future narratives, followed by normalized and adaptive future narratives. These sections recap how these analytic concepts were derived from the research data, what each narrative consists of, and how they may be applied to the examination of high-risk technologies. After that a conclusion is drawn about the importance of the temporal dimension and the value of considering the space industry – and other related sectors – as 'high-risk long-term' (HRLT) industries instead of continued use of the existing high-risk moniker. The chapter concludes by suggesting two potential directions for future research to further build upon the work presented here.

7.2.1. Finite Future Narratives

One of the three major findings of the research was the presence of 'finite future narratives' within the space industry. Explored in Chapter 4, these are narratives designed for programmes which may take many years or decades to complete, which is most often programmes with 'scientific' (in keeping with grounded theory's mandate to follow interviewee definitions) rather than technological objectives (cf. Pinch & Bijker, 1984; Hughes, 1986; Faulkner, 1994). The finite future narrative is designed to mitigate the chance that in a multi-decade programme some actors involved will drop out, lose commitment, lose funding, or that the objectives of the programme may drift from their original conception. As well as being designed to prevent a programme stalling in the middle of its lengthy development, these future narratives are also designed to entice actors into these programmes at their inception and subsequently throughout the process. This objective is achieved by promising clear and distinct temporal outcomes – that the programme will complete by date X, and yield outcome Y – and by listing a number of interim steps that are designed to keep those who do sign up involved in the programme until its completion. In doing so, finite future narratives were found to consist of two parts: a 'roadmap' of how to achieve a programme's goals, and the nature of the goals themselves. The combination of these two aspects is designed to make the objectives of the dominant frame in a high-risk programme appear well-planned, compelling, and likely to succeed at the end of the lengthy time it may take.

The first of these – 'roadmaps' – are documents and plans designed to describe all the intermittent steps required in a space programme, list all the benefits to various actors, and in turn recruit those actors into the programme and serve as a tool to keep all actors committed to a common conception of the programme. These are designed to make the dominant frame appear to be well-planned, and that it has sufficient oversight and diligence that those involved can feel confident in its impending success. They serve as what Wynne (1983:15) calls 'taken-for-granted' frameworks that can act as a foundation for any number of actors to understand the programme. The fates of all actors involved in a roadmap become quickly tied to the fate of the roadmap and thus all involved become obliged to support the programme throughout its long time-span (Brown, 2003).

Interviewees also explained that roadmaps often contained a number of points where they were expected to ‘link up’ with other technologies also in development. This was a way of mitigating the uncertainty within such temporally lengthy programmes by acknowledging this uncertainty and considering it ‘within’ the programme. By stating explicitly at the beginning that there was uncertainty – but that it had been planned for and anticipated – a programme is presented as having already predicted any future concerns. This future-proofing (Woolley, 2003; Anderson, 2008; Lucquiaud *et al,* 2011; Georgiadou *et al*, 2012) presents the programme’s uncertainties as something that can be *predicted* and managed, rather than as issues which may arise suddenly and upset the programme’s development.

The second part of a finite future narrative is the crucial role played by the selection of outcomes promised in the programme. The scientific benefits of space missions have always been a core argument behind the value of space technology (Cornelius, 2005; Swaminathan, 2005), and this was reflected in these promises. Interviewee statements about scientific outcomes took two forms. The first was the quantification of eventual knowledge in the form of the expected volume of journal articles (cf. Peterson, 1988; Ezzy, 2001; Aaltojärvi, 2008) which served to express clear and distinct value to scientific programmes within an understanding of research that privileges quantitative data over qualitative. The second was the importance of breakthrough science (Brown, 2000). The thesis explored this as a concept for qualifying the predicted eventual results as being highly significant – the creation of a distinct future for the programme – and that such a promise is created by experts in the field who are trusted to be able to objectively assess the eventual value and outcome of the programme.

In addition to these scientific promises, another benefit for such missions was the proposal reiterated by several interviewees that space programmes requiring finite future narratives are those that are most likely to generate 'inspiration'. Interviewees raised the claim that the Apollo missions paid for themselves via the number of students they inspired into STEM subjects and the subsequent economic benefits (Jones *et al,* 2007), and that this was a hard to quantify but important outcome from science missions. Related to this was the promise of national pride, which although less significant than in the days of the Space Race remained a promised outcome from missions of this sort. Lastly the role of spin-offs was argued by many to be very important to the modern space industry – these are products or applications for *terrestrial* technologies which are not directly related to the objective of the mission itself, but are supposedly generated by the use of involved technologies (Walsh, 2004). This is thereby distinct from the adaptive futures of Chapter 6 which sought to create off-the-shelf components for further *space* applications. Our understanding of the role these promises play built upon the work of Michael (2000), who argues that futures with clear and distinct goals are strengthened by such declarations of intent, and they may overcome some of the negative implications of the temporal distance that must be navigated in order to reach them. Lengthy programmes – focused upon scientific data, the delivery of services based on that data, and spin-off potential – have developed this repertoire of new and highly explicit promised outcomes which are a clear contrast to the earlier Space Race narratives that emphasized competitive geopolitical benefits from cutting-edge space technology (Launius, 2003; Ehrenfreund & Peter, 2009). They have instead been reoriented to emphasize the value of such missions to both the scientific community and further afield including actors involved in private commerce and education, making for clearly beneficial outcomes that a finite future narrative can promise to sell the value of the programme.

These two above facets are combined to create future narratives specially designed for science-orientated high-risk programmes, which present their objectives as clear and easily-attained, despite the significant length of time they may take. This model of the two-part future narrative is a key contribution of this thesis to the understanding of the oft-neglected temporal dimension of high-risk technologies, and how cutting-edge high-risk technological developments – be they supercolliders and particle accelerators (Galison, 1997; Knorr-Cetina, 1999), fusion reactors (Kinsella, 1999), or space technologies – can make compelling promises, appeal to a wider range of actors, and seek to keep those involved on-track until the completion of the programme, however distant that may be. In this way the finite future narrative demonstrates the importance of *time* for STS research into high-risk technologies, and outlines how those developing such technologies seek to negotiate these timescales.

7.2.2. Normalized Future Narratives

The second type of future narrative proposed from the research data is the normalized future narrative. Whereas finite future narratives aim to promote the types of programme many associate with the space industry – mostly long, complex scientific missions – the normalized future narratives propose the opposite, and emphasize ordinary, mundane and predictable space missions. This second form of future narrative was described in Chapter 5, which proposed the case study of the 'Skylon' spaceplane as illustrative of this trend, and identified three specific conservative themes from the interview data that have encouraged the space sector towards this normalization.

The first theme was the nature of the changing customer base for the space industry, and why this customer base demands such high reliability. Interviewees argued that those previously integral to the space industry such as national military establishments (Huntley *et al*, 2010), governments (von der Dunk, 2011) and scientists (Pickering, 1984:11) have not been entirely forced out, but many of the key actors in the space industry now are businesses, commercial actors and private industries. This new commercial presence within the space sector (Fisk, 2008) has strong motivations for encouraging a more cautious use of technology. Interviewees argued that much of the space sector is now concerned with being able to provide a *service*, such as phone communications, television, and broadband access. The space industry normalizes future narratives in order to emphasize that these programmes are safe, trusted and reliable ways to provide such services, and they focus upon the service the technology provides, rather than the technology that provides the service. Satellites of this sort are defined in terms of the length and quality of services they can provide to the customer, rather than by the specifics of the technologies, and this means emphasizing their reliability and ordinariness over their technical specifications.

The second conservative theme was the importance of the past, specifically in terms of established human actors and well-trusted components (the development of which was specifically explored in Chapter 6). A number of interviewees explained a two-part preference for older components, consisting of both the observation that older components are perceived as being well-used, well-trusted, and suitably tested (unlike their newer equivalents), and that older circuit boards were potentially technically superior for in-space use due to radiation damage being reduced across circuitry which had ‘wider spacing’ than their more modern equivalents. By using older components a programme appears more appealing to conservative customers who do not require the newest and most innovative components, but instead desire components that have routinely demonstrated their correct functioning. Other interviewees described the role of individuals who have been well-established within the industry for several decades as another source of conservative preference, arguing that such individuals support older components that they feel confident with using or had a hand in developing, rather than their newer equivalents (cf.

van Maanen & Schein, 1977; Wynne, 1983; King & Sethi, 1992; Chompalov & Shrum, 1999).

The third theme was a three-part issue. Interviewees explained that satellites cannot be retrieved after they have been launched and that launch itself is currently limited to chemical rockets, which are highly expensive and must be booked several months or years in advance. These meant that service satellites are expected to function correctly for significant lengths of time because they cannot be repaired after launch, and because each launch is a large investment. In turn this requirement for lengthy survival in space pushes the space industry towards proposing reliable missions that can meet this requirement. These were therefore the three themes drivers towards normalizing the future narratives for the service-led parts of the space industry – to satisfy a conservative market-focused customer base, to use reliable components rather than newer untested equivalents, and to survive for as long as possible in the space environment.

Chapter 5 explored the impact of these three themes by examining the case study of the Skylon spaceplane. A number of interviewees were involved in the Skylon programme, and they described the importance of presenting Skylon – intended to be a highly innovative form of satellite delivery system – as being ordinary, mundane, and in keeping with previous expectations of the space industry. Although the interviewees working on this programme were generally keen to emphasize to me the new nature of several of the technologies involved and its potential to 'revolutionize' the space industry, the Skylon programme is depicted and defined publicly in language that emphasizes its ordinariness and evolution from older launch vehicles. Instead of affirming the break with the dominant chemical rocket launch regime, the future narrative for Skylon has been normalized. It emphasizes the continuity of Skylon with existing launch vehicles in terms of cost, turn-around time, efficiency and safety, and says little of the technologies underpinning the programme. It is presented as an improvement in these space industry metrics that customers care about, and plays down the precise ways these improvements will be technologically delivered. Viewed within the context of the three conservative themes identified, Skylon appeals to conservative commercial actors by stressing its proximity to current launch technologies in terms of the service it provides; by building upon the past by downplaying its riskier new components and emphasizing its older components; and by promising a reduction to the cost of launch coupled with the potential to retrieve a satellite, therefore suggesting that future satellites may not need to survive untouched in the space environment for as long, and more sophisticated and higher-risk satellites may be acceptable for use in the future.

