SPACE FOR TECHNICIANS?

AN ANALYSIS OF TECHNICIAN DUTIES, SKILLS AND TRAINING IN THE UK SPACE INDUSTRY

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EXECUTIVE SUMMARY

1. The Coalition government has set itself the goal of creating 'a modern class of technicians.' Technicians are highly productive people who apply proven techniques and procedures to the solution of practical problems. They carry supervisory or technical responsibility and competently deliver their skills and creativity in the fields of science, engineering and technology. There are currently concerns both about skills shortages at the technician level and also about the age of the technician workforce. The government is attempting to address these concerns by adopting policies that are intended to increase both the status and also the numbers of technicians in the UK economy.

2. This report investigates the role of technicians in an important part of the advanced manufacturing sector of the UK economy, namely the space industry. The space sector is comprised of all the public and private sector actors involved in the producing of goods and services via the exploration, understanding and utilisation of space. It has two main parts: the 'upstream' consists of organisations that manufacture (parts of) satellites; the downstream companies use satellites to provide telecommunications and broadcasting, weather-forecasting, and location and navigational services. In 2008-09, the space sector had a turnover of about £7.5 billion, adding £3.6 billion of value to UK GDP and directly employing around 25,000 people. It accounts for a little under 10% of the global space economy. Labour productivity in the sector is about 2¾ times greater than the average for UK manufacturing and 3½ times the average for the economy as a whole. The sector grew at around 9-10% per annum in real terms throughout the first decade of the twenty-first century.

3. The aim of the project on which this report is based was to inform government policy towards technicians by investigating their duties, the skills they are required to have, and how employers obtain them, in the space sector. The project forms part of a wider programme of research into technician duties, skills and training in various strategically important sectors of the economy, including – in addition to space – the aerospace, composites, chemicals, and nuclear sectors.

4. More specifically, the research reported here focused on five sets of questions.
    - In what roles are technicians employed in the UK space industry and what are their principal duties?
    - What qualifications do those technicians typically possess?
    - How do organisations in the space sector acquire the technicians they need?
    - Are there skills shortages at the technician level in the space industry?
    - What provision do employers make for the ongoing training and career development of their technicians?

5. Data was collected via interviews with 15 sector-level organisations, including government departments, learned societies, and trade bodies, and through case studies of 25 space sector employers (12 upstream, eight downstream, and five involved in both upstream and downstream activities). The case study organisations included component and sub-system manufacturers, space primes, satellite operators, IT and software engineering companies, and downstream service providers. Case studies included both public- and private-sector organisations.

6. The data indicate that the vast majority of the technicians who work in the sector are employed by upstream manufacturers, where they account for around 20% of the total workforce. Few – in many cases, no - technicians are employed by satellite operators, by the organisations that specialise provide software and engineering support for the space industry, and by downstream service providers. The reason is that, given the technical demands of the work carried out in such organisations, technical roles must be filled by people who are qualified at least to degree level.

7. The roles filled by the technicians who work in organisations involved in upstream manufacturing activities include the following: machinist; mechanical assembly technician; production/manufacturing engineer; electronics assembly and integration technician; electronic/component engineer; test technician; and test engineer. The most common qualification possessed by technicians is an HNC in some form of engineering.

8. Only a minority of the upstream manufacturers and space primes that employ technicians have had apprenticeship schemes in place long enough for them to make a significant contribution to their technician workforce. Until very recently, most of the organisations involved in upstream manufacturing obtained their technicians in one of two main ways: either by hiring people who already work in the space industry from the external labour market; or by recruiting people who have done an apprenticeship and worked for some time in a different industry and then providing them with the extra training – concerning the exacting tolerances to which work must be completed and the quality assurance procedures that must be followed – that they need to be able to work in space manufacturing ('upgrade training').

9. However, there is evidence that organisations involved in manufacturing for the space sector are beginning to move away from this reliance on a combination of recruitment and upgrade training towards a greater use of in-house training and, in particular, apprenticeships, as a means of satisfying their need for technicians. Several such organisations have either recently set up an apprenticeship scheme or are in the process of doing so. The reasons for this are twofold. First, it is becoming increasingly difficult to recruit experienced technicians – whether they be 'space ready' or technicians from other industries who can be 'upgraded' for work in the space industry – from the external labour market. Second, in keeping with the rapid growth of the space sector as a whole, many firms are growing and therefore increasing the size of their workforce in general and their technician workforce in particular (the latter point reflecting the fact that – as the firms in question expand and adopt a more elaborate division of labour – there is more scope for specialist technician roles to be used).

10. Apprenticeship training is also said to bring three other advantages. First, it helps organisations in their efforts to plan for the orderly succession of an ageing technician workforce. Second, it affords employers an opportunity to take young people and socialise them into the relevant organisational culture, so that they acquire the values and habits – concerning the exceptionally high standards of work required, and the importance of adhering rigidly to the relevant procedures – insisted upon by space manufacturers. Third, the provision of apprentice training can signal to young people that they are valued by their employer, who will support them and give them the opportunity to develop their career within that organisation, thereby helping to build apprentices' loyalty and commitment to the employer that initially trained them.

11. Apprentices are typically studying for qualifications in mechanical and electronic/electrical engineering, with a view to achieving an HNC or (less commonly) an HND by the end of their apprenticeship. Apprentice numbers tend to be relatively small, reflecting the small size of most employers in the space sector. Only three organisations recruit more than 10 apprentices per annum (and, in one of those cases, some of the apprentices are likely to be destined for the organisation's non-space related business). In the case of the other organisations that take apprentices, or are considering doing so, the employers in question are typically looking to recruit just one or two apprentices per year at present.

12. Employers face a number of impediments to their efforts to establish apprenticeship training programmes. Some have had difficulty finding a further education college that is willing to offer the kind of off-the-job training they want their apprentices to have (in particular, HNCs in electronics). Several have been disappointed by the quality of the support provided by FE colleges once their training schemes have been set up.

13. So far as ongoing training for more established technicians is concerned, most of the organisations that employ technicians are willing to support them to do part-time Foundation Degrees or full honours degrees, usually in physics or engineering. Those electrical and electronics assembly technicians who are certified by the European Space Agency must re-trained every two years if they are to retain their status. Uncertificated ongoing training in technical matters is also often provided either in-house by more experienced staff or delivered externally by equipment suppliers, and is an important source of skills development. Only a small minority of organisations currently support their technicians for professional registration (i.e., EngTech).

14. In view of the fact that more and more organisations in the upstream, manufacturing part of the space sector are looking towards apprenticeship training, but are finding it difficult to discover high-quality provision, it would be worthwhile for policy-makers to explore (i) whether the incentives currently confronting further education colleges provide sufficient encouragement for them to offer off-the-job training ('technical certificates') of the kind needed by space manufacturers, and (ii) whether there is a way for the smaller organisations that wish to take apprentices to 'piggy back' on the established apprentice training schemes already being offered by one or two of the larger space organisations.

1. INTRODUCTION[1]

Recent policy statements issued by the Coalition government have emphasised the importance of increasing both the status and also the numbers of technicians in the UK economy. Technicians may be defined as 'highly productive people who apply proven techniques and procedures to the solution of practical problems. They carry supervisory or technical responsibility and competently deliver their skills and creativity in the fields of science, engineering and technology' (Technician Council 2012). Current practice in UK policy-making circles is for the term 'technician' to be used to describe people occupying technical roles that require level 3 skills (e.g. advanced apprenticeship), and which are therefore categorised as 'skilled trades', as well as those whose job requires them to have level 4/5 skills and who therefore fall into the category of 'associate professional/technical' workers (e.g. HNC/HND, Foundation degree) (BIS 2010a: 7; Jagger *et al*., 2010; Technician Council 2011, 2012).

The goal of policy, stated in two recent White Papers, is to create a 'modern class of technicians' (BIS 2009: 18, 2010a: 7, 18). The background against which this goal has been adopted is one in which there is increasing concern about skills shortages at the technician level (UKCES 2010a, 2010b; HM Treasury and Department of Business, Innovation and Skills 2011: 85; Spilsbury and Garrett 2011). Accordingly, ambitious targets have been set for increasing the number of apprentice technicians (BIS 2010a: 7, 15; HM Treasury and Department of Business, Innovation and Skills 2010: 18-19; House of Commons Library 2011: 4-6). In addition, a Technician Council has been established in an attempt to ensure that the significant contribution made by technicians to the organisations in which they work, and thereby to society at large, is more widely recognised than hitherto, to increase the opportunities for career development open to technicians, and to increase the number of technicians being trained in the UK (BIS 2009, 2010a: 18; HM Treasury and Department of Business, Innovation and Skills 2011: 89; Technician Council 2011, 2012: 2, 5).

The policy goals of increased technician numbers and enhanced status will be achieved only if the nature of technician work, and the demand for and supply of technician skills, are well understood. It is towards the goal of achieving such an understanding that the current paper aims to contribute. It does so by exploring the duties, skills, and training, of one important, but hitherto largely unstudied, group of technicians, namely those who work in the UK Space Sector. The space industry, along with the aerospace sector of which it forms a part, is viewed by policy-makers as one of the key advanced manufacturing sectors upon which the future of UK manufacturing hinges. As a rapidly growing, advanced manufacturing industry, space is naturally of interest to policy-makers who – like the current government – are seeking to increase the number of apprentices in training (BIS 2010b, 2010c; SEMTA 2009: 11-18). This is because, in the words of a recent report on technicians, 'the level and type of skills that technicians have are vital to emerging markets in the UK, such as [the] advanced manufacturing and engineering industries. Becoming more production and export-led means becoming more technician led' (Skills Commission 2011: 16). In keeping with such remarks, a recent report outlining an overall growth strategy for the space industry, penned by a group representing both the commercial and academic arms of the space sector as well as government, specified a target of doubling the number of apprentices in the space industry by January 2015

1 The research upon which this report is based was funded by the Gatsby Foundation. I am grateful to the Foundation and, in particular, Daniel Sandford Smith, for that support. I am also extremely grateful to all of the interviewees, who generously gave of their time and knowledge and were unfailingly helpful and patient in answering follow-up questions. Matthew Harrison, Daniel Sandford Smith and Richard Smith provided very useful comments on earlier versions of this report, for which I am also most grateful. Any remaining errors are solely my responsibility.

(albeit without specifying how many apprentices are currently being trained by space firms) (Space IGS 2010a: 45).