These narratives were thereby found to be primarily concerned with the mitigation of perceived risk in a high-risk sector, rather than the negotiation of lengthy timescales, and seek to present a programme as a *reliable* method of service provision above all else. A normalized future narrative takes an established set of assumptions about the expected high-risk nature of a technological industry, and undermines these assumptions by playing down the technical details of the technology and playing up what the technology can offer the customer. This showed that much of the space industry in established space-faring nations is no longer concerned with providing spectacle or technological firsts – although these concerns remain significant for some nations developing a space industry for the first time (Luukkonen *et al*, 1992; Peter, 2006:109) – but rather with the normalization of the space industry as a field of high-risk technology that is now well-suited to the provision of certain services. Much as the Internet shifted from a high-reliability organization (cf. Boin & Schulman, 2008) focused on guaranteeing communication infrastructure in a time of nuclear war towards being a global communication and information exchange (Abbate, 1999), the aerospace industry shifted from military concerns (Law, 2002) towards passenger jets (Downer, 2010), and nuclear power moved from military-scientific research (Rosenberg, 1983) to a major source of global energy production (Winner, 1986), this is a reorientation of space industry promises towards providing ‘real’ and practical benefits rather than pushing the boundaries of science or technology. This means iterating upon a service that already exists instead of developing something new and innovative, whilst emphasizing the ordinariness and standardization of their objectives in order to present a high-risk technology as something much reliable and mundane. The concept of the normalized future narrative therefore allows us to examine how a previous version of a complex high-risk technology (such as aerospace, nuclear power, the Internet, or space technology) may reorient and normalize in order to meet consumer needs after a loss of state investment, or an increase in private investment, and what forms their predictions for future service provision subsequently take.

7.2.3. Adaptive Future Narratives

The third contribution of this thesis is the ‘adaptive future narrative’, the final form of future narrative identified from the research data. This is a narrative designed to be used for individual *components* such as circuit boards or communications hardware, not entire satellites, fleets of satellites, or space probes. Whereas the finite future narrative is concerned with securing and promoting a long timescale programme, and a normalized future narrative is concerned with reducing the perception of risk and presenting a programme as conservative and reliable, an adaptive future narrative is focused on the concept of *credibility*. The analysis of the research data showed that credibility serves to both mitigate concerns of timescale and risk equally, whilst the previous two forms of future narrative are focused almost entirely on each of these in turn. Chapter 6 explored in detail the sequence of steps required to make a component ‘credible’, with interviewees arguing that new space components must be carefully planned, documented, tested, accredited and qualified before any launch can take place. Interviewees presented these in a linear sequence of progression through three ‘stages’, and in keeping with grounded theory, this was the analytical structure used.

The first step was the acquisition of ‘early credibility’. Based on interviewee data the chapter identified two central aspects of this first stage – accreditation from a seemingly-neutral technical arbiter such as a space agency, or initial funding from a government body. Both of these were seen as methods for a new component to immediately gain an initial level of credibility and in many cases to then ‘unlock’ funding from private investors. Accreditation from third-party bodies and space agencies like ESA were seen as neutral and objective judgements on the future potential of a new component. Initial funding from governments – seen as more willing to continue support for long periods of time – was perceived as a way to convince private actors that the component development was unlikely to stall, should not lose funding, and had a public ‘anchor tenant’ in the government who would continue to contribute to its development. In turn, each of these allows for the acquisition of further support for developing the component.

Interviewees argued that as development continued, a discursive construct known as ‘Technology Readiness Levels’ was of eminent importance. The TRL system is presented as a method for quantifying the ‘stage’ a technology is at into a number between 1 and 9. Not just used within the space industry, the TRL system is also utilized in other high-risk industries including energy (e.g. Sanchez, 2011) and aviation (Krois *et al*, 2003). This system was found to make two key assumptions: that developing technology is a linear process (Williams, 2006) and that the stage of this process a technology is at may be readily and objectively assessed (cf. Ezzy, 2001). Interviewees suggested that the TRL system was universal and impossible to misconstrue – those judging a technology’s TRL will always judge it correctly, and this judgement can then easily be transferred to other engineers or outside actors to give them an impression of the component's 'level' of development. TRLs actually serve as a rhetorical tool for recruiting actors into component development by presenting a seemingly objective measure of the component's technological 'level', and therefore how far it has to go until it can be safely used. The research found that within the space industry the TRL system is closely tied to the creation of testing standards, and their use in extensive regimes of testing, due to the shift in much of the industry towards the provision of services. These testing regimes involved the construction of a similarity relationship (Pinch, 1993) between the tests on the ground – involving vacuum, vibration, and extreme levels of heat and cold – and what a component would undergo when actually deployed in a space environment. These tests are carried out according to certain standards which many interviewees argued were as universal as the TRL systems and had remained the same over time, though others stepped outside this 'public image' discourse and explained the iterative and debated nature of standardization within the space industry. Chapter 6 argued that the eventual documentary evidence of a component having been tested *per se* is just as important as the actual metrics by which those tests were carried out, and that this form of public visibility of appropriate testing forms another type of evidence used for an adaptive future narrative.

The third and final stage of acquiring credibility was what I termed 'launch credibility', and consisted of two parts. The first of these parts was a component being qualified for launch, which once more involved trusted bodies or industry experts who look back at the history of testing (and therefore the *visible* and documented history of credibility) that a component has accrued, and decide whether or not it is ready for flight. Much like testing, qualification is also a public act focused upon the presentation of appropriate expert judgement and the transformation of a component-in-development into a 'product' or a piece of 'flight standard equipment'. Qualification leads to the second part of launch credibility –

flight testing and subsequent flight heritage. Interviewees described this as a process where new components would be flown for the first time, sometimes on what were termed ‘technology development missions’ (e.g. TDS1), and their performance in a space environment would be monitored and recorded. This was not, however, an implicit admission that the similarity relationship between the test environment and the space environment were not as closely intertwined as interviewees had previously claimed. Chapter 6 showed that it was instead a matter of further creating documentation and credibility evidence that can later be used by that component: the evidence of the component performing correctly *in situ* is a necessary step to gain more credibility, not a tacit admission that it is considered at all possible the component could fail after reaching this stage.

Having gained flight heritage, a component’s past narrative of credibility and success is complete, and this enables the construction of an adaptive future narrative. An adaptive future narrative consists of the sum total of all the evidence of testing and qualification and *credibility* up to the present that a component has accumulated. The greater this body of credible evidence, the more easily adaptable the component will seem to any new programme. This future narrative is thereby dependent on the strength of the narrative about the component’s successful past (Michael, 2000:22). This transforms the component into an ‘off-the-shelf’ (Buckley & Vangaasbeck, 1994; Goodman, 2002; Underwood, 2003) piece of hardware that can be used in any number of roles for a potentially limitless (or at least highly significant) length of time in the future. In the space industry this transformation takes place as a component is used in a greater and greater number of satellites, but this concept of component credibility and promised adaptability also has potential analytic use in other high-risk industries that utilize significant numbers of similar or identical components.

Therefore, just as many of these credibility forms were designed to make a component look less risky and reduce its perception as being ‘untested’, they are also relevant to the temporal dimension of high-risk technologies. A credible component is fundamentally one that has *already been used*. For those constructing a high-risk technology, a credible off-the-shelf component that can be easily adapted to their needs is far more appealing than having to design, test and qualify one anew. An off-the-shelf component is not only highly credible because it gained initial interest and passed the appropriate testing regimes, but also because it has been used in the past and never failed. In this way a second similarity relationship is established – it is assumed that it will behave the same the *next* time it is used, and *every* time after that. The meaning of ‘credibility’ used in this thesis is therefore distinct from the meaning of ‘reliability’ that was essential to normalized future narratives. Reliability is a metric used for determining whether or not a service will continue to function for a suitably long period of time. By contrast, credibility refers to the belief that a component will function correctly in any possible role in any future mission. This is not to say the two are not interrelated – credible components contribute to a reliable service – but reliability is a question of *service provision*, whereas credibility is a question of *technical failure*. In this way, adaptive future narratives are a tool for STS to elucidate how components designed for a single iteration of a high-risk technology may be applied to many other programmes within that same industry. This concept has potential applicability to other sectors including air traffic control (e.g. Wickens *et al*, 1998), chemical plants (e.g. Perron & Friedlander, 1996; Perrow, 1999), and nuclear weapons (e.g. Mackenzie, 1990). The concept of the adaptive future narrative makes clear the process by which a component is made credible, how an untested component is transformed into an off-the-shelf component, and how an eventual redeployment of use from one programme to another is achieved.

7.3. From ‘High-Risk’ to ‘High-Risk Long-Term’

It is clear from the above summaries that the term ‘high-risk’ is not analytically adequate to describe the space industry or other similar technological sectors. Whilst naturally the entire analysis presented in the previous six chapters cannot ever be satisfactorily compressed into a single term, it is nevertheless apparent that ‘high-risk’ only makes visible one of the two crucial dimensions to these sectors. I therefore conclude this thesis by proposing that technological developments of this sort would benefit from being analytically re-framed into ‘high-risk, long-term’ (HRLT) technologies.

This term is designed to build upon prior work on high-risk industries by identifying the importance of the temporal dimension both in this study, and as a route for future research into similar technological sectors. Timescales of technological development are an aspect previously noted as being important to many futures (Giddens, 1997; Michael, 2000; Elzinga, 2004) and narratives (Ewick & Silbey, 1995; Orbuch, 1997), and in proposing this term I seek to more closely integrate these analyses into research on high-risk technologies. The thesis has demonstrated both the importance of the temporal dimension to future planning within the space industry, and the close interplay between the risk and the timescales – the longer a programme, the greater the financial risk will become. The more reliable a programme must be in order to reduce the perception of risk, the longer its components will take to undergo the appropriate processes of acquiring credibility. The further in the past a component was developed, the less risky it appears. By highlighting the importance of the temporal dimension as identified in the research data, this thesis has brought into greater focus for STS the importance of the development timescales of high-risk technologies, hitherto ordinarily a distant secondary characteristic to their risk or complexity. As such the space industry can be much more accurately understood as a HRLT sector rather than the high-risk definition which this thesis began with, and this new definition in turn brings us to the potential future research questions raised by this study.

7.4. Implications for Future Research

The aim of this thesis was to understand the use of future narratives in high-risk industries, motivated by a relative scarcity of STS literature exploring the variables which determine the outcomes of such endeavours. To answer this question this thesis has presented a typology of future narratives that describe and analyze the processes by which a high-risk technological industry seeks to promotes the value of its technology developments, and negotiate the pitfalls of high-risk and long-term development programmes. This contributes to the existing sociological body of work on high-risk technologies (which the space industry is a relatively new addition to) by both proposing these future narratives as mechanisms to support and promote dominant frames, and by bringing to the fore the importance of the temporal dimension.

The first route for future research would be into the applicability of this work's three-part future narrative analysis into other high-risk industries, and therefore how important the temporal dimension is to high-risk industries beyond the space sector. The question that opened this research was the use of narratives within high-risk industries, using the space industry as an example. Three forms of narrative have been identified and this thesis has demonstrated the uses of all three forms within the space industry, all of which to a greater or lesser extent acknowledge and attempt to deal with the long development times of the space industry. Subsequently in this chapter (and in the summaries in each of the three preceding chapters) I have presented a number of examples from existing scholarly work into high-risk technologies where potential overlaps with this thesis can be identified. This included other cutting-edge science orientated programmes (Kinsella, 1996; Galison, 1997; Knorr-Cetina, 1999), high-risk sectors which have shifted towards normalizing their promises and providing services (Winner, 1986; Abbate, 1999; Downer, 2010), and high-risk sectors where standardized components are of particular importance (Mackenzie, 1990; Wickens *et al,* 1998; Perrow, 1999). Many of these existing studies into high-risk industries covered in Chapter 2 acknowledge the lengthy temporal dimension, but this is rarely the analytic focus. A study into how well the typology presented here can be generalized would take the form of an examination of another high-risk industry, using the same research methods and emphasis on grounded theory as in this thesis. Such a study would examine whether the forms of narrative that emerged from another high-risk industry were comparable to those within this thesis, and whether that industry's long development times are as consequential as they are within the space industry.

For such a study to confirm the findings of this thesis, it is not sufficient that other high-risk technologies are developed over long periods of time. To consider other industries to be HRLT, the temporal dimension must be *important* or essential to their development processes, not merely a backdrop over which the technology develops as it has hitherto been understood (2.2.2). Towards the end of this research I considered proposing that a range of related high-risk technologies should also potentially be re-framed as high-risk long-term technologies, due to both the identified importance of temporality within the space industry coupled with the tacit acknowledgement in other scholarly works about the long timescales of such industries. However, despite this work's significant contribution to understanding the temporal dimension of high-risk technological development, I believe such a conclusion is premature. A proposed redefinition of this sort may be inappropriate for high-risk industries that can still rely on significant state investment, and therefore may not suffer as many of the temporal pitfalls as the newly-commercialized space industry.

This potential research direction would therefore seek to answer this question, look more closely into the long development times of other high-risk sectors, and explore which other industries would be more accurately defined with the HRLT label.

A second potential research direction involves a second study of the space industry itself. The arguments summarized were derived from the descriptions provided by interviewees of how future narratives are constructed within the space industry and the kinds of uses to which they are put. In doing so this thesis followed a grounded theory approach to data acquisition and analysis, allowing the three future narratives to emerge from the gathered data on the methods by which space programmes are promoted and managed. Throughout this thesis the comments of interviewees have often emphasized the importance of documents for roadmaps, testing results, testing standards, or qualifications. However, for reasons explored in Chapter 2, a documentary analysis was considered unviable for this research. Many of the documents I wished to view were classified (Winner, 2004), whilst other documents required the navigation of lengthy procedures to secure my access to them, and in many cases only a single stakeholder denying access would have been enough to fully deny access. In a few cases documents were offered that I could read but not quote, whilst a final category of document I was not allowed to view the smallest part of, apparently on the rationale that even the slightest breach of programme secrecy would be unacceptable (cf. Balmer, 2004:223).

A decision was thus made to focus upon a detailed analysis of interview data instead of conducting a partial textual analysis with potentially insufficient data to support it. Therefore, in future research a documentary analysis could be pursued at the start of the research, in order to both allow the casting of a much wider net for those who might provide access to such documents, and a greater length of time for going through the processes and procedures required to access certain documents. Such research would provide a valuable secondary perspective to the analysis presented here. This thesis has shown how these future narratives are created, how space industry employees subsequently use them, and how the space industry subsists on the back of these three narrative types. A subsequent accompanying study of this sort would pursue the textual content of the documents which support these narratives and examine how these future narratives are presented on paper, to complement the primary analysis presented here about their use and construction. This would be particularly applicable to the choices of language used for normalized future narratives as explored in Chapter 5, and further study of testing regimes and standards as forms of documentary visibility as explored in Chapter 6.

APPENDIX A: INFORMED CONSENT FORM (IN-PERSON INTERVIEWS)

My name is Mark Johnson. I am doing a research project on space technology in the United Kingdom, looking particularly at the construction of futures for space technology (long-term planning, goals, objectives, foresight, etc) and how space as an area for human activity is perceived by those within the space industry (whether human activity in space should be focused on private development, public goods, scientific advancement, infrastructure, communication, exploration, experimental technology, some combination of the above, or anything else).

This interview will be recorded, but the recording will be confidential, anonymised and then deleted from my recorder as soon as it is typed up. The data will be used for no purpose other than this study. Anything that identifies you or others by name or association will be removed from the data. I would like to emphasize that your participation is entirely voluntary, you may withdraw at any point (and ask for any prior data to be deleted if you do) and choose not to answer any question you don't feel comfortable with. The interview will last for between an hour and an hour and a half, depending on the directions the interview takes. I am interested in your personal perspectives on the questions and reflections on your specific roles in the projects – not the 'official line' – and no value judgments will be passed on any of your comments.

My supervisor is Mr Brian Loader, who can be contacted on 01904 432639, brian.loader@york.ac.uk, or at:

Mr Brian Loader
Department of Sociology
University of York, Heslington

York, YO10 5DD
brian.loader@york.ac.uk

Please sign, print & date this form to show I have explained the contents and you understand them.

Signed:

Printed:

Date:

APPENDIX B: INFORMED CONSENT FORM (PHONE INTERVIEW)

My name is Mark Johnson. I am doing a research project on space technology in the United Kingdom, looking particularly at the construction of futures for space technology (long-term planning, goals, objectives, foresight, etc) and how space as an area for human activity is perceived by those within the space industry (whether human activity in space should be focused on private development, public goods, scientific advancement, infrastructure, communication, exploration, experimental technology, some combination of the above, or anything else).

This interview will be recorded, but the recording will be confidential, anonymised and then deleted from my recorder as soon as it is typed up. The data will be used for no purpose other than this study. Anything that identifies you or others by name or association will be removed from the data. I would like to emphasize that your participation is entirely voluntary, you may withdraw at any point (and ask for any prior data to be deleted if you do) and choose not to answer any question you don’t feel comfortable with. The interview will last for between an hour and an hour and a half, depending on the directions the interview takes. I am interested in your personal perspectives on the questions and reflections on your specific roles in the projects – not the ‘official line’ – and no value judgments will be passed on any of your comments.

My supervisor is Mr Brian Loader, who can be contacted on 01904 432639, brian.loader@york.ac.uk, or at:

Mr Brian Loader
Department of Sociology
University of York, Heslington
York, YO10 5DD

brian.loader@york.ac.uk

Please sign, print & date this form to show I have explained the contents and you understand them. Since this form has been emailed, not signed in person, you – the interviewee – understand that a name written below is valid in the same way as a signature would be.

Signed:

Printed:

Date:

APPENDIX C: REPRESENTATIVE INTERVIEW QUESTIONNAIRE

(Final Version)

Introduction, job description, personal history

- Career to date
- What projects have you worked on?
- Project objectives? How were they decided?
- Importance of objective? Closed/open objectives?

Credibility

- How does credibility vary between different programmes?
- Component credibility,
- Private/public credibility
- Scientific/technological credibility

Roadmapping and Planning

- Roadmapping, uses of roadmapping, types of roadmap
- Affect future, or respond to future?
- Importance of timescale
- Roadmaps as justification and legitimation

Mundanity

- Risk and Reliability
- Customers, service provision, private spaceflight
- Old components, new components, trusted components
- Lifespan, launch, retrieval

Other, broader questions, relate to earlier questions

- Return to Apollo, big state funding, etc.
- Private spaceflight Next Big Thing?
- Future public goods/impacts? Achievability of 10% by 2030?
- What is the future role for UK space?