The goal of the research project described in this paper is to inform policy by shedding light on the use, and acquisition by employers, of technicians in the space industry. More specifically, the paper focuses on five sets of questions. First, in what roles are technicians employed in the UK space industry and what are their principal duties? Second, what qualifications do those technicians typically possess? Third, to the extent that they need technicians, how do organisations in the space industry acquire them? In particular, what balance do employers strike between recruitment and (different forms of) training in satisfying their need for suitably skilled technicians? Fourth, are there skills shortages at the technician level in the space industry? And, if there are, is government policy helping to alleviate them? Fifth, and finally, what provision do employers make for the ongoing training and career development of their technicians?

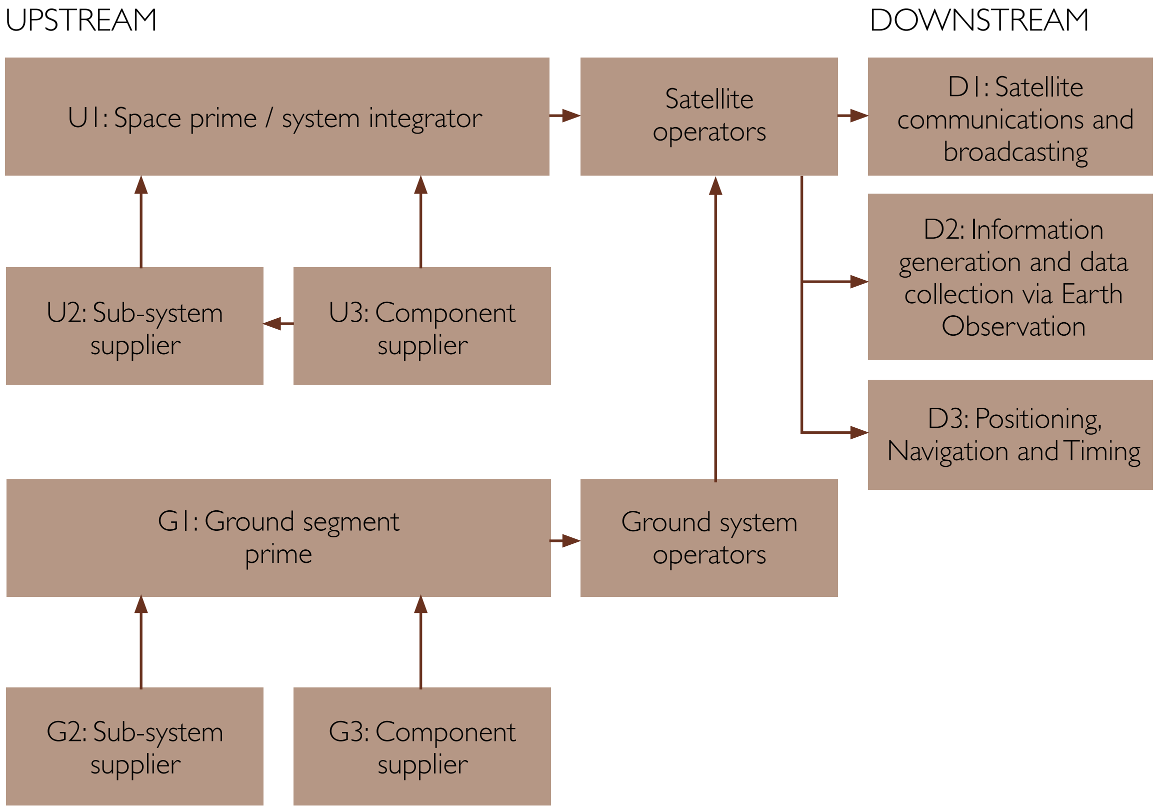
The structure of the report is as follows. Section 2 provides an overview of UK Space industry, in order to provide background information and context for the ensuing discussion of technician duties, skills and training. Section 3 briefly outlines the research methodology adopted in this study. Section 4 begins the presentation of the study's findings, focusing in particular on the types of space firms that employ technicians, the kind of roles those technicians fill, their qualifications, and the route through which they came to be employed in the space industry. Section 5 continues with the presentation of the results, focusing in particular on the way in which the current state of the technician labour market is affecting employers' decisions about the appropriate balance to strike between recruitment and, in particular, apprenticeship training. This section also considers the ongoing training provided for established technicians. Section 6 summarises the discussion.

2. THE UK SPACE INDUSTRY: AN OVERVIEW

The space sector is comprised of all the public and private sector actors involved in the producing of goods and services via the exploration, understanding and utilisation of space (OECD 2004: 164, 2011: 14-15). At first glance, the space sector might seem remote and esoteric, the province of academic scientists and engineers who are – literally and metaphorically – rather unworldly. However, a little reflection reveals that in actual fact work carried out in the sector now touches the lives of ordinary people in numerous ways. Many of the things that we all use and take for granted in our everyday lives – such as direct-to-home or 'satellite' television and radio programmes, mobile telephone services, weather forecasts, and GPS navigation – rely on space-derived data and services. Governments rely increasingly on space-based data, whether in monitoring climate change and other environmental phenomena, in managing air traffic, or in providing emergency services, security and national defence.

The sector consists of a long and rather complex chain of activities that begins with the manufacturers of space hardware – that is, of satellites, ground stations, and the constituent parts thereof - and ends with the providers of space-enabled services – such as weather forecasts, satellite television and satellite navigation - to final users. This value chain is usually broken down into two main sections, known as the 'upstream' and the 'downstream' parts of the sector. Roughly speaking, upstream firms provide the technology required to exploit space and downstream companies use that technology to provide services. These two groups are connected to each other via satellite operators, who – as that description suggests - operate satellites when they are in service, and by ground system operators, who manage communications with the satellites. This picture of the structure of the space industry is illustrated in Figure 1, where boxes denote various parts of the sectors and the arrows indicate how of goods and services flow between those parts.

FIGURE 1: THE STRUCTURE OF THE SPACE SECTOR



(Source: modified from UK Space Agency 2010: 2 and BIS 2010b: 4.)

The upstream part of the sector has two main elements. The first consists of the organisations that contribute to the design, manufacture and launch of satellites, most notably:

- the firms that actually build the satellites (the so-called 'space primes' or 'systems integrators') (labelled U1 in the Figure);
- the companies that supply the various sub-systems that constitute a satellite, including: its central carbon fibre core and aluminium skeleton; fuel tanks and engines; in-orbit propulsion and attitude control systems; on-board computing and signal processing devices; antennae; solar panels/arrays; fuel cells; software; and, last but certainly not least, the payloads that the satellite carries into orbit, such as telecommunications and navigational equipment, scientific instruments, and various kinds of remote-sensing/earth observation devices[2] (labelled U2 in the diagram); and
- the suppliers of the components from which satellites and sub-systems of the kind just mentioned are made (e.g. electronic components, microwave equipment, optical devices and solar cells, and batteries) (denoted U3).

2 Earth observation involves the use of satellite-borne remote-sensing devices – such as radar, altimeters, cameras, microwave systems, and infra-red, X-ray and UV detectors - to measure a wide range of geo-physical and environmental parameters, including air and surface temperature, sea ice coverage, the size of the world's rainforests, ocean salinity and colour, and atmospheric pollution. The data thus provided can be used to assess and improve models of climate change, high-impact weather events, and earthquakes, to name but a few fields of study (Space IGS 2010b: 104; NSTSG 2011: 16; OECD 2011: 64).

The second part of the upstream sector is known as the 'ground segment'. It has two main parts: first, the ground segment 'primes', who supply and operate the facilities and systems needed to control the operation of the satellites and to receive and process the earth observation data they transmit once they are in orbit (labelled G1 in Figure 1); and second, the firms that manufacture the sub-systems and components that, taken together, make up the ground systems (such as RF equipment, tracking, telemetry and communications/signalling terminals) (denoted G2 and G3 respectively in the diagram) (Oxford Economics 2009: 3-11; BIS 2010b: 3-4, 75).

Before moving on to consider the downstream part of the sector, it will be useful for what follows to elaborate in a little more detail on the nature of upstream manufacturing for space. The space industry is a part of the advanced manufacturing sector of the economy that builds very high value products that are tailored to suit the specific requirements of a particular customer. Satellite manufacturing is worth £800 million, or around 14% of the UK space sector, and – in the case of the so-called space primes or systems integrators - involves the manufacture, assembly and testing of the mechanical and electrical/electronic systems, including the payload, that constitute a satellite. UK companies operating in the manufacturers' supply chain also provide many of the components and sub-assemblies – such as electronic components, RF signalling equipment, batteries, detectors and instruments – that are used in the construction and launch of satellites, as well as the instruments and other parts of the payload that those satellites carry.

The organisations that operate in the upstream part of the space industry manufacture and assemble components and systems to the highly exacting standards required if satellites are to survive the launch process intact and then operate with guaranteed reliability for 15 years in the remote and hostile environment that is space. This leads on to one of the distinguishing features of the space industry, namely the extremely thorough quality assurance procedures that govern all stages and aspects of the manufacturing process. In order to be able to demonstrate that a product will work reliably in orbit, it is necessary to document both the origins of all raw materials and components used in the manufacturing process and also where, how and by whom they were processed, fitted and tested. To that end, all materials and components are bar-coded or laser-marked to ensure that their entire history, along with that of any sub-assembly or assembly of which they form a part, can be traced. All of the manufacturing processes they undergo, and all of the tests to which they subject, must also be fully documented, according to well-established and widely accepted protocols (e.g. those accredited by ESCC, ISO and ESA[3]). The aim is to ensure that it is possible to state with considerable confidence that a particular item has been manufactured with the appropriate materials, in the correct ways, and to the required standard – in short, that it really is what it is supposed to be - and that as a result it will work reliably once it is in space. Items that are produced in accordance with these procedures are classified as 'flight standard' and are said to be 'space qualified' (that is, suitable for use in space).

3 The 'ESCC System' is an international system of procedures and standards governing the qualification of electrical, electronic and electro-mechanical components for use in the space industry. 'ESA' stands for the European Space Agency.