LIST OF ABBREVIATIONS

ANT	Actor-Network Theory
ECSS	European Cooperation for Space Standardization
EQSR	Engineering Qualification Status Review
ESA	European Space Agency
HRLT	High-Risk Long-Term
HRO	High-Reliability Organization
NASA	National Aeronautics and Space Administration
SCOT	Social Construction of Technology
SSK	Sociology of Scientific Knowledge
STEM	Science, Technology, Engineering and Mathematics
STS	Science and Technology Studies
TSB	Technology Strategy Board
TDS1	TechDemoSat 1
TRL	Technology Readiness Level
UKSA	United Kingdom Space Agency

BIBLIOGRAPHY

Aaltojärvi, I.; Arminen, I.; Auranen, O. & H-M Pasanen (2008). Scientific Productivity, Web Visibility and Citation Patterns in Sixteen Nordic Sociology Departments. *Acta Sociologica,* 51 (1), 5-22.

Abbate, J. (1999). *Inventing the Internet, Inside Technology.* Cambridge MA: MIT Press.

Adam, B. (1995). *Timewatch: The Social Analysis of Time.* Cambridge, UK: Polity Press.

Adam, B. (2004). *Time.* Cambridge UK: Polity Press.

Akiwate, G.; Aras, S.; Muralikrishnan, S.; Mhatre, N.; Karve, M. & Deshmukh, V. (2012). Open Source Student Satellites: Benefits and Implementation. *Proceedings of 63rd International Astronautical Congress* [Online]. Available at http://www.coep.org.in/csat/wp-content/uploads/2014/08/Open-Source-Student-Satellites-Benefits-and-Implementations.pdf [Accessed on 22/12/2014].

Akrich, M. (1997). The De-Scription of Technical Objects. In Bijker, W. E & Law, J. (Eds.) *Shaping Technology/Building Society: Studies in Sociotechnical Change* (205-225). Cambridge, MA: MIT Press.

Alexander, C. (1983). Preserving High Technology Secrets: National Security Controls on Research and Trading. *Law and Policy in International Business*, 15 (1), 173-240.

Alic, J. A.; Branscomb, L. M.; Brooks, H.; Carter, A. B. & Epstein, G. L. (1992). *Beyond the Spinoff: Military and Commercial Technologies in a Changing World*. USA: Harvard Business School Press.

Ancarani, V. (1995). Globalizing the World: Science and Technology in International Relations. In Jasanoff, S. *et al* (Eds.), *Handbook of Science and Technology* Studies (652-671). New York: Sage Publications.

Anderson, R. (2008). Future-Proofing the Library: Strategies for Acquisitions, Cataloging, and Collection Development. *The Serials Librarian: From the Printed Page to the Digital Age*, 55 (4), 560-567.

Ashforth, B. & Kreiner, G. E. (1999). “How Can You Do It?” Dirty Work and the Challenge of Constructing a Positive Identity. *Academy of Management Review*, 24, 413-434.

Autio, E.; Hameri, A-P. & Nordberg, M. (1996). A framework of motivations for industry-big science collaboration: a case study. *Journal of Engineering and Technology Management*, 13 (3-4), 301-314.

Bach, L.; Cohendet, P. & Schenk, E. (2002). Technological Transfers from the European Space Programs: A Dynamic View and Comparison with Other R&D Projects. *The Journal of Technological Transfer*, 27 (4), 321-338.

Baldesarra, M. (2005). A Decision-Making Framework to Determine the Value of On-Orbit Servicing Compared to Replacement of Space Telescopes. [Online]. Available at http://dspace.mit.edu/bitstream/handle/1721.1/40857/197043508.pdf?...1 [Accessed on 21/12/2014].

Balmer, B. & Sharp, M (1993). The Battle for Biotechnology: Scientific and Technological Paradigms in the Management of Biotechnology in Britain in the 1980s. *Research Policy*, 22, 463-478.

Balmer, B. (2006). A Secret Formula, a Rogue Patent and Public Knowledge about Nerve Gas: Secrecy as a Spatial-Epistemic Tool. *Social Studies of Science*, 36 (5), 691-722.

Balmer. B. (2004). How does an accident become an experiment? Secret science and the exposure of the public to biological warfare agents. *Science as Culture*, 13 (2), 197-228.

Balogh, W. (2011). Capacity building in space technology development: a new initiative within the United Nations programme on space applications. *Space Policy*, 27 (3), 180-183.

Balogh, W.; Canturk, L.; Chernikov, S.; Doi, T,.; Gadimova, S.; Haubold, H. J.; and Kotelnikov, V. *(*2010). The United Nations Programme on Space Applications: Status and direction for 2010. *Space Policy,* 26, 185-88.

Barnes, B. (1974). *Scientific Knowledge and Sociological Theory*. Oxford: Routledge & Kegan Paul.

Barry, A. (2001). *Political Machines*. New York: Athlone Press.

Baskaran, A. & Boden, R. (2004). Science: A Controversial Commodity. *Science, Technology and Society*, 9 (1), 1-26.

Behn, R. D. (1995). The Big Questions of Public Management. *Public Administration Review*, 55 (4), 313-324.

Berg, M. (1998). The Politics of Technology: On Bringing Social Theory into Technological Design. *Science, Technology and Human Values*, 23, 456-490.

Bijker, W. E. (1993). Do Not Despair: There Is Life after Constructivism. *Science, Technology & Human Values*, 18 (1), 113-138.

Bijker, W. E. (1995). *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change*. Cambridge MA: MIT Press.

Bijker, W. E. & Law, J. (Eds.) (1997). *Shaping Technology/Building Society: Studies in Sociotechnical Change*. Cambridge, MA: MIT Press.

Bijker, W. E. & Pinch, T. (2002). SCOT Answers, Other Questions: A Reply to Nick Clayton. *Technology and Culture,* 43 (2), 361-369.

Bijker, W; Pinch, T. & Hughes, T. (2012). *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. Cambridge, MA: MIT Press

Blankenship, L. (1974). Management, Politics and Science: A nonseparable system. *Research Policy*, 26 (7), 24-46.

Blume, S. (1974). *Toward a Political Sociology of Science*. London: Collier Macmillan Publishers.

Boin, A. & Schulman, P. (2008). Assessing NASA's Safety Culture: The Limits and Possibilities of High-Reliability Theory. *Public Administration Review,* 68 (6), 1050-1062.

Bonometti, R. J.; Wheatley, A. A.; Flynn, L.; Nicastri, E. & Sudol, R. (1991). DARPA Initiatives in small-satellite technologies. *Proceedings of SPIE*, 166 [Online]. Available at http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=965607 [Accessed on 22/12/2014].

Borup, M.; Brown, N.; Konrad, K. & van Lente, H. (2006). The Sociology of Expectations in Science and Technology. *Technology Analysis and Strategic Management*, 18 (3-4), 285-298,

Bourdieu, P. (1975). The specificity of the scientific field and the social conditions of the progress of reason. *Social Science Information,* 14 (6), 19-47.

Bowden, G. (1995). Coming of Age in STS: Some Methodological Musings. In Jasanoff, S. *et al* (Eds.), *Handbook of Science and Technology Studies* (64-79). Thousand Oaks, CA: Sage Publications.

Briggs, H. (2004). Beyond Beagle: Where now for British Space? *BBC News* [Online]. Available at http://news.bbc.co.uk/1/hi/sci/tech/3377115.stm [Accessed on 21/12/2014].

British Interplanetary Society (2014). Human Space Flight. *British Interplanetary Society* [Online]. Available at http://www.bis-space.com/what-we-do/advocacy/human-space-flight [Accessed on 24/12/2014].

Broniatowski, D, Faith, G & Sabathier, V. (2006). The Case for Managed International Cooperation in Space Exploration. *Center for Strategic and Internatinal Studies*, Washington DC.

Brown, N. (2000). Organising/Disorganising the Breakthrough Motif: Dolly the Cloned Ewe meets Astrid the Hybrid Pig. In Brown, N, Rappert, B. & Webster, A. (Eds.), *A Sociology of Prospective Techno-science* (87-109). United Kingdom: Ashgate Publishing.

Brown, N. (2003). Hope Against Hype – Accountability in Biopasts, Presents and Futures. *Science Studies*, 16 (2), 3-21.

Brown, N., Rappert, B. & Webster, A. (2000). Introducing Contested Futures: From looking into the Future to look at the Future. In Brown, N, Rappert, B. & Webster, A. (Eds.), *A Sociology of Prospective Techno-science* (3-20). United Kingdom: Ashgate Publishing.

Brown, N. & Kraft, A.(2006). Blood Ties: Banking the Stem Cell Promise. *Technology Analysis & Strategic Management*, 18 (3/4), 313-327.

Bruner, J. S. (1990). *Acts of Meaning*. Cambridge MA: Harvard University Press.

Bruun, H. & Hukkinen, J. (2003). Crossing Boundaries: An Integrative Framework for Studying Technological Change. *Social Studies of Science*, 33 (1), 95-116.

Bryman, A. (2008). *Social Research Methods.* New York: Oxford University Press.

BSA (2004). Statement of Ethical Practice. [Online]. Available at www.britsoc.co.uk/media/27104/StatementofEthicalPractice.doc [Accessed on 21/3/2012].

Buckley, B. & Vangaasbeck, H. (1994). SCL: An off-the-shelf system for spacecraft control. *Third International Symposium on Space Mission Operations and Ground Data System s* [Online]. Availabe at http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19950010828.pdf [Accessed on 21/12/2014].

Burgel, O. & Murray, G. C. (2000). The International Market Entry Choices of Start-Up Companies in High-Technology Industries. *Journal of International Marketing*, 8 (2), 33-62.

Callon, M, Law, J. & Rip, A. (1986). How to Study the Force of Science. In Callon, M. Law, J & Rip, A (Eds.), *Mapping the Dynamics of Science and Technology* (3-19). London: Macmillan.

Callon, M. (1986a). Some elements of a sociology of translation: Domestication of the scallops and the fishermen of St Brieuc Bay. In Law, J. (Ed.) *Power, Action and Belief: A new Sociology of Knowledge* (196-223). London: Routledge.