The members of the downstream part of the space sector exploit the capabilities of the satellites manufactured by firms in the upstream segment to provide various kinds of services to end users. Three broad categories of service can be distinguished (Space IGS 2010b: 5-20; NSTSG 2011: 14-18). The first, and largest, involves the provision of telecommunications and broadcasting services, such as direct-to-home television, satellite phones, broadband access, and secure military communications (labelled D1 in Figure 1). The second centres on data collection and information generation based on satellite-facilitated earth observation. In essence, the organisations working in this market turn the raw data generated by satellites into usable information that can form the basis of services such as weather forecasting, mapping, disaster relief, national security, emergency services, and the analysis of climate change, land use and population movements (labelled D2 in the diagram). The third downstream market, denoted D3 in Figure 1, is for location, positioning, navigation and timing services, and involves the use of satellite-enabled location-finding and navigation devices, often colloquially known as GPS, and clocks so accurate that they lose just one second in hundreds of thousands of years. The users of such services include both individuals and also firms working in sectors such as logistics and air traffic control. It is also worth noting that while some of the services listed above can be provided only via the exploitation of space, in other cases space-enabled provision competes with terrestrial provision (e.g. cable television) (Oxford Economics 2009: 4-5, 31-36; BIS 2010b: 13-14, 75; OECD 2011: 62-65).[4]

The global space economy is estimated to be worth around $260 billion, divided into parts of roughly equal value that are accounted for by government space budgets, by commercial space infrastructure (satellites, launch vehicles, and supporting ground infrastructure), and by space-enabled services (telecommunications, weather forecasting, global navigation and transport services, etc). Growth rates in the commercial sector are impressive, averaging 7-8% per annum in real terms between 2000 and 2008 and being driven primarily by enhanced demand for satellite services and ground equipment (as distinct from satellite manufacturing and launch). Increasing consumer demand for mobile communications, broadcasting, and real-time data on navigation and weather, coupled with a growing need on the part of governments for data on environmental, security and humanitarian issues, is expected to lead to continued high growth in commercial space revenue (BIS 2010b: 7-9, 17). As we shall see below, the sector appears to be continuing to fare well during the ongoing economic downturn, its resilience underpinned by growing markets for services such satellite broadcasting and robust demand from certain categories of user (e.g. defence agencies) (OECD 2011: 29-31).

The UK is thought to account for between 6 and 9% of the global space economy. The country is home to upstream companies that have considerable expertise in the manufacture and operation of satellites, in space exploration, in remote sensing, in the development of the software and control systems that facilitate the operation of satellites, and in systems integration. There is also a cadre of established and well-respected downstream firms that operate satellites and provide a broad range of space-based services. Circa 2008-09, the sector had a turnover of about £7.5 billion, adding £3.6 billion of value to UK GDP and directly employing around 25,000 people (UK Space Agency 2010: 3, 6).[5] A majority of both turnover (around 85%) and employment

4 In practice, the actual division between upstream and downstream companies and, within the upstream, between space primes and ground systems primes, is less stark than this schematic overview suggests. The reason lies in the existence within the industry of vertically integrated firms that encompass several links in the value chain, for example firms that manufacture components and sub-systems as well as integrating them into a complete spacecraft, organisations that operate as well as manufacture satellites, and firms that not only manufacture satellites but also transform the data they provide into marketable services (BIS 2010: 12).

5 These figures refer to the space industry's *direct* contribution to the UK economy. If *indirect* contributions are taken into account, then the space industry contributed around £6.9 billion to UK GDP and helps to support around 83,000 jobs in 2007/08 (UK Space Agency 2010: 3-4).

(about 70%) derive from the downstream sector, in particular telecommunications. Between 1999 and 2008, both the upstream and downstream parts of the UK space sector grew at an average of 9% per annum in real terms, some three times the corresponding figure for the economy as a whole, driven largely by an expansion in the demand for broadcasting and telecommunications services. The sector has continued its impressive rate of progress since the advent of the global recession, its growth averaging 10% per annum between 2008 and 2010. Gross value added per worker is just over £140,000, indicating that labour productivity in the sector is about 2¾ times greater than the average for UK manufacturing and 3½ times the average for the economy as a whole. This reflects the above-average levels of both physical and human capital per worker employed in the industry. The space sector has a highly qualified workforce; surveys suggest that 60-70% of all jobs are filled by graduates, many of whom also hold higher degrees (Oxford Economics 2009: 7-19; BIS 2010b: 22-35; UK Space Agency 2010: 4, 10; Smith 2011: 2).

The sector also enjoys good prospects for continued rapid growth: the global market for space industry products and services is projected to grow by 5% per annum in real terms up to 2030, driven by developments in earth observation, global positioning applications, satellite broadband internet systems, and high-definition television. Estimates indicate that the UK enjoys considerable scope for growth in turnover, value and employment over the coming decades: the recent *Innovation and Growth Strategy* report set the ambitious goal of increasing the UK's share of the global space market to 10% by 2030, a target which if achieved would to lead an increase in turnover to £40 billion and the creation of up to 100,000 jobs (Oxford Economics 2009: 37-42; Space IGS 2010a: 7, 22, 24; BIS 2010b: 17-21; UK Space Agency: 11-13).

3. RESEARCH METHODOLOGY

In the absence of a large data set concerning the duties, skills and training of technicians in the space industry, a case study method was adopted for this study. This has the benefit of making it possible to explore employers decisions how about to obtain and use technicians in considerable contextualised detail.

There were two main stages to process of data collection. The first involved a series of 15 interviews with various sector level organisations, such as the Department of Business, Innovation and Skills, the UK Space Agency, the UK National Space Centre, the Technology Strategy Board, sector skills councils, and learned societies, along with attendance at the 2011 UK Space Conference. These interviews, along with the use of secondary sources such as reports and policy documents concerning the space industry, were used both to obtain background information on the key issues arising from the space industry's use of technicians and also to inform the choice of case study organisations.

The second stage of the research saw a total of 32 employers from the space sector being invited to become involved in the project, of which 25 agreed to participate. Those 25 cases covered all the main parts of the space industry, including both upstream and downstream organisations as well as satellite operators and organisations involved in ground segment activities (see Table 1).

Table 1: Summaries of Case study organisations, by type of organisation

Type of organisation	Upstream (U) and/or downstream (D)	Number	Average workforce employed on space-related projects	Average share of technicians in the space workforce (%)
Component/sub-system manufacturer	U	11	55[a]	23[a]
Consultancy (upstream)	U	1	8	0
Space prime/system integrator	U and D	2	1550	20
Upstream manufacturer and downstream service provider	U and D	3	110	3
Downstream service provider	D	3	18[b]	10[b]
IT and software engineering service providers	D	3	150	2
Satellite operators	-	2	390	4

a: Averages based on data from 9 component/sub-system manufacturers only

b: Averages based on data from one downstream service provider only

More specifically, 12 of the organisations operate exclusively in the upstream part of the industry: 11 are engaged in the manufacture of components or sub-assemblies; while the twelfth provides high-level consultancy services to upstream organisations. Two of the case study organisations are space primes or systems integrators, whose activities span the full range of activities from upstream manufacture through ground station and satellite operations to the supply of downstream services. Three organisations combine some upstream manufacturing with downstream service provision, typically in the field of earth observation and remote sensing, while three more concentrate exclusively on the downstream provision of services to final users. Three organisations provide high-level IT and software engineering services to clients in both the upstream and downstream of the sector. The final two cases are satellite operators.

Information was collected via 32 semi-structured interviews with a total of 34 interviewees, whose ranks included HR, training and production managers, directors of engineering and production, and technicians, using a schedule piloted in the early cases. The interviews were carried out between July 2011 and March 2012 and averaged a little over 60 minutes in length. Notes were written up and, where gaps were revealed, these were filled by e-mail follow-ups. Primary and secondary documentation was also collected where available.

Of the 25 case study organisations, 20 are in the private sector and five in the public sector (though the latter also typically attempt to win contracts and, therefore, acquire revenue, for the goods and services they supply from sources other than the UK government, so they are not completely reliant on the public purse for their income). 14 had fewer than 100 employees working on space-related projects, three employed between 100 and 200 people in their space business, three employed between 200 and 500 people for space-related work, and two organisations - one of them a space prime, the other a satellite operator - had over 500 people working on space-related projects. The remaining three organisations, two of which supply components to the space industry and so form part of the upstream segment and one of which is an organisation that uses earth observation data to produce downstream services, all employ over 500 people, but they are also involved in non-space work and it proved impossible to identify precisely what proportion of their workforce is devoted to space-related activity. Excluding the latter three organisations, the average size of the space-related workforce in the case studies was 240 employees. Including them lifts that average to 380.

4. RESULTS I: THE CURRENT TECHNICIAN WORKFORCE: SIZE, ROLES, QUALIFICATIONS, AND ORIGINS

This section of the report outlines what the research carried out for this project reveals about issues such as: the size of the technician workforce; the types of roles that are typically undertaken by technicians in the space industry and the kinds of duties that are associated with those roles; the kind (level, and subject-matter) of qualifications those technicians typically possess; and how organisations in the space industry have until now gone about satisfying their need for technicians, in particular the balance they have struck between recruitment and (various forms of) training as a means of acquiring the technicians they need.

4.1. THE SIZE OF THE TECHNICIAN WORKFORCE

The evidence gathered for this study indicates that the vast majority of the technicians who are employed in the case study organisations work on upstream manufacturing projects. All 16 of the organisations that are involved, in whole or part, in upstream manufacturing activities – namely, the 11 manufacturers of components and sub-systems, the two space primes, and the three other organisations that combine upstream manufacturing with some downstream service provision – employ technicians. On average, in the space primes and specialist upstream manufacturers, technicians account for around 20% of the total workforce (see Table 1). In the organisations that combine upstream manufacturing with the provision of downstream services, the share of technicians is much smaller, averaging under 5% of the total workforce. The employment of technicians is confined in all these cases exclusively to upstream manufacturing roles; neither of the space primes employs technicians to work in its ground stations or in its downstream operations; while none of the three organisations that combine upstream manufacturing with downstream service provision has technicians who contribute directly to their downstream work. Technicians occupying upstream manufacturing roles account for over 95% of the total number of technicians employed across the 25 organisations visited for this study.

The highly demanding and specialised nature of the work undertaken both by the three organisations that supply software and IT engineering services to the space sector, and also by the consultancy that provides advice to firms operating in the upstream segment, implies that when they are filling technical roles they only hire people who are qualified to at least degree level. The one exception is to be found in one of the consultancies, which employs a small handful – amounting to well under 10% of its space workforce - of vocationally educated IT technicians in database management and front-line helpdesk roles. The picture is similar in the case of the two specialist satellite operators: one employs no technicians whatsoever; the other employs a small number of IT technicians, once more amounting to well under 10% of its total workforce, and again primarily in front-line technical support roles. Finally, only one of the three specialist downstream organisations in the sample has any technicians, employing a very small number to manage its databases and to do some simple coding. The other two specialist downstream organisations employ no technicians whatsoever, the highly technical nature of the work undertaken by these organisations militating heavily in favour of employing people with degrees or postgraduate qualifications. The upshot is that downstream firms and satellite operators accounted for fewer than 5% of the total number of technicians employed by the 25 firms visited for this study.