Callon, M. (1986b). The Sociology of an Actor-Network: The Case of the Electric Vehicle. In Callon, M. Law, J & Rip, A (Eds.), *Mapping the Dynamics of Science and Technology* (19-35). London: Macmillan.

Campbell, S. W. & Russo, T. C. (2003). The social construction of mobile telephony. *Communication Monographs*, 70 (4), 317-334.

Carayannis, E. G. & Alexander, J. (2001). Virtual, wireless mannah: a co-opetitive analysis of the broadband satellite industry. *Technovation*, 21, 759-766.

CERN (2014). Science and Education: Training Tomorrow's Scientists and Engineers. *CERN* [Online]. Available at http://cern60.web.cern.ch/en/science-education [Accessed on 21/12/2014].

Charmaz, K. (2000). Grounded Theory: Objectivist and Constructivist Methods. Denzin, N. & Lincoln, Y. (Eds.) *Handbook of Qualitative Research* (509-537), California: Sage Publications.

Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis*. London: Sage Publications.

Chompalov, I. & Shrum, W. (1999). Institutional Collaboration in Science: A Typology of Technological Practice. *Science, Technology and Human Values,* 24 (3), 338-372.

Collins, H. & Pinch, T. (1998). *The Golem At Large: What you should know about Technology.* Cambridge: Cambridge University Press.

Collins, H. M. (1992). *Changing Order: Replication and Induction in Scientific Practice*. Chicago: University of Chicago Press.

Collins, R. (1998). *From Satellite to Single Market: New Communication Technology and European Public Service Television*. London: Routledge.

Comaroff, J. & Comaroff, J. (1991). *Of Revelation and Revolution.* Chicago: University of Chicago Press.

Cornelius, C. (2005). Science in the National Vision for Space Exploration: Objectives and Constituencies of the "discovery-driven" paradigm. *Space Policy*, 21, 41-48.

Cowan, R. (1990). Nuclear power reactors: a study in technological lock-in. *Journal of Economic History*, 50 (3), 541-567.

Cowan, R. S. (1994). The Consumption Junction: A Proposal for Research Strategies in the Sociology of Technology. In Bijker, W. E, *et al* (Eds.) S*ocial Construction of Technological Systems: New Directions in the Sociology and History of Technology* (261-280). Cambridge, MA: MIT Press.

Cowen, R. (1995). Space: The International Approach. *Science News,* 147 (20), 312-314.

Crawford, I. A. (2001). The Scientific Case for Human Space Exploration. S*pace Policy,* 17, 155-159.

Davila, J.; Gopalswamy, N.; Haubold, H. J. & Thompson, B. (2007). International Heliophysical Year 2007: Basic Space Science. *Space Policy,* 23, 121-126.

de Laat, B. (2000). Scripts for the Future: Using Innovation Studies to design Foresight Tools. In Brown, N, Rappert, B. & Webster, A. (Eds.) *A Sociology of Prospective Techno-science* (175-208), Ashgate Publishing.

de Montluc, B. (2009). The new international political and strategic context for space policies. *Space Policy*, 25 (1), 20-28.

de Montluc, B. (2012). What is the State of Play in European Governance of Space Policy?. *Space Policy*, 28, 74-76.

Denzin, N. (1998). *Strategies for Qualitative Enquiry*. Thousand Oaks: Sage Publications.

Department of Business, Innovation and Skills (BIS). (2010a). The Size and Health of the UK Space Industry. *BIS* [Online]. Available at http://www.bis.gov.uk/assets/ukspaceagency/docs/industry/oxecon%20executive%20summary%20for%20final%20web%20version.pdf [Accessed 5/9/2012] .

Department of Business, Innovation and Skills (BIS). (2010b). The Space Economy in the UK: An economic analysis of the sector and the role of policy. *BIS* [Online]. Available at http://www.bis.gov.uk/assets/biscore/economics-and-statistics/docs/10-624-bis-economics-paper-03 [Accessed 5/9/2012].

Deuten, J. & Rip, A. (2000). Narrative Infrastructure in Product Creation Processes. In *Organization*, 7 (1), 69-93.

Diener, E. & Crandall, R. (1978). *Ethics in Social and Behavioural Research*. Chicago: University of Chicago Press.

Douglas, S. (1999). *Listening In: Radio and the American Imagination, from Amos N Andy and Edward R Murrow to Wolfman Jack and Howard Stern*. New York: Times Books.

Douglas, S. (2010). Some Thoughts on the Question “How Do New Things Happen”?. *Technology and Culture,* 51, 293-304.

Downer, J. (2010). Trust and Technology: the Social Foundations of Aviation Regulation. *British Journal of Sociology*, 61 (1), 83-106.

Downer, J. (2011). On audits and airplanes: redundancy and reliability-assessment in high technologies accounting. *Organizations and Society*, 36, 269-83.

Ehrenfreund, P. & Peter, N. (2009). Toward a paradigm shift in managing future global space exploration endeavours. *Space Policy*, 25 (4), 244-256 .

Elhefnawy, N. (2004). Viewpoint: Feeling the Pinch: Societal Slack and Space Development. *Astropolitics,* 2 (3), 323-334.

Ellul, J. (1964). *The Technological Society.* Toronto: Random House.

Elo, S. & Kyngas, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing* 62 (1), 107-115.

Elzinga, A. & Jamison, A. (1995). Changing Policy Agendas in Science and Technology. In Jasanoff, S. *et al* (Eds.), *Handbook of Science and Technology Studies* (572-598), New York: Sage Publications.

Elzinga, A. (2004). Metaphors, Models and Reification in Science and Technology Policy Discourse. In *Science as Culture*, 13 (1), 105-121.

Entradas, M. C. d F. (2011). Who's For The Planets? *Doctoral Thesis* [Online]. Available at http://discovery.ucl.ac.uk/1334448/1/1334448.pdf [Accessed on 21/12/2014].

ESA (2014). Launchers Home: International Cooperation. *European Space Agency* [Online]. Available at http://www.esa.int/Our_Activities/Launchers/International_cooperation [Accessed on 21/12/2014].

Eurospace (1994). Small missions: Exploiting the Opportunities. *Space Policy*, 10, 322-326.

Ewick, P. & Silbey, S. (1995). Subversive Stories and Hegemonic Tales: Toward a Sociology of Narrative. *Law and Society Review*, 29 (2), 197-226.

Eysenbach, G. & Till, J. (2001). Ethical Issues in Qualitative Research on Internet Communities. *British Medical Journal*, 332 (7321), 1103-1105.

Ezzy, D. (2001) Are Qualitative Methods Misunderstood?. *Australian and New Zealand Journal of Public Health*, 25 (4), 294-297.

Faulkner, W. (1994). Conceptualizing Knowledge Used in Innovation: A Second Look at the Science-Technology Distinction and Industrial Innovation. *Science, Technology and Human Values*, 19 (4), 425-458.

Feenberg, A. (1999). *Questioning Technology*. New York: Routledge.

Fischer, C. (1992). *America Calling: A Social History of the Telephone to 1940*. Berkeley: University of California Press.

Fisk, L. (2008). The impact of space on society: Past, present and future. *Space Policy*, 24 (4), 175-180.

Futrell, R. F. (1989). Ideas, Concepts, Doctrine: Basic Thinking in the United States Air Force, 1907-1960, Volume 1. USA: Progressive Management.

Gad, C. & Jensen, C. B. (2010). On the Consequences of Post-ANT. *Science, Technology and Human Values*, 35 (1), 55-80.

Galison, P. (1997). *Image and Logic: Material Cultures of Microphysics*. Chicago: University of Chicago Press.

Galvin, R. (1998). Science roadmaps. *Science*, 280, 803.

Garcia, M.L. and Bray, O.H. (1997). "Fundamentals of Technology Roadmapping". *Strategic Business Development Department, Sandia National Laboratories* [Online]. Available at http://www.sandia.gov/PHMCOE/pdf/Sandia'sFundamentalsofTech.pdf [Accessed on 21/12/2014].

Garforth, L. (2011). In/Visibilities of Research: Seeing and Knowing in STS. *Science, Technology and Human Values,* 37 (2), 264-285.

Geels, F. W. & Smit, W. A. (2000). Failed Technology Futures: Pitfalls and Lessons from a Historical Survey. *Futures*. 32 (9-10), 867-885.

Georghiou, L. (1996). The UK Technology Foresight Programme. *Futures,* 28 (4), 359-377.

Georgiadou, M. C.; Hacking, T. & Guthrie, P. (2012). A conceptual framework for future-proofing the energy performance of buildings. *Energy Policy* 47, 145-155.

Gibbons, M. (1994). *New Production of Knowledge: Dynamics of Science and Research in Contemporary Societies.* London: Sage Publications.

Giddens, A. (1997). Risk Society: Context of British Politics. In Franklin, J. (Ed) *Politics of Risk Society* (23-25), Cambridge: Polity Press.

Giere, R. N. (1993). Science and Technology Studies: Prospects for an Enlightened Postmodern Synthesis. *Science, Technology and Human Values*, 18 (1), 102-112.

Glaser, B. & Strauss, A. (1967). *The Discovery of Grounded Theory: Strategies for Qualitative Research*. USA: Transaction Publishers.

Goehlich, R. A.; Blanksby, C.; Goh, G. M.; Hatano, Y.; Pecnik, B. & Wong, J. (2005). Space spin-offs: Making them known, improving their use. *Space Policy*, 21 (4), 307-312.

Goldman, N. (1992). *Space Policy*. Iowa: Iowa State University Press.

Gooday, G. (1998). Re-writing the ‘book of blots’: Critical reflections on histories of technological ‘failure’. *History and Technology: An International Journal*, 14 (4), 265-291.