If the sample of employers visited for this project is representative of the space sector as a whole, the overall picture that emerges, is – perhaps unsurprisingly – of an industry in which technicians form a relatively small fraction of the workforce, probably no more than one fifth, and in which the vast majority of those technicians are employed in upstream manufacturing roles. In the next section of the report, we shall focus on the upstream manufacturing part of the industry and describe in more details the kinds of roles that are filled by technicians.

4.2 TYPES OF TECHNICIAN AND THE NATURE OF TECHNICAL SUPPORT

A number of different types of technician work within the organisations that make up the space industry. In what follows, a range of typical technician roles will be described in order to provide the reader with a sense of the kinds of duties undertaken by those technicians. Before proceeding, three related qualifications to what follows should be noted.

First, none of the technician roles distinguished below are to be found in every organisation. As noted above, most of the organisations that specialise in providing services based on earth observation data, along with firms offering high-level software and systems engineering support for both upstream and downstream activities, simply do not employ technicians. In addition, few of the upstream manufacturers who employ the vast majority of the technicians found in the space industry employ all the types of technician listed below. For example, specialist composites technicians tend to found only in the larger space primes, while firms supplying electronics components tend not to employ mechanical assembly technicians. In the role descriptions that follow, an attempt will be made to provide a sense of the kind of organisation(s) in which particular technician roles are commonly found.

Second, far from offering an exhaustive account of all the nuances and variations that arise in the case of real technician roles, the descriptions provided below portray 'ideal types' that are intended only to set out the broad features of the different kinds of technician found in the space industry. As a result, there may well be cases where the technicians employed by one particular firm are allocated a set of duties that combines elements of more than one of the roles described below, as for example: when the same technicians machine, assemble and test particular items; or when electrical and mechanical assembly duties are carried out by the same person; or where the boundaries between the roles occupied by more experienced technician and those occupied by less experienced and/or more practically inclined graduates become blurred. Such cases are only to be expected in an industry where the small size of many firms impedes the elaborate division of labour required for the creation of specialised technician roles. (This is a point which we shall return in Section 5 below.)

Third, over time a combination of accumulated experience and informal on-the-job training may lead to a situation where the performance and contribution made by a particular worker exceeds what is specified in his/her particular job role. Often, of course, this will be recognised through promotion to a new role. But the worker's enhanced skills and competences may not be formally certificated, so the links between roles and formal qualifications may not always be as clear cut as it sometimes indicated below.

Notwithstanding these caveats, the following account should provide a reasonably accurate initial overview of the kind of roles occupied by people qualified to technician level in the space industry, and of the qualifications associated with each role.

4.2.1: Mechanical Engineering Technicians

The first broad group of technicians consists of workers whose expertise lies in the area of mechanical engineering, broadly understood. Workers of this kind are to be found in 11 of the organisations visited for this project, all of which are of course situated in the upstream part of the space sector. Broadly speaking, such workers manufacture and/or assemble and/or test the mechanical components and assemblies that help to make up a satellite. More specific examples of the kind of roles filled by these workers are described below.

4.2.1 (a) Machinists

One prominent task carried out by some – though not, as we shall elaborate below, all – mechanical engineering technicians who work in the space industry is machining. Typically, this involves the technician carrying out both manual and CNC milling, turning and drilling in order to produce a variety of components and sub-assemblies for satellites, including: the aluminium and composite panels that constitute a satellite's basic structure; various optical components used for the thermal control of spacecraft; and parts for the scientific instruments, detectors, and optical devices that make up the satellite's payload. Much of this work must be carried out to very fine tolerances, in some cases requiring the technicians to view the part being machined under a microscope. In the case of CNC devices, the operators will typically work from 3-D CAD drawings provided either by technicians occupying the role of manufacturing or production engineer (see Section 4.2.1 [d] below) or by graduate-level engineers, but will programme, set and operate CNC machines themselves. Machinists may also be involved in making the mould tools, jigs and fixtures required for the manufacture and assembly of novel metal and composite parts.

Technicians engaged in machining were found in nine of the 11 upstream organisations that employ mechanical engineering technicians. They are most numerous in the case of organisations that manufacture components and sub-assemblies for satellites but can also be found – in smaller numbers – in the space primes. In both the larger, specialist component manufacturers, and also in the space primes, machinists tend to have done some kind of manufacturing engineering apprenticeship at level 3. In the smaller organisations, especially those involved in the manufacture of bespoke instruments, machinists tend to be qualified to level 4 or even 5, having taken an HNC or even in some cases an HND. Perhaps this ought not to be too surprising, given that in the cases where novel instruments are being made, technicians may not only manufacture the instrument but may also have an input into its design, a task that demands a higher level of expertise than mass-producing standardised items (see Section 4.2.1 [d] below).

Two of the larger organisations have dedicated roles for machinists, whose incumbents specialised in machining – as distinct from assembling and testing - components. In other cases, the task of machining parts was combined with other duties - such as those of fitting the components together to form larger sub-assemblies and/or testing the item that is thereby produced - to form a single, multi-dimensional role. This brings us to the next kind of task carried out by workers with mechanical engineering skills, namely that of mechanical assembly.

4.2.1 (b) Mechanical Assembly Technician

Mechanical assembly involves technicians combining sets of mechanical components in order to form larger sub-assemblies or assemblies. Three examples will be given here, two drawn from organisations that make sub-assemblies for satellites, the third from a system integrator. In the case of the sub-assembly manufacturers, the technicians' duties might, for instance, involve them welding together the pipework that forms part of a satellite's propulsion system. Alternatively, they might work in a clean room and use certain components – which, depending on the division of labour within the organisation for which they work, they may or may not have fabricated themselves – to build a scientific instrument or detector that will form part of a satellite's payload. Finally, to take an example drawn from one of the space primes, mechanical assembly technicians are charged with the task of positioning the satellite's carbon fibre core and aluminium structural panels in jigs and then fastening them to one another in order in order to construct the satellite's basic skeleton. Other key mechanical components - such as the satellite's main engine, subsidiary thrusters, insulation and thermal control systems, and fuel tanks and associated pipework - will then be attached to the basic structure to form a larger assembly known as the service module. The service module will ultimately be connected to the second major part of the satellite, namely the communications module, in order to complete the main body of the satellite. More will be said about the role of technicians in making the communications module in Section 4.2.2 (b) below. In all of these cases, the manufacturing technicians who fabricate items will also be involved in testing them (by checking that the flight bolts that hold the main parts of a satellite's structure together have been tightened to the right torque, for example, or by testing to ensure that the satellite's propulsion system works properly).

All told, 11 of the case study organisations have technicians engaged in various forms of mechanical assembly. Of these, three organisations have specialist mechanical assembly technicians. In the other eight organisations, the task of assembling the mechanical components is combined with that of manufacturing the components, or of testing the final assembly, so that the technician roles are multi-faceted. As was the case with the machinists described above, in larger organisations where there are dedicated assembly technicians, they tend to be qualified to level 3. In the smaller organisations, and once again especially in those involved in the precision manufacture of scientific instruments and detectors, there is a more of a tendency for people engaged in mechanical assembly to have an HNC or HND and therefore to be qualified to level 4/5.[6]

Aside from the formal qualifications just noted, it is important to note another important skill that many mechanical – and, as we shall see, electrical and electronics – assembly technicians are required to possess, namely that of adhering to very high standards of cleanliness. The contamination of mechanical and electrical/electronic space hardware by dirt, dust or even fingerprints can severely and adversely affect its performance once it is in space. Accordingly,

6 The one notable exception to this general picture is to be found in one systems integrator, where the assembly of the mechanical parts of the satellite is carried out, not by vocationally educated technicians, but rather by workers are qualified to at least the graduate level. Such graduates would, therefore, be carrying out some tasks that in other organisations are typically undertaken by vocationally educated workers with qualifications below the graduate level.

technicians need to be aware both of the procedures for working in temperature- and humidity-controlled clean rooms (e.g. how to use the special gowns and gloves that must be worn, what materials and equipment can and cannot be brought into the clean room, etc.) and also of the methods used for the precision-cleaning of parts so as to avoid contamination that might jeopardise the reliability of a sub-assembly or assembly (e.g. the use of vacuum ovens for the dry heat sterilisation of parts).

4.2.1 (c) Composites Laminators

A third, smaller group of workers with level 3 qualifications in mechanical engineering was composed of laminators. More specifically, the two systems integrators or space primes visited for this study employ a relatively small number of specialist laminators who use techniques such as filament winding and carbon pre-preg laminating in order to make composite parts for satellites, including: carbon fibre cores; the panels that form parts of a satellite's solar arrays; and various smaller items such as camera casings and covers for microsat wheels.

4.2.1 (d) Manufacturing or Production Engineers

Another role often occupied by technicians with level 4/5 vocational qualifications is variously described as that of a production engineer, manufacturing engineer or draughtsman. One of the duties associated with such roles is that of writing the work instructions that specify the procedures that machinists and mechanical assembly technicians should follow in order to manufacture a particular part or assembly. For example, if a mechanical fitter is assembling parts of a satellite, it will be the manufacturing engineer who, in the course of drafting the work instructions, specifies the torque that has to be applied to the flight bolts that are used to connect the various modules. In addition to drafting work instructions, manufacturing engineers will typically oversee the day-to-day activities of the workers who are actually manufacturing items, responding to queries and dealing with relatively straightforward problems. They are also usually charged with the task of continually reviewing and improving the manufacturing process. Finally, they will normally also prepare the quality assurance paperwork that is used to document the operations carried out on each item during the stage(s) of the production process for which they are responsible.

In addition to overseeing and guiding the production workers in their team, manufacturing engineers also advise the chartered engineers in their organisation about the ease with which the components and modules can actually be built. Manufacturing engineers' experience of the difficulties that can arise in implementing certain designs enables them to provide advice and feedback to ostensibly better qualified, but in certain key respects often less knowledgeable, chartered engineers about how to design components, sub-assemblies and assemblies in ways that will make them (relatively) easy to build. The institutional manifestation of the need to have people who are experienced in the practical side of manufacturing involved in the design process is to be found in the existence of manufacturing engineers who work in the design office rather than on the shop floor. Situated thus, manufacturing engineers can bring their practical expertise in the practical side of manufacturing to bear on the design of hardware. This is likely to involve them using 3-D CAD packages to help design components: while the chartered design engineers might produce the broad schematic overview of a particular component, specifying for example the broad performance requirements it has to satisfy, it is the manufacturing engineers who turn those general schematic ideas into detailed designs of individual parts. To use a phrase employed by one interviewee, the manufacturing engineer will take over once the chartered engineer 'has done the sums'. In addition to designing individual components, manufacturing engineers may also be involved in helping to design the jigs and fixtures that are used to hold parts in place in the course of producing and testing components and assemblies.