Goodman, J. L. (2002). Lessons learned from flights of ‘Off the shelf’ Aviation Navigation Units on the Space Shuttle’. *Joint Navigation Conference 2002* [Online]. Available at http://www.nasa.gov/offices/oce/llis/1370.html [Accessed on 24/12/2014].

Greenberg, J. S. (1993). Competitiveness of commercial space transportation services. *Space Policy*, 9 (3), 220-232.

Hackett, E. J; Amsterdamska, O; Lynch, M & Wajcman, J. (2007). Introduction. In Hackett, E. *et al* (Eds.), *Handbook of Science and Technology Studies* (1-9). Cambridge MA: MIT Press.

Hamlin, C. (1992). Reflexivity in Technology Studies: Toward a Technology of Technology (And Science?. *Social Studies of Science*, 22 (3), 511-544.

Handberg, R. B. (2011). Public Sector Actors. In Sadeh, E. (Ed) *The Politics of Space: A Survey* (161-175), London: Routledge.

Heckathorn, D. (2002). *Respondent-Driven Sampling II: Deriving Valid Population estimates from Chain-Referral samples of hidden populations*. [Online]. Available at http://www.princeton.edu/~mjs3/heckathorn02.pdf [Accessed on 21/3/2012].

Hempsel, M. (2010). A phased approach to orbital public access. *Acta Astronautica*, 66 (11-12), 1639-1644.

Hermanowicz, J. C. (2007). Argument and Outline for the Sociology of Scientific (and Other) Careers. *Social Studies of Science*, 37 (4), 625-646.

Hertzfeld, H. R. (2007). Globalization, commercial space and spacepower in the USA. *Space Policy,* 23 (4), 210-220.

Hilgartner, S. (1990). The Dominant View of Popularization: Conceptual Problems, Political Uses. *Social Studies of Science*, 20 (3), 519-539.

Hill, C. N. (2012). *A Vertical Empire: History of the British Rocketry Programme.* London: Imperial College Press.

Hodkinson, P. (2008). Grounded Theory and Inductive Research. In Gilbert, N. (Ed.), *Researching Social Life* (80-101), London: Sage Publications.

Hoerber, T. (2012). New Horizons for Europe: A European Studies perspective on European Space Policy. *Space Policy,* 28 (2), 77-80.

Horneck, G. *et al* (2010). Towards a European vision for space exploration: Recommendations of the Space Advisory Group of the European Commission. *Space Policy*, 26 (2), 109-112.

Hughes, T. P. (1986). The Seamless Web: Technology, Science, Etcetera, Etcetera. *Social Studies of Science*, 16 (2), 281-292.

Huntley, W; Bock, J. & Weingartner, M. (2010). Planning the unplannable: Scenarios on the Future of Space. *Space Policy*, 26 (1), 25-38.

International Business Publications (IBP) USA, (2011). European Space Agency (ESA) Handbook. [Online]. Available at https://books.google.co.uk/books?id=v0R37wUUtOAC [Accessed on 21/12/2014].

Jakhu, R. (2006). Legal Issues relating to the Global Public Interest in Outer Space. *Journal of Space Law*, 32 (1), 31-110.

Jamison, A. (2006) Social Movement and Science: Cultural Appropriations of Cognitive Praxis. *Science as Culture*, 15 (1), 45-59.

Jarritt, I, Peeters, W & Simpson, M. (2010). Space financing in the aftermath of the financial crisis. *Space Policy*, 26 (2), 119-120.

Jasentuliyana, N. (1995). Basic space science and developing countries. *Space Policy*, 11 (2), 89-94.

Jeffries, S. (2003). Sweet smell of failure. *The Guardian Online* [Online]. Available at http://www.theguardian.com/science/2003/dec/30/spaceexploration.britishidentityandsociety [Accessed on 21/12/2014].

Jensen. C. B. & Zuiderent-Jerak, T. (2007). Editorial Introduction: Unpacking "Intervention" in Science and Technology Studies. *Science as Culture*, 15 (3), 227-235.

Jones, H.; Yeoman, K. & Cockell, C. (2007). A pilot survey of attitude to space sciences and exploration among British school children. *Space Policy*, 23, 20-23.

Jørgensen, M. S, Jørgensen, U. & Clausen, C. (2009). The social shaping approach to technology foresight. *Futures*, 41, 80-86.

Kauffman, J. (1997). NASA in Crisis: The Space Agency's Public Relations efforts regarding the Hubble Space Telescope. *Public Relations Review*, 23 (1), 1-10.

Kelland, K. (2015). The Beagle has landed: Britain's missing spacecraft found on Mars. Reuters [Online]. Available at http://www.reuters.com/article/2015/01/16/us-space-beagle-idUSKBN0KP13X20150116 [Accessed on 27/1/2015].

Kenney, M. & Patton, D. (2005). University Entrepreneurial Geographics: Support Networks in Three High-Technology Industries. *Economic Geography*, 81 (2), 201-228.

Kilker, H. & Gay, G. (1998). The Social Construction of a Digital Library: A case study examining implications for evaluation. *Information Technology and Libraries*, 17 (2), 60-70.

King, R. C. & Sethi, V. (1992). Socialization of professionals in high-technology firms. *The Journal of High Technology Management Research*, 3 (2), 147-168.

Kinsella, W. (1996). A "Fusion" Of Interests: Big Science, Government and Rhetorical Practice in Nuclear Fusion Research. *Rhetoric Society Quarterly*, 26 (4), 65-81.

Kinsella, W. (1999). Discourse, Power and Knowledge in the Management of "Big Science": The Production of Consensus in a Nuclear Fusion Research Laboratory. *Management Communication Quarterly*, 13, 171-208.

Kleeschulte, S. & Büttner, G. (2008). European land cover mapping – the CORINE Experience. In Campbell, J. C.; Jones, K. B.; Smith, J. H. & Koeppe, M. T. (Eds.) *Proceedings of the North America Land Cover Summit 2006* (31-44). Washington DC: Association of American Geographers.

Klein, H. K. & Kleinman, D. L. (2002). The Social Construction of Technology: Structural Considerations. *Science, Technology and Human Values*, 27 (1), 28-52.

Kline, R. & Pinch, T. (1996). Users as Agents of Technological Change: The Social Construction of the Automobile in the Rural United States. *Technology and Culture*, 37 (4), 763-795.

Knorr-Cetina, K. (1999). *Epistemic Cultures: How the Sciences Make Knowledge.* USA: Harvard University Press.

Kostoff, R. N. & Schaller, R. R. (2001). Science and Technology Roadmaps. *IEEE Transactions on Engineering Management*, 48 (2), 132-143.

Krige, J. & Russo, A. (2000). A History of the European Space Agency. *European Space Agency* [Online]. Available at http://www.esa.int/esapub/sp/sp1235/sp1235v1web.pdf [Accessed on 18/9/2012].

Krige, J. (2000). Crossing the Interface from R&D to Operational Use: The Case of the European Meteorological Satellite. *Technology and Culture*, 41 (1), 27-50.

Krois, P.; Mogford, R. & Rehmann, J. (2003). FAA/NASA Human Factors for Evolving Environments: Human Factors, Attributes and Technology Readiness levels. *Federal Aviation Authority* [Online]. Available at http://www.hf.faa.gov/docs/508/docs/TRL.doc [Accessed on 21/12/2014].

Kvale, S. (1996). *InterViews: an introduction to qualitative research interviewing*. Thousand Oaks: Sage Publications.

La Porte, R. & Consolini, P. (1991). Working in practice but not in theory: Theoretical Challenges of High-Reliability Organizations. *Journal of Public Administration Research and Theory*, 1, 19-47.

Lachow, I. (1995). The GPS Dilemma: Balancing Military Risks and Economic Benefits. *International Security*, 20 (1), 126-148.

Laird, F. N. (2003). Constructing the Future: Advocating Energy Technologies in the Cold War. *Technology and Culture*, 44 (1), 27-49.

Lakoff, S. & York, H. F. (1989). *A Shield in Space*, University of California Press.

Lambright, W. H. (1994). The Political Construction of Space Satellite Technology. *Science, Technology and Human Values*, 19 (1), 47-69.

Latour, B. (1987). *Science in Action: how to follow scientists and engineers through society*. Cambridge, MA: Harvard University Press.

Latour, B. (1996). On Actor-Network Theory: A Few Clarifications. *Soziale Welt*, 47 (4), 369-381.

Latour, B. (1999). *Pandora's Hope: Essays on the Reality of Science Studies*. Cambridge, Massachusetts/London, England: Harvard University Press.

Latour, B. (2005). *Reassembling the Social: An Introduction to Actor-Network Theory*. Oxford: Clarendon.

Launius, R. (2000). The historical dimension of space exploration: reflections and possibilities. *Space Policy,* 16 (1), 23-38.

Launius, R. (2003). Looking backward/looking forward: Space Flight at the turn of the New Millenium. *Astropolitics,* 1 (2), 64-74.

Lave, R, Mirowski, P. & Randalls, S. (2010). Introduction: STS and Neoliberal Science. *Social Studies of Science*, 40 (5), 659-675.

Law, J. & Hassard, J. (1999). *Actor-Network Theory and After*. Oxford: Blackwell.

Law, J. (1987). Technology and Heterogeneous Engineering: The Case of Portuguese Expansion. In Pinch, T, Bijker, W, E. & Hughes, P. (Eds.) *The Social Construction of Technological Systems* (105-129). Cambridge MA: MIT Press.

Law, J. (2002). *Aircraft Stories: Decentering the Object in Technoscience*. USA: Duke University Press.

Lee, R. (2000). Reconciling International Space Law with the Commercial Realities of the Twenty-First Century. *Singapore Journal of International and Comparitive Law*, 4, 194-251.

Lester, D. F. & Robinson, M. (2009). Visions of Exploration. *Space Policy*, 25 (4), 236-243.