A closely related role that is usually occupied by people with good vocational qualifications is that of a drawing office technician or draughtsman. Like manufacturing engineers, people occupying such roles will assist technicians, for example by drafting drawings and instructions that specify for machinists the dimensions of the parts they are meant to be fabricating or that set out for the benefit of assembly technicians such key issues as: the order in which various mechanical, electrical and electronic components, assemblies and sub-assemblies should be mounted on the satellite structure; where those parts are to be placed; and how they are to be attached (e.g. what length of bolt should be used). As one source put it, 'The draughtsman's task is to turn the engineer's schematic ideas into the detailed plans used … to build the hardware.' As was true for the manufacturing engineers who occupy design-related roles, so it is also true of draughtsmen that while they operate within the broad parameters specified by chartered engineers, they exercise discretion and bring their own expertise to bear in deciding how precisely the engineer's broad schematic designs are to be realised. As one interviewee put it, far from simply passing on information provided to them by the graduate-level designers about where exactly to locate particular modules, or in precisely what order to mount them on the satellite, 'the drawing office technicians have to generate this kind of information themselves.'

8 organisations in the sample visited for this project have roles that closely resemble those of the manufacturing engineer and draughtsman just described, though the precise term used to describe the role may vary between organisations. The occupants of such roles tend to be qualified to at least level 4/5, possessing HNCs, HNDs and – in the case of some people who have only recently come into post - Foundation degrees (in mechanical engineering). This is also a case where there is sometimes a blurring of the boundaries between technician-level roles and graduate-level roles; manufacturing engineering roles may be occupied either by technicians of the kind just described or by more practically-oriented graduates.

4.2.2 Electrical and Electronics Engineering Technicians

Having considered those technician roles that fall under the head of mechanical engineering, broadly conceived, we now move on to examine roles that involve electrical and electronics engineering (while acknowledging, of course, that in practice there may well be roles that straddle the mechanical-electrical/electronic divide). Workers whose duties require them to display a knowledge of electrical and/or electronic engineering were found in 16 of the case study organisations (all upstream). Broadly speaking, such workers assemble and test electrical and electronic components, sub-assemblies and assemblies. Some of the more common roles filled by workers with that kind of expertise are described below.

4.2.2 (a) PCB (Electronics) Assembly and Inspection Technician

One common role, found in nine of the upstream organisations visited for this project, is that of the PCB (electronics) assembly technician. The workers who occupy this role – who are found both in both components and sub-system suppliers as well as in the space primes - help to make the electronic devices that constitute much of a satellite's communications module or payload. This involves them: populating printed circuit boards (PCBs) with components, either by hand or using automatic 'pick and place' machines; and then carrying out the micro-soldering, and epoxy- and wire-bonding required both to hold the components in place and also to connect the completed boards to each other and to integrated circuits so as to form larger electronic modules and devices. In addition to the specific techniques required for this kind of PCB layout or surface mount assembly, as it is known, electronics assembly technicians must also adhere to the protocols for working in clean rooms, displaying an understanding both of how to prevent electrostatic discharges that might damage electronic components/ assemblies and also of how to avoid contaminating parts with dirt and dust that might hamper their reliable operation once in orbit.

The technicians who fabricate these electronic devices often also inspect and test them, using various kinds of non-destructive testing – such as using microscopes and X-rays to check for defects in the solder – in order to ensure that the quality of their workmanship meets the rigorous standards required of flightworthy components. We shall return to the issues of testing below, when we discuss the specialist test technicians who work in many upstream space companies (see Section 4.2.3).

The workers who fill these roles are typically apprentice-trained in electronics, sometimes to level three but often – and especially in smaller organisations – to level 4 (HNC). In addition, all nine of the organisations ensure that the skills of their electronics assembly technicians are ESA-certificated. ESA certification involves the technician attending training courses of 3-5 days in length, usually at an approved training centre, during which they will receive training in various aspects of electronics assembly for the space industry, including high-reliability soldering and the repair, modification and inspection of PCBs. The training is designed to ensure that the electronics technicians consistently achieve the very high standards of work required to manufacture electronic devices that are reliable enough to be used in satellites. Technicians must be retrained every two years to retain their status as certified ESA operators. While ESA-certification is not obligatory, save for work that is funded by the European Space Agency, it provides an important signal to other potential customers that an organisation has a skilled workforce and therefore helps firms to win contracts for space-related work. What this illustrates, of course, is one – in this case, relatively formal - way in which the extremely high quality products demanded by space firms drive training in the sector.

4.2.2 (b) Electronics and Electrical Assembly Technicians

While PCB assembly is perhaps the most common kind of electronics and electrical assembly work found in the space sector, technicians may also specialise in combining electronic and/or electrical components to form other kinds of sub-assembly and assembly. For example, in the case of some of the firms that supply sub-systems to space primes, technicians skilled in electronics and electrical work are involved in the assembly - and, where relevant, calibration - of detectors, scientific instruments, RF signalling and test equipment, batteries, and power and propulsion sub-systems. In the case of one space prime, integration technicians who are skilled in electrical and electronic engineering will mount onto the satellite's structural panels various electrical and electronics devices - including wiring and cable harnesses, the transponders that enable the satellite to receive, amplify, process, and transmit radio signals to and from earth, along with the scientific instruments, detectors and sensors that constitute the rest of the satellite's payload - in order to form the so-called communications-module. The communications module is the part of the satellite that - by providing a means of communication, or of broadcasting television pictures, or of taking images of the earth - actually delivers the services required by the organisation for which it is being built. The communications modules will ultimately be 'mated' with, or joined to, the service module in order to complete the main body of the satellite. Technicians may also be involved in the assembly of electrical and electronic communications, monitoring and testing equipment for satellite ground stations. The same technicians are often also involved in testing the electrical systems (e.g., batteries, electrical connections, etc.) and the electronic components and devices (e.g. the RF signalling equipment that enables the satellite to transmit signals to and from earth, scientific instruments and detectors) to ensure that they work properly.

Technicians carrying out work of this kind – sometimes as specialists, sometimes as part of a role that includes other duties – were found in 11 of the organisations visited for this study. The modal qualification was an HNC in electrical and/or electronics engineering, though a minority the occupants of this kind of role were formally qualified only to level 3, while a (slightly larger) minority had HNDs. Many of these technicians are also ESA-certified in soldering, crimping and wiring, so that both their employer and potential clients can be assured that their workmanship meets the high standards required of space-qualified hardware. Once again, a good deal of this work takes place under clean room conditions, and technicians must be conversant with the rules that govern work in such an environment as well as with the equipment – such as aqueous batch cleaners and ultrasonic baths - that is used to clean electronic components and devices.

4.2.2 (c) Electrical/Electronics Engineer/Draughtsman/Component Engineer

As was the case with the more experienced mechanical engineers, so it is also true of electrical and electronics engineers that more experienced and better qualified workers are often found in roles that involve them contributing to the design of electronic and electrical assemblies and sub-assemblies. Workers of this kind occupy roles that are given various titles, including electrical and electronics engineer, parts and materials engineer, and draughtsman. Analogously to production or manufacturing engineers, electrical and electronics engineers may well draft work instructions that specify for less qualified workers how a particular electronic or electrical device should be made. For instance, an electronics engineer may specify the amount of heat and pressure that a PCB assembly worker needs to apply in order to fabricate a particular kind of electronic device. Electrical and electronics engineers will typically be responsible for the day-to-day activities of the workers who form part of their team and also for preparing the documentation required as part of the stringent quality assurance procedures used in space manufacturing. Their responsibilities typically also include dealing with routine problems and identifying potential improvements to the manufacturing process.

Technicians skilled in electrical and electronics engineering may also have a role to play in the design of assemblies and sub-assemblies, augmenting the important contribution made by chartered design engineers. For instance, to use examples drawn from four component suppliers and sub-assembly manufacturers visited for this study, technician-level workers occupying roles with titles such as Parts and Materials Engineer, Component Engineer or PCB Designer take the general performance specifications provided by graduate-level design engineers and flesh them out by adding the details required to produce a complete design of the electronic device in question. There may be several aspects to this. In the first place, as one source put it, '[A]fter receiving guidelines and schematic input from the [chartered] engineer, I have to complete the creation of PCBs … [by finalising the relevant] drawings.' Second, the technician will also typically identify and procure the individual components, choosing them so that, once appropriately assembled, they will constitute a device that has the required properties. To take another example, drawn this time from a space prime, vocationally-educated draughtsmen will produce engineering drawings that specify for the benefit of assembly and integration technicians where various electronics components and devices – such as waveguides and wiring harnesses – should be fitted to a satellite's structural panels. Third, higher-level technicians participate in design reviews and provide feedback to design engineers on the ease with which the item can be manufactured, thereby – as one interviewee put it – contributing to 'design for manufacture and test'. In all these ways, in the words of two other interviewees, technicians 'take an idea developed by a designer … and translate it into reality', thereby 'bridg[ing] the gap between design and manufacture.'[7]

Higher-level technician roles of this kind were found in eight of the case study organisations. The occupants of such roles are almost invariably educated to at least HNC or HND level. These roles may also on occasions be occupied by more practically inclined graduates.

7 For an account of similar contributions made by technicians working in universities, see Lewis and Gospel (2011: 16-17), and by technicians working in the aerospace sector, see Lewis (2012: section 3.1.5).

4.2.3 Test Technicians and Engineers

One of the most distinctive features of the space industry is the extremely rigorous regime of testing to which all space hardware is subjected. Components, sub-systems and assemblies all undergo a variety of tests designed to ensure, with a very high probability, that they will perform reliably in face of the extreme conditions they will experience both during launch and also once they are in orbit. Components will typically be tested before they are integrated to form a sub-assembly or assembly, tested again once they are part of that sub-assembly, and then tested once more after the sub-assembly or assembly has been installed onto the satellite. Since satellites cannot be tested in flight, the process of qualifying a component or sub-assembly as being of flight standard requires that it be tested in ways that simulate the extreme conditions of the launch and orbital environment as realistically as possible. Such tests include: mechanical vibration, acoustic and shock tests, which are designed to ensure that the components, sub-assemblies and assemblies can withstand the vibrations and shock waves that they will experience during launch and in the course of deployment into orbit; thermal vacuum tests, which simulate the extreme variation in temperatures, from +120°C to -170°C, that the hardware will undergo in space; and radiation tests, which are intended to ensure that hardware will continue to function in the face of the intense solar radiation to which it will be exposed whilst in orbit. Test results must be formally documented using established protocols.

4.2.3 (a) Test technicians

Many, though not all, of the requisite tests are carried out by technicians. As we have already seen, basic functional inspection and testing of mechanical and electronic/electrical components and assemblies is sometimes carried out by the same technicians who manufactured them. However, other, more specialized kinds of testing may be undertaken by specialist testing technicians, ultimately under the supervision of graduate-level engineers. Seven of the case study organisations have dedicated testing technicians who carry out the vibration, thermal vacuum and radiation testing described above, or who specialize in non-destructive testing (using automated optical inspection machines to check the quality of PCBs or X-rays to check the integrity of the welding and other forms of bonding used on satellites), or who are involved in the destructive physical analysis of individual components (using methods such as dye-sheer testing or bond-pull testing to ascertain whether electronic components are robust enough to qualify as space worthy). These technicians typically have either level three qualifications, such as City and Guilds or BTECs, or HNCs in mechanical and/or electrical and electronic engineering. Such tasks are not, however, the exclusive preserve of the technician, and in 3 other case study organisations all such testing is carried out by graduates. Given that much of the testing takes place in clean rooms, test technicians – whether they be vocationally educated or graduates - must also be familiar with clean room working procedures.

4.2.3 (b) Test engineers

As was the case with the mechanical and the electrical/electronic engineering functions, so too it is true of test engineering that more experienced and highly qualified technicians do less of the hands-on work and instead play a more supervisory role. Test systems engineers, as they are sometimes known, will write procedures specifying how tests are to be carried out by the assembly and test technicians. They will, for example, determine how much pressure a test technician needs to apply in carrying out a 'bond pull' test on an electronic component. They will also be responsible for the production of reports documenting the results of the tests, thereby ensuring compliance with the relevant quality standards.

Six of the organisations visited for this study have people in such roles. Their occupants are typically qualified to HNC, HND or Foundation degree level. Similarly to the case of manufacturing/production engineers and electrical/electronics engineers, these roles may also be filled by degree-qualified people.

4.3 QUALIFICATIONS

This section draws out and summarises the findings concerning the qualifications typically possessed by technicians working in the space industry. The evidence presented above indicates that the technician workforce in the space industry is highly qualified, with technicians typically possessing an HNC. The main exceptions to this broad finding are to be found in: two of the larger organisations considered for this study – one a space prime, the other a manufacturer of components and sub-assemblies – both of which employ mechanical technicians who are qualified only to level 3; and also in some of the manufacturers of electronics components, some of whose PCB technicians have no more than a level 3 qualification. Notwithstanding these exceptions, the modal technician qualification in the space industry appears to be an HNC, a finding that reflects the way in which the industry's emphasis on the high-integrity manufacturing of bespoke products implies a need for a highly skilled technician workforce as well as a high proportion of graduates.

4.4 DIVISION OF KNOWLEDGE AND EXPERTISE BETWEEN TECHNICIANS AND GRADUATES

At the present time, when policy-makers are concerned about the low status accorded technicians relative to graduates, it is worthwhile drawing out some of the implications of the points made above for the esteem in which technicians are – or at least ought to be – held (Science Council 2011; Skills commission 2011: 16; Technician Council 2012). As we have seen, especially when it comes to technicians occupying roles such as manufacturing or production engineer, there is a genuine division of knowledge and expertise between technicians and chartered engineers, such that the two groups possess distinct, but complementary, skills, knowledge and expertise: the chartered engineers possess more of the relevant abstract, theoretical knowledge; but the technicians possess hands-on technical knowledge of the kind required to bring projects to a successful conclusion that chartered engineers sometimes lack (see Sections 4.2.1 [d] and 4.2.2 [c] above). The knowledge of the two groups is pooled in order to bring the project at hand to a successful conclusion. Thus, as one chartered design engineer put it, 'Working with our technicians is very much a partnership.'[8]

The problem, however, is that because technicians' duties involve them supporting and facilitating the work of another, supposedly more eminent occupation - in this case, chartered engineers - that commonly exercises authority over them, their contribution is easily underestimated by those who are not intimately involved in the industry. One consequence of this is that the social standing of technicians is

8 For similar points, in the case of the technicians who work in university laboratories and engineering workshops, see Lewis and Gospel (2011: 16-18).

not commensurate with their true significance of their work.[9] By helping to draw attention to the fact that technicians are often highly skilled workers who make a distinctive and genuinely important contribution to the work carried out in their organisation, technician registration schemes promise to help overcome some of the misconceptions about the nature both of technical work and also of the people who carry it out, thereby helping to raise the status and esteem in which both are held (Technician Council 2012).

4.5 SOURCES OF TECHNICIANS

We consider first the question of the 'source' or 'origins' of the technicians who currently work in the space sector. This question concerns the route via which the technicians came to work for their current employer and acquire the skills required to carry out his current role. Broadly speaking, three alternative possibilities may be distinguished. First, the technician might be recruited 'ready-made' from the external labour market, either as a permanent member of staff or as a contract worker who already possess all the relevant skills required to fill the role for which they have been hired. Second, the employer might rely on apprentice training. The latter involves taking young people, usually recent school-leavers with little if any work experience, and providing them with a combination of structured on-the-job training, including rotation around a variety of roles, and off-the-job technical education - typically leading to a formal qualification - and thereby enabling them to make the transition from school to work. The third possibility involves what is known as 'upgrade training', which involves an employer taking people who have already undergone some post-compulsory education and training, typically leading to vocational qualifications but sometimes to a degree, and who have often worked in industry – though not necessarily in the space sector - for some years, and then providing them with the additional training required to fill a specific role in the space industry. In contrast to apprenticeship training, therefore, upgrade training: is typically offered to adults, who have already acquired formal qualifications – which may be below, equivalent to, or above, the level of an apprenticeship - and considerable work experience, upon which foundation the upgrade training then builds; is usually closely tailored to the requirements of a specific role; is often provided informally, on-the-job; and is usually uncertificated (Ryan *et al*. 2007: 130, 137; Lewis *et al*. 2008: 7).

The discussion that follows will focus principally on those technicians who occupy upstream, manufacturing roles, simply because – as was noted above - workers of that kind account for the vast majority of the technicians employed in the space sectors. We shall, however, briefly discuss how the downstream firms that employ specialist IT technicians acquire them. In two cases, the technicians were recruited ready made from the external labour market, with no use being made of apprenticeship training. In the third case, however, a small but quite rapidly growing downstream company has recently decided to begin to employ technicians, having never done so before, and has recruited two apprentice IT technicians to help to manage its database and to write some of the simpler 'pockets' of code it needs (which work will subsequently be checked by a graduate-level software architects).

9 This is a long standing issue. Aristotle, for example, wrote in his *Metaphysics* that, 'We consider that the architects in every profession are more estimable and know more and are wiser than the artisans, because they know the reason of the things which are done' (quoted in Sennett 2008: 23). For more on this kind of problem, see Shapin (1989) and Barkley and Bechky (1994: 91).

The remainder of the discussion will concentrate on technicians working in upstream manufacturing roles. While it proved to be difficult to gain accurate data on this issue, with the origins of many long-standing technicians being obscured by the mists of time, 14 of the 16 organisations that employ such technicians were able to provide a rough sense of how their current technician workforce was acquired. Only four firms of the 14 for whom data are available have had apprenticeship schemes that have been in place long enough to make a significant contribution to their technician workforce.[10] The group of firms comprises one space prime and three organisations that manufacture components and sub-assemblies for the space industry. Estimates of the precise contribution made by apprenticeship training to the current technician workforce in these organisations vary from around 15% to almost 90%. These organisations in question adduced the highly specialised nature of the skills they require, and the consequent difficulty of acquiring workers possessing those skills from the external labour market, as the principal reason for their reliance on apprentice training.

By far the most common approach for acquiring technicians, adopted until very recently – the qualification is important, and will be explained shortly - by 10 of the 14 organisations who were able to provide data, was to rely solely on a combination of recruitment and upgrade training, with no use whatsoever being made of apprenticeships. The organisations obtained all of their technicians either by hiring them ready-made from the external labour market – sometimes as permanent employees, sometimes as contractors – or by recruiting people who had done an apprenticeship and worked for some time in another industry and then providing them with the extra training they need to be able to work in the space industry.

The need for upgrade training was said by interviewees at nine of the organisations that use it to reflect the fact that, while the basic principles of mechanical, electrical and electronic engineering are of course universal, the context in which those principles have to be applied is significantly different for the space sector compared to the traditional industries from which space firms typically recruit technicians. There are two main aspects to this point, both of which have implications for the kind of upgrade training that recruits to technician posts in the space industry must receive if they are to become fully productive. First, as noted earlier, the fact that spaceworthy products must work in a vacuum and withstand extreme variations in temperature, strong radiation and considerable vibration implies that the standards/tolerances to which technicians must work are high even by the standards of advanced manufacturing. Consequently, even experienced technicians from outside the space sector require training and time to master the techniques - such as high precision milling and turning, very high quality soldering and wiring, and the use of clean rooms - required to produce work of the requisite standard. Second, the technicians must also acquire the discipline of following, and documenting, the rigorous quality assurance procedures typical of space manufacturing, which are typically more comprehensive and stringent than those to which they will have become accustomed in other industries.

10 One other firm, a component manufacturer located in the upstream part of the sector, also has a long-standing apprenticeship scheme, so that in total 5 of the 16 organisations that employ technicians in upstream manufacturing roles have taken apprentices for several years. However, this firm was unable to estimate of the proportion of its space workforce had been obtained via that scheme.

Common sources of recruits were said to be the armed forces, in particular RAF avionics and Royal Navy radar technicians, and the aerospace and defence industries. Experienced technicians drawn from such backgrounds were said to provide good 'raw material' for upgrading, because the kind of work they had been doing was reasonably similar to that involved in space manufacturing not only technically but also in terms of being 'safety critical', so people would be used to working to high standards. Naturally, the amount of time that such recruits require to become fully productive will depend on a number of factors, most notably the precise nature of their previous and new roles and, of course, their aptitude. Estimates of the length of upgrade training varied from six months to two-three years. The upgrade training is typically provided on-the-job and is usually uncertificated, the principal exception being the use of ESA-certified training for electrical and electronics technicians, which is often provided via external training courses and is by its very nature formally certificated.