Levine, A. (1985). Commercialization of Space: Policy and Administration Issues. *Public Administration Review*, 45 (5), 562-569.

Levins, R. (1998). The internal and external in explanatory theories. *Science as Culture* 7 (4), 557-582.

Lucquiaud, M.; Errey, O.; Chalmers, H.; Liang, X.; Gibbins, J. & Zahra, M. A. (2011). Techno-economic assessment of future-proofing coal plants with postcombustion capture against technology developments. *Energy Procedia: 10 International Conference on Greenhouse Gas Control Technologies*, 4, 1909-1916.

Luukkonen, T. *et al* (1992). Understanding Patterns of International Scientific Collaboration. *Science, Technology & Human Values,* 17 (1), 101-126.

Lyotard, J-F (1984). *The Postmodern Condition.* (trans G. Bennington & B. Massumi). Manchester: Manchester University Press.

Macdonald, K. (2008). Using Documents. In Gilbert, N. (Ed.) *Researching Social Life* (285-304). London: Sage Publications.

Mackenzie, D. (1990). *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance.* Cambridge, MA/London: MIT Press.

Marshall, W. (2008). Reducing the Vulnerability of Space Assets: A Multitiered Microsatellite Constellation Architecture. *Astropolitics*, 6 (2), 154-199.

McBride, N. (2003). Network Theory and the Adoption of Mobile Communications. *Geography*, 88 (4), 266-276.

Michael, M. (2000). Futures of the Present from Performativity to Prehension. In Brown, N., Rappert, B. & Webster, A. (Eds) *A Sociology of Prospective Techno-science* (21-39). United Kingdom: Ashgate Publishing.

Mort, M. (2008). *Building the Trident Network: A Study of the Enrollment of People, Knowledge and Machines*. Cambridge, MA: MIT Press.

Nelson, R. (1992). What is “commercial” and what is “public” about technology, and what should be?. In Rosenberg, N, Landau, R & Mowery, D. (Eds.), *Technology and the Wealth of Nations* (57-73). USA: Stanford University Press.

Neyland, D. (2006). Dismissed Content and Discontent: An Analysis of the Strategic Aspects of Actor-Network Theory. *Science, Technology and Human Values,* 31 (1), 29-51.

Nolte, William L., *et al*. (2003). Technology Readiness Level Calculator, Air Force Research Laboratory. *Presented at the NDIA Systems Engineering Conference* [Online]. Available at http://www.dtic.mil/ndia/2003systems/nolte.ppt, accessed on 25/2/2014 [Accessed on 22/12/2014].

Nordlund, G. (2012). Time-scales in futures research and forecasting. *Futures,* 44, 408-414.

Ocampo, A.; Friedman, L; Logsdon, J. (1998). Why space science and exploration and benefit everyone. *Space Policy*, 14, 137-143.

Orbuch, T. (1997). People’s Accounts Count: The Sociology of Accounts. *Annual Review of Sociology,* 23, 455-78.

Orlikowski, W. (1992). Management of Technology. *Organization Science*, 3 (3), 398-427.

Pantzar, M. (1997). Domestication of Everyday Life Technology: Dynamic Views on Social Histories of Artifacts. *Design Issues*, 13 (3), 52-65.

Pass, J. (2011). Examining the Definition of Astrosociology. *Astropolitics*, 9 (1), 6-27.

Peeters, W. (2002). Effects of commercialisation in the European space sector. *Space Policy,* 18 (3), 199-204.

Perron, M. J. & Friedlander, R. H. (1996). The Effects of Downsizing on Safety in the CPI/HPI. *Process Safety Progress*, 15 (1), 18-25.

Perrow, C. (1999). *Normal Accidents: Living with High Risk Technologies*, New Jersey: Princeton University Press.

Pestre, D. (2008). Challenges for the Democratic Management of Technoscience: Governance, Participation and the Political Today. *Science as Culture*, 17 (2), 101-119.

Peter, N. (2006). The changing geopolitics of space activities. *Space Policy*, 22 (2), 100-109.

Peterson, C. J. (1988). Citation Analysis of Astronomical Literature: Comments on Citation Half-Lives. *Publications of the Astronomical Society of the Pacific*, 100 (623), 106-115.

Peterson, M. (1997). The Use of Analogies in Developing Outer Space Law. *International Organization,* 51 (2), 245-274.

Petrik, I. J. & Echols, A. E. (2004). Technology roadmapping in review: A tool for making sustainable new product development decisions. *Technological Forecasting and Social Change*, 71, 81-100.

Phaal, R; Farrukh, C. J. P. & Probert, D. R. (2004). Technology Roadmapping – a planning framework for evolution and revolution. *Technological Forecasting and Social Change*, 71, 5-26.

Pickering, A. (1984). *Constructing Quarks: A Sociological History of Particle Physics*. Chicago: University of Chicago Press.

Pinch, T. (1993). "Testing – One, Two Three… Testing!": Toward A Sociology of Testing. *Science, Technology and Human Values*, 18 (1), 25-41.

Pinch, T. (1996). The Social Construction of a Technology: A Review. Fox, R. (Ed.) *Technological Change: Methods and Themes in the History of Technology* (17-37), Amsterdam: Harwood Academic Publishers.

Pinch, T. (2002). Why You Go to a Music Store to Buy a Synthesizer. In Garud, R. & Karnoe, P. (Eds.) *Path Dependence and Creation* (381-399). New York: Lawrence Erlbaum Associates.

Pinch. T. & Bijker, W. E. (1984). The Social Construction of Facts and Artefacts: Or how the Sociology of Science and the Sociology of Technology Might Benefit Each Other. *Social Studies of Science,* 14 (3), 399-441.

Polkinghorne, D. (1988). *Narrative Knowing and the Human Sciences*. Albany NY: State University New York Press.

Radder, H. (1992). Normative Reflexions on Constructivist Approaches to Science and Technology. *Social Studies of Science*, 22(1), 141-173.

Rammert, W. (1997). New Rules of Sociological Method: Rethinking Technology Studies. *British Journal of Sociology*, 48 (2), 171-191.

French, J. R. P. & Raven, B. (1960). The Bases of Social Power. In Cartwright, D. & Zander, A. (Eds.) *Group Dynamics* (259-269). New York: Harper and Row.

Rappert, B; Balmer, B, & Stone, J. (2007). Science, Technology and the Military: Priorities, Preoccupations and Possibilities. In *Handbook of Science and Technology Studies* (719-739). Cambridge MA: MIT Press.

Reaction Engines. (2010). Skylon User Manual. *Reaction Engines* [Online]. Available at http://www.reactionengines.co.uk/tech_docs/SKYLON_User_Manual_rev1-1.pdf [Accessed on 21/12/2014].

Reaction Engines. (2012). REL Heat Exchangers. *Reaction Engines* [Online]. Available at http://www.reactionengines.co.uk/heatex_rel.html [Accessed on 21/12/2014].

Redd, N. T. (2014). What if Apollo 11 Failed? President Nixon Had Speech Ready. *Space.com* [Online]. Available at http://www.space.com/26604-apollo-11-failure-nixon-speech.html [Accessed on 21/12/2014].

Redfield, P. (1996). Beneath a Modern Sky: Space Technology and Its Place on the Ground. *Science, Technology and Human Values*, 21 (3), 251-274.

Rip, A. (2003). Constructing Expertise: In a Third Wave of Science Studies?. *Social Studies of Science* 33 (3), 419-434.

Rosen, P. (1993). The Social Construction of Mountain Bikes: Technology and Postmodernity in the Cycle Industry. *Social Studies of Science*, 23 (3), 479-513.

Rosenberg, D. A. (1983). The Origins of Overkill: Nuclear Weapons and American Strategy, 1945-1960. *International Security*, 7 (4), 3-71.

Rosenberg, N.; Landau, R. & Mowery, D. (Eds.) (1992). *Technology and the Wealth of Nations*. USA: Stanford University Press.

Rubin, H. & Rubin, I. (1995). *Qualitative Interviewing: the art of hearing data*. Thousand Oaks: Sage Publications.

Sadeh, E. (2005). The Evolution of Access to Space as an Idea and Technology. *Astropolitics,* 3 (3), 305-318.

Sadeh, E. (2011). *The Politics of Space: A Survey.* New York: Routledge.

Sagan, S. D. (1995). *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*. New Jersey: Princeton University Press.

Salomon, J-J. (1996). A Science Policy to Cope with the Inevitable?. *Science, Technology and Society,* 1 (1), 73-100.

Sanchez, R. (2011). Technology Readiness Assessment Guide. *Department of Energy* [Online]. Available at https://www.directives.doe.gov/directives-documents/400-series/0413.3-EGuide-04a [Accessed on 21/12/2014].

Sans-Menéndez, L. & Cabello, C. (2000). Expectations and Learning as Principles for Shaping the Futures. In Brown, N, Rappert, B. & Webster, A. (Eds.), *A Sociology of Prospective Techno-science* (229-249). United Kingdom: Ashgate Publishing.

Schatzberg, E. (2004). On Attempting to Construct Alternative Narratives. *Technology and Culture* 45 (2), 406-412.

Schwarz, M. (1979). European policies on space science and technology 1960-1978. *Research Policy*, 8 (3), 204-243.

Sclove, R. (1995). *Democracy and Technology*. New York: Guilford Press.

Selwyn, N. (2007). The use of computer technology in university teaching and learning: a critical perspective. *Journal of Computer Assisted Learning*, 23 (2), 83-94.

Sismondo, S. (2010). *An Introduction to Science & Technology Studies*. Oxford: Blackwell.

Shapin, S. (1995). Here and Everywhere: Sociology of Scientific Knowledge. *Annual Review of Sociology*, 21, 289-321.

Sheehan, M. (2007). *The International Politics of Space*. New York: Routledge.