The finding, reported above, that the most common way for organisations to acquire their manufacturing technicians was via a combination of recruitment and upgrade training was qualified by the remark that this was true 'until very recently.' Two points are noteworthy in this regard. Both concern what appears to be the beginnings of a gradual shift in the approach through which organisations in the space sector acquire their manufacturing technicians towards a greater reliance on apprenticeships. First, two of the 10 organisations just mentioned have within the past two years begun to take on apprentices. Those apprentices are still in the early stages of their training programmes – in one case, at a training school away from the employer's facilities - and therefore have yet to become a fully-fledged part of their employer's workforce. Nonetheless, especially because both employers indicated that more apprentices would be taken on in the future, the inception of these schemes seems to signal a shift in strategy in favour of a greater reliance on in-house training. Second, no fewer than five of the remaining 8 organisations, which have hitherto relied exclusively on recruitment/upgrade training, are planning to establish an apprenticeship scheme in the near future, and are in discussions with local colleges and training providers about how to do so. Again, such plans testify to the organisations' desire to rely more on the in-house training of young people, as distinct from the recruitment and upgrade training of older, more experienced workers, as a means of acquiring technicians in the future. We shall elaborate on the reasons for these this change in strategy, along with obstacles that might impede efforts to translation the organisations' intentions into reality, in more detail in the next section of the report, where we discuss in some detail the role of apprentice training in the space industry.

Before doing so, however, we shall briefly consider the use of contractors by firms in the space industry, a topic which – as we shall see – also leads on to the topic of an increasing interest in apprenticeship training. Four case study organisations – both space primes and two suppliers of electrical and electronics components and sub-assemblies – made use of contractors, who are invariably experienced at carrying out technician duties in the space industry and who are expected, in the words of one production manager, 'to hit the ground running.' The percentage of the total technician workforce in these organisations accounted for by contract staff varies from a low of around 10% to a high of just over 50%. The rationale for using contractors was rather different in the case of the two space primes than it was for the two components suppliers. The space primes, which – as we shall discuss below – typically find it reasonably straightforward to recruit experienced technicians to permanent posts – tend to hire contractors to deal with cyclical peaks in the amount of work they need to complete. In those cases, therefore, contractors are not being used primarily as a means of dealing with recruitment problems. However, matters are rather different in the case of the two components suppliers, both of which find it rather hard to recruit permanent staff and therefore have to hire contractors simply to deal with their normal level of business, not just with cyclical peaks. As an interviewee from one of the components firms put it, contractors are used 'mostly due to lack of availability of permanent recruits.' Unsurprisingly, the two firms in question are amongst those currently in the process of setting up an apprenticeship training scheme.

5. RESULTS II: THE FUTURE TECHNICIAN WORKFORCE

Having discussed the origins of the case study organisations' *current* technicians, we move on now to consider how the organisations in question propose to satisfy their *future* need for technicians. That is to say, we shall consider in this section the workforce planning strategies adopted by those space companies that employ technicians. This is an interesting and important issue, for a number of reasons. The first is that, as noted above, the increasingly difficulty of recruiting experienced technicians means that the approach most commonly adopted hitherto, namely recruitment-plus-upgrading, may not be as sustainable in the future as it was in the past. Second, many of the case study organisations, including seven of the 12 who are either currently training apprentices or are planning to do so – are growing, often very rapidly, and require increasing numbers of technicians. Of course, this reflects the more general point – made above – that the space industry is growing rapidly, both in terms of the value of its business and also in terms of total employment. It is also worth noting in this context a point made by three firms in particular, namely that as these firms grow the number of technicians may rise as a share of their total employment. The reason is as follows. The firms in question are currently rather small, both in terms of the volume of business they have and also in terms of total employment. Their small size is significant, because it means that in the past they had little or no scope to employ specialist technicians, simply because they have not had enough technician-type work to warrant employing a specialist of that kind. (Typically, the technician-type work has instead been done by graduates.[11]) However, as the volume of business undertaken by the firms expands, there arises a point at which it becomes worthwhile for the firms in question to employ specialist technicians in some parts of their business. There is some reason to think, therefore, that as at least some space companies move from very small-scale batch manufacturing of bespoke commercial satellites to building (somewhat) more standardised products, the number of specialist technicians employed will grow as a share of the manufacturing workforce.

5.1 RECRUITMENT

With the exception of certain specialist roles, such as non-destructive testing technicians and composites laminators, the two space primes find it relatively straightforward to recruit experienced mechanical and electrical/electronics technicians, perhaps – interviewees thought – because those firms are able to offer higher wages than other space manufacturers.[12] Two small manufacturers also said that they had found it straightforward to recruit technicians. In both cases, this appeared to reflect the conditions in their local labour market, where (in one case) the closure of a local instrument-making firm, and (in the other) a significant military presence (and consequent availability of experienced forces technicians) made it possible for the organisations to recruit experienced technicians as raw material for upgrade training.

The picture appears to be rather different, however, in the case of the other firms in the sample who are engaged in upstream manufacturing activities. Nine of the remaining 11 firms that employ manufacturing technicians, and who expressed an opinion, found it hard to recruit.[13] These organisations all commented that it was becoming increasingly difficult for them not only to hire experienced technicians

11 The upshot, as one engineering manager put it, is that currently 'we do use some highly skilled people to do stuff that's "beneath them"'. This over-skilling is expected gradually to disappear as the size of organisations, and the consequent scope for a more elaborate division of labour, increases.

12 Even so, it should be noted at this stage that one of the space primes has a well-established apprenticeship scheme, from it is has drawn a significant proportion – estimated at about 30% - of its current technician workforce.

13 Three small upstream manufacturers with a stable workforce had not attempted to recruit a technician for some time, and were therefore unable to offer an unable with the current state of the technician labour market.

as permanent members of staff but even to recruit technicians from other industries who could then be upgraded into space technicians.[14] For example, in the words of one production manager, 'We really, really struggle to get good people'. He went on to note that his organisation, which makes sub-assemblies for satellites, had had one technician vacancy open for six months. Or, as the owner of one expanding space manufacturer who was finding it increasingly difficult to recruit experienced technicians, put it, 'These people are rare, so we're all fighting over the good ones.' The shortage of experienced technicians was described by one production manager as the 'biggest issue' that his firm faced in its efforts to expand.[15] As mentioned in the previous section, the difficulty that these firms have in recruiting manifests itself in two ways: first, the fact that – in two cases – firms have to use contractors to help them deal not with exceptional but standard volumes of business; and, second, the fact that more and more firms are turning towards apprenticeship training.

5.2 APPRENTICESHIP

5.2.1 Definition and involvement

Apprenticeship training may be defined as a programme of learning, usually for young people, that couples on-the-job training and experience at a workplace with part-time, formal technical education, and which leads to an externally recognised vocational qualification (Steedman *et al*., 1998: 11; Ryan *et al*. 2007: 129). Training programmes that satisfy the requirements embedded in this definition may – or, more rarely, may not - be carried out under the auspices of a government-funded apprenticeship training scheme: one can distinguish between 'apprenticeships', which are training programmes that meet all the key requirements of the definition just given, but which are not publicly funded, and 'Apprenticeship', which term denotes publicly funded, state-regulated training programmes (Ryan *et al*. 2007: 129).

As has been suggested above, manufacturers of space hardware are becoming increasingly involved in apprenticeship training, both because of internal pressures, most notably the fact that many of the firms in question are growing, and also in response to external forces, in particular the increasing scarcity of experienced technicians. In the case of the 16 organisations in the sample considered here who employ manufacturing technicians, the current situation is as follows:

- First, five organisations – comprising one space prime and four suppliers of components or sub-assemblies – are currently running apprenticeship schemes that are established in the sense that at least one – and, in some cases, many – young people have completed their training programmes.

- Second, two more manufacturers of space hardware have within the past two years set up apprenticeship training programmes and taken on apprentices, the first cohort of which are still in training. One downstream company has also recently begun an apprenticeship scheme.

- Third, five more manufacturers are currently in the process of setting up an apprenticeship scheme.

14 Two firms, both of which manufacture sub-assemblies for the space industry, also reported that their recruitment difficulties are exacerbated by MOD restrictions on their ability to hire foreign nationals.

15 As the UK Space Agency has noted, '[The] [g]rowth of the space sector is hampered by the scarcity of graduates and technicians with relevant qualifications' (UK Space 2011: 1). On the pressing need for additional technician skills more generally, in sectors other than space, see UKCES (2010a: 6, 30-34, 2010b: 182).

Overall, then, 12 of the 16 upstream manufacturers – along with one downstream company - either currently train apprentices, or are planning to do so, as a means of satisfying their need for skilled technicians.[16] The evidence presented here suggests that there is more involvement in apprenticeship training than certain previous reports have suggested (Bishop 2008: 3; BIS 2010b: 35) and that the claim, made by some interviewees and in also some publicity documents, that only two organisations in the UK space industry take apprentices, underestimates the extent to which space organisations are involved in apprenticeship training.

5.2.2 Rationale

The most commonly expressed reason for taking apprentices, or planning to do so, emphasised by 10 of the 12 organisations, is the need to acquire specialist technician skills in the face of a declining availability of such skills on the external labour market. In the words of one production manager, 'We can't recruit the right people so we have to train our own.' In four of those cases, all relatively small but expanding private sector components suppliers, apprenticeships are seen a means of meeting the medium term skills of the organisation in the face of persistent recruitment problems. In three of the other cases - all of which are older, established organisations - the attractiveness of apprenticeships as a means of acquiring specialist skills is reinforced by the need to plan for the orderly succession of an ageing technician workforce. As one HR manager said, 'Apprenticeships provide a pipeline of talent at a younger age.' All 10 of these organisations are using apprenticeship as a means of workforce planning (that is, as a way of dealing with their future skills needs, whether the latter are being generated by expansion or by the anticipated retirement of skilled workers). The research reported here thus lends support to the view expressed in a recent report on the space sector that, 'Industry will also need to offer more training and apprenticeships to fill the jobs that will arise from the planned growth in manufacturing and services' (Space IGS 2010a: 20; also see p. 45).

The other, oft-cited advantage of apprenticeship training, mentioned by five firms, is that it gives employers an opportunity to take young people and, at a formative age, socialise them into the organisation's culture, so that they acquire the habits and modes of thought – in particular concerning the tolerances and standards to which work has to be done, and the importance of adhering rigidly to the specified procedures - desired by the employers. In the words of one interviewee, '[I]t's good to get people with no preconceptions about doing particular tasks … [to the] standards required in the space industry.' Of course, it is possible to do this with older workers, whose habits have already been formed but may be susceptible to modification. Indeed, this is one of the goals of the upgrade training that has hitherto been the primary method of acquiring technicians for so many firms. However, as one manager of a small components manufacturer noted in this context, 'It's easier to start with someone who is a relatively clean sheet of paper … They don't come with bad habits. They're a blank canvas and we can mould their habits.'[17]

16 One of the remaining 4 upstream manufacturing organisations had also taken on a young person to be trained as a mechanical technician. However, with the exception of one week-long training course delivered by an external provider, the trainee has had no off-the-job training. Given the centrality of formal technical education, and the off-the-job training through which it is provided, to STEM apprenticeships, the trainee in question is not counted as an apprentice for the purposes of this study (cf. Ryan *et al*. 2006: 362-64; Hogarth *et al*. 2012: 4, 11).