Sheldon, J. B. (2010). The Strategic Rationale for Britain in Space. *The RUSI Journal*, 155 (6), 28-34.

Siddiqi, A. A. (2010). Competing Technologies, National(ist) Narratives, and Universal Claims: Toward a Global History of Space Exploration. *Technology and Culture*, 51 (2), 425-443.

Sjöberg, L. (2008). Genetically Modified Food in The Eyes of the Public and Experts. *Risk Management*, 10, 168-193.

Slaughter, R. (2002). Futures studies as a Civilizational Catalyst. *Futures*, 34 (3-4), 349-363.

Slayton, R. (2007). Discursive Choices: Boycotting Star Wars Between Science and Politics. *Social Studies of Science,* 37 (1), 27-66.

Slotten, H. R. (2002). Satellite Communications, Globalization, and the Cold War. *Technology and Culture*, 43 (2), 315-350.

Smith, A, Stirling, A. & Berkhout, F. (2005). The Governance of Sustainable Socio-Technical Transitions. *Research Policy*, 32, 1491-1510.

Smith, D. (1993). Technology and the Modern World-System: Some Reflections. *Science, Technology and Human Values,* 18 (2), 186-195.

Sørensen, K. & Levold, H. (1992). Tacit Networks, Heterogeneous Engineers and Embodied Technology. *Science, Technology and Human Values*, 17 (1), 13-35.

Sovacool, B. J. (2010). A Critical Evaluation of Nuclear Power and Renewable Electricity in Asia. *Journal of Contemporary Asia*, 40 (3), 369-400.

Spaceflightnow. (2015). Spaceflight now – Worldwide Launch Schedule. *Spaceflightnow.com* [Online]. Available at http://spaceflightnow.com/launch-schedule/ [Accessed on 21/12/2014].

Stacey, J. (1991). Can There be a Feminist Ethnography?. Gluck, S. & Patai, D. (Eds.) *Women's Words: The Feminist Practice of Oral History* (111-121). New York: Routledge.

Stalder, F. (1997). Actor-Network Theory and Communication Networks: Toward Convergence. [Online]. Available at http://felix.openflows.com/html/Network_Theory.html [Accessed on 21/12/2014].

Stephenson, P. (2012). Talking Space: The European Commission's Changing Frames in Defining Galileo. *Space Policy*, 28 (2), 86-93.

Strathen, M. (1996). Cutting the Network". *Journal of Royal Anthropological Institute*, 2 (3), 517-535.

Swaminathan, S. (2005). Making space law relevant to basic space science in the commercial space age. *Space Policy*, 21, 259-266.

Symmons, J. (2010). Policy and regulatory risk considerations for satellite communications. *Space Policy,* 26 (2), 121-123.

Tutton, R. (2012). Personalizing Medicine: Futures Present and Past. *Social Science and Medicine*, 75 (10), 1721-1728.

UKSA (2012). UK Space Agency Civil Space Strategy, 2012-2016. *BIS* [Online]. Available at http://www.bis.gov.uk/assets/ukspaceagency/docs/uk-space-agency-civil-space-strategy.pdf [Accessed on 5/9/2012].

UKSA (2014). About Us. *United Kingdom Space Agency* [Online]. Available at https://www.gov.uk/government/organisations/uk-space-agency/about [Accessed on 21/12/2014].

Underwood, C. (2003). Observations of Radiation in the Space Radiation Environment and Its Effect on Commercial Off-The-Shelf Electronics in Low-Earth Orbit. *Philosophical Transactions: Mathematical, Physical and Engineering Sciences*, 361 (1802), 193-197.

Unikel, R. (1998). Bridging the 'Trade Secret' Gap: Protecting 'Confidential Information' Not Rising to the Level of Trade Secrets. *Loyola University Chicago Law Journal*, 29 (4), 841-890.

Union of Concerned Scientists (2011). UCS Satellite Database. *Union of Concerned Scientists* [Online]. Available at http://www.ucsusa.org/nuclear_weapons_and_global_security/solutions/space-weapons/ucs-satellite-database.html [Accessed on 22/12/2014].

van den Eede, G.; van de Walle, b. & Rutkowski, A-F. (2006). Dealing with Risk in Incident Management: An Application of High Reliability Theory. *Proceedings of the 39th Annual Hawaii International Conference on System Sciences* [Online]. Available at http://www.researchgate.net/publication/4216083_Dealing_with_Risk_in_Incident_Management_An_Application_of_High_Reliability_Theory/links/0deec523b45c16d232000000.pdf [Accessed on 28/12/2014].

van Dijk, T. (1977). T*ext and Context: Explorations in the Semantics and Pragmatics of Discourse*. London: Longman.

van Lente, H. (2000). Forceful Futures: From Promise to Requirement. In Brown, N., Rappert, B. & Webster, A. (Eds.) *A Sociology of Prospective Techno-science* (43-63). United Kingdom: Ashgate Publishing.

van Maanen, J. & Schein, E. H. (1977). Toward a theory of organizational socialization. *Research in Organizational Behaviour*, 1, 209-264.

Varvill, R. & Bond, A. (2004). Application of Carbon Fibre Truss Technology to the Fuselage Structure of the SKYLON Spaceplane. *Journal of the British Interplanetary Society*, 57 [Online]. Available at http://www.reactionengines.co.uk/tech_docs/JBIS_v57_x-x.pdf [Accessed on 26/12/2014].

Vedda, J. (2002). Space Commerce. In Sadeh, E. (Ed.), *Space Politics and Policy* (201-229), London: Kluwer.

Vedda, J. (2008). Challenges to the Sustainability of Space Exploration. *Astropolitics*, 6 (1), 22-49.

Venturini, T. (2010). Diving in Magma: How to Explore Controversies with Actor-Network Theory. *Public Understanding of Science*, 19 (3), 258-273.

Veroff, J, Sutherland, L, Chadiha, L. & Ortega, R. M. (1993). Newlyweds tell all their stories: a narrative method for assessing martial experiences. *Journal of Social and Personal Relationships,* 10 (3), 437-457.

Vikkelsø, S. (2007). Description as Intervention: Engagement and Resistance in Actor-Network Analyses. *Science as Culture*, 16 (3), 297-309.

von der Dunk, F. (2011). Space tourism, private spaceflight and the law: key aspects. *Space Policy,* 27 (3), 146-152.

Vuola, O. & Hameri, A-P. (2006). Mutually Benefitting Joint Innovation Process between Industry and Big Science. *Technovation*, 26 (1), 3-12.

Walker, J. (1993). A Rocket a Day Keeps the High Costs Away. [Online]. Available at http://www.fourmilab.ch/documents/rocketaday.html [Accessed on 21/12/2014].

Wall, T. D. & Wood, S. J. (2005). The romance of human resource management and business performance, and the case for big science. *Human Relations*, 58 (4), 429-462.

Walsh, S. (2004). Roadmapping a disruptive technology: A case study: The emerging mirosystems and top-down nanosystems industry. *Technological Forecasting and Social Change*, 71, 161-185.

Weick, K. E.; Sutcliffe, K. M. & Obstfeld, D. (1999). Organizing for High-Reliabilty: Processes of Collective Mindfulness. In Sutton, R. S. & Staw, B. M. (Eds.), *Research in Organizational Behaviour*, Volume 1 (81-123). Stanford: Jai Press.

White, H. (1987). *The Content of the Form*. Baltimore: John Hopkins University Press.

Whitten, B. L. (1996). What Physics is Fundamental Physics? Feminist Implications of Physicists' Debates over the Superconducting Supercollider. *NWSA Journal*, 8 (2), 1-16.

Wickens, C. D.; Mavor, A. S.; Parasuraman, R. & McGee, J. P. (1998). *The Future of Air Traffic Control*. USA: National Academies Press.

Williams, R. (2006). Compressed Foresight and Narrative Bias: Pitfalls in Assessing High Technology Futures. *Science as Culture,* 15 (4), 327-348.

Winner, L. (1977). *Autonomous Technology.* USA: To the Lighthouse Press.

Winner, L. (1986). *The Whale and the Reactor: A search for limits in the age of High Technology*. Chicago: University of Chicago Press.

Winner, L. (2004). Trust and Terror: The Vulnerability of Complex Socio-Technical System. *Science as Culture*, 13 (2), 155-172.

Woods, B. & Watson, N. (2004). In Pursuit of Standardization: The British Ministry of Health's Model 8F Wheelchair, 1948-1962. *Technology and Culture*, 45 (3), 540-568.

Woolgar, S. (1976). Writing an Intellectual History of Scientific Development. *Social Studies of Science*, 6 (3-4), 395-422.

Woolgar, S. (1991). The Turn to Technology in Social Studies of Science. *Science, Technology and Human Values*, 16 (1), 20-50.

Woolley, M. (2003). Choreographing obsolescence – ecodesign: the pleasure/dissatisfaction cycle. *DPPI 2003 Proceedings of the 2003 international conference on Designing pleasurable products and interfaces* [Online]. Available at http://dl.acm.org/citation.cfm?id=782916 [Accessed on 24/12/2014].

Worms, J-C. & Haerendel, G. (2004). The European White Paper on space: enough support for basic science?. *Space Policy*, 20 (2), 73-77.

Wynne, B. (1983). Redefining the Issues of Risk and Public Acceptance: The Social Viability of Technology. *Futures,* 15 (1), 13-32.

Wynne, B. (1988). Unruly Technology: Practical Rules, Impractical Discourses and Public Understanding. *Social Studies of Science*, 18, 147-167.

Wynne, B. (2002). Risk and Environment as Legitimatory Discourses of Technology: Reflexivity Inside Out?. *Current Sociology*, 50 (3), 459-477.

Zervos, V. & Siegel, D. S. (2008). Technology, security, and policy implications of future transatlantic partnerships in space: Lessons from Galileo. *Research Policy*, 37, 1630-1642.