17 For similar observations by employers in other sectors, see Ryan *et al*. (2007: 140, 145-46), Lewis *et al*. (2008: 7, 15), Hogarth *et al*. (2012: 10), and Lewis (2012: section 4.2.2).

5.2.3 Organisation

There is a good deal of common ground, but not complete uniformity, in the way that the eight organisations – seven downstream, one upstream – that are currently taking apprentices have organised their training programmes. In every case, the apprentices have been recruited under the auspices of the government's Advanced Apprenticeship programme (that is to say, using the terminology introduced in Section 5.2.1 above, all the apprentices are 'Apprentices' rather than 'apprentices'). Every employer has delegated formal responsibility for organising the apprenticeship to an external training provider. In four cases, these duties have been assumed by a local further education college, in one case by a private training provider, and in one instance by a group training association. These external training providers hold the apprenticeship training contract with the Skills Funding Agency and, as a result, are in direct receipt of the government training subsidy. The latter contributes towards the fees for the college courses taken by the apprentices and also to covering the cost of the assessment of their practical skills required for the award of the NVQ part of the apprenticeship training framework.

The remaining two cases involve slightly more unusual approaches to organising apprentice training. In the first case, one small space manufacturer has 'piggy-backed' on the well-established apprentice training scheme offered by another high-tech organisation located in the same geographical area. Although the space manufacturer employs the apprentices, most of their on-the-job training is provided by the other high-tech organisation, which also arranges their off-the-job training. The advantage of this approach, compared to the alternatives offered by local colleges and training providers, is that it relieves the space manufacturer of the burden of providing most of the training whilst still ensuring that the apprentices will become accustomed to, and skilled in, the kind of advanced manufacturing techniques needed for the space industry. The second case involves the one downstream firm to take apprentices doing so via a local Apprenticeship Training Association (ATA). Under the ATA scheme, the apprentices are formally employed by the ATA, but they are placed with a 'host' employer who covers their wages and provides them with work experience and on-the-job training, as well as paying a small administration fee (typically equal to 15% of the apprentice wage) to the ATA. The host has the option to hand the apprentices back to the ATA at short notice if it feels the need to do so, or to take them on as full-time employees, at any stage of their apprenticeship. The fact that the host does not formally employ the apprentice, and can hand them back to the ATA (which is obliged to find them the apprentice a new host) at short notice, is thought to help overcome some of the barriers – such as uncertainty about the merits of young people or about how apprenticeships will fit with their organisation - that deter small and medium-sized employers from taking apprentices. In the case under consideration here, the fact that the firm did not have to employ the apprentice was said to be an important factor, because it meant that the space company, which had never employed any technicians before, let alone taken apprentices, could explore whether or not there was work for the apprentice technicians to do, confident in the knowledge that, if such work could not be found, the apprentices could be handed back to the ATA without penalty.

The apprentices who have been taken on by the upstream manufacturers are invariably studying for qualifications in mechanical and, most commonly of all, electrical and electronics engineering. In keeping with the point made earlier in this report that most of the technician roles in space manufacturing require their occupants to be qualified to least level 4, all six of the manufacturers that are currently taking apprentices aim for them to progress beyond the level 3 qualification that is required for the award of an Advanced Apprenticeship certificate and achieve either an HNC (four cases) or a Foundation Degree (two cases). (In the case of the lone downstream company that takes apprentices, the current goal is for the apprentices to achieve a BTEC level 3 qualification in IT.) In three cases, all of which are manufacturers of components and/or (sub-) assemblies, the apprenticeship schemes have been approved by professional bodies such as the IET and the IMechE, so that apprentices will achieve an EngTech award upon completion of their training.

Two of the larger organisations – one a space prime, the other a relatively large components manufacturer – explicitly distinguish between apprenticeship schemes of the kind just described, where the target is a level 4/5 qualification, and schemes where the goal is a level 3 qualification. The latter tend to be focused more on training apprentices in mechanical than in electrical/electronic engineering, and are intended for people who are more likely to remain in shop floor manufacturing roles – such as machinists, mechanical assembly technicians, and composites laminators – rather than those who will be seeking to leave the shop floor and move into production/manufacturing engineering positions. Consistent with this, the 'level 3' apprenticeships typically require lower GCSE grades ('C's or even 'D's) than those schemes whose apprentices are expected to reach level 4 or above.

The components manufacturer just mentioned is the one employer amongst the case study organisations that has become involved in a Higher Apprenticeship scheme, having just taken on a small number of Higher Apprentices in Engineering.[18] The Higher Apprenticeship was said to be appealing because, when the apprentices in question complete their training, they are expected to fill roles that often require their occupants to lead projects, for which both the higher-level technical skills provided by the Foundation Degree and the management skills provided by the NVQ4 in Engineering Leadership are expected to be useful. Only two other case study employers had heard of Higher Apprenticeships. Both thought it unlikely that they would take on Higher Apprentices, perceiving little benefit in switching away from the HNC/Ds currently taken by their apprentices.[19] Of those employers who first become aware of the Higher Apprenticeship during the course of the interviewees conducted for this study, two expressed initial interest and thought it possible that the combination of management and technical skills provided by the Higher Apprenticeship might provide suitable training for certain roles within their organisation. No other employers expressed a view about Higher Apprenticeships.

18 The Higher Apprenticeship in Engineering Technology involves apprentices gaining: a NVQ2 in Performing Engineering Operations, so that they gain basic hand skills; an HNC, HND or Foundation Degree in Engineering, to give them appropriate theoretical knowledge; and an NVQ4 in Engineering Leadership that assesses their competence at more advanced engineering activities such as creating and evaluating engineering designs, specifying and evaluating engineering processes, and implementing quality assurance methods and procedures (SEMTA 2011).

19 This reflects the point, noted by Wolf (2011: 33, 73-74), that employers tend to rely on qualifications with which they are familiar and happy and, understandably, show little desire to keep up with the constant reforms and changes to which the UK vocational education and training system is subject.

There are considerable variations in the annual intake of apprentices across the seven downstream manufacturers that currently take apprentices. The three larger (500+ employees) firms who currently train apprentices – two components suppliers and one space prime – tend to take apprentices every year, in some cases recruiting more than 10 per annum (although in at least one of those cases, involving a firm that supplies components to non-space as well as space manufacturers, some of the apprentices will end up working on non-space projects). Three of the other four manufacturers that currently run apprenticeships are relatively small (fewer than 100 employees in total), do not need to take apprentices every year, and – when they do take them – tend to recruit only one or at most two at any one time. The downstream organisation has two apprentices and, depending on its business needs, may take more in the next year or so.

The most common entry requirement set by employers is for prospective technician apprentices to have GCSEs at grade C in mathematics, English and a science subject, sometimes coupled with the requirement to have four, five or even six GCSEs passes in total. In one case, a large employer required its apprentices to achieve B grades in maths and science, whilst in another technical apprentices were required to have A-levels. The quantity and quality of applicants for apprenticeship places appears to be acceptable to most employers, with all but one of the eight case study organisations that currently take apprentices saying that they were able to fill the places they offered without significant difficulty. (The one exception to this broad finding was an upstream manufacturer that wanted to increase the minimum GCSE mathematics required of its apprentices from a 'C' to a 'B' but found that, when it did so, it could not fill all the places on offer.[20]) Completion rates are uniformly high, with all five of the organisations that have taken apprentices for long enough for them to complete the course reporting success rates of over 90%.

What is proposed by the five upstream manufacturers who are in the process of setting up an apprenticeship scheme – all of which are relatively small, with only one employing more than 100 people - is very similar to what is being done by those firms that are currently taking apprentices. As noted earlier, the principal reason for planning to take apprentices lies in the difficulty of recruiting experienced technicians who have the specific skills required by these organisations. four of the five organisations specialise in supplying electronics/electrical components and sub-assemblies to the space industry, while the fifth does a mixture of mechanical and electrical/electronics work. Unsurprisingly, therefore, the organisations are typically looking for their apprentices to specialise in electronics engineering, supplemented in some cases with elements of electrical and mechanical engineering as well. Four of the organisations anticipate taking the apprentice as far as an HNC; the fifth is looking for nothing more than a level 3 qualification. All would expect to devolve much of the responsibility for organising the apprenticeship to a specialist training provider.

20 Although this organisation's desire to increase the entry requirements for its apprenticeship programme from a grade 'C' in GCSE mathematics to a grade 'B' did not come to fruition, its reasoning is in keeping with that of the large employer mentioned in the text which does require that its apprentices possess a 'B' grade. In both cases, the rationale for demanding the higher grade is that, in the experience of these organisations, both of which have been running engineering apprenticeship programmes for over 10 years, it is those apprentices who achieve only a 'C' in GCSE mathematics who struggle with the mathematical aspects of the college work associated with their apprenticeship and who as a result tend to fail to complete the programme.

5.2.4 Impediments to the use apprenticeships

Neither those organisations that are currently take apprentices, nor the ones thinking of doing so, have found in the process of running on apprenticeship to be entirely straightforward. Finding an FE college to provide the off-the-job training, and in many cases also the assessment for the on-the-job element of the apprenticeship, has been a particular source of difficulty, both for those organisations that currently take apprentices and also for those intending to do so. More specifically, four of the eight space sector organisations that currently take apprentices highlighted problems in their relations with FE colleges, including apprentices being put on the wrong technical certificates, inadequate support and feedback being provided by external NVQ assessors, and concerns about the quality of the practical, hand-skills training being provided in college workshops for apprentices spending their first year on block release. While, as noted above, all the organisations taking apprentices had delegated formal responsibility for organising the training to an external provider, it is clear from interviews that employers still have to work hard to ensure that the colleges deliver the quality of support required for the apprenticeship programme to be a success.[21]

Moreover, of the five organisations that are currently in the process of setting up a scheme, two – both situated in relatively rural areas - are having difficulties in finding a college willing to offer courses of the kind the employer want their apprentices to take (namely, HNCs in electronics). As one employer put it, 'The colleges aren't geared up for what I want … They haven't got the departments [to teach it].' The main problem in these cases was that there were insufficient numbers of students wanting to take the courses in question to make it worthwhile, given the prevailing funding regime, for colleges to offer them. As one of the frustrated employers summarised the problem, 'College funding is contingent on student numbers and it's easier to get them via hairdressing, customer service, etc., than via engineering.'[22] Indeed, one of the space organisations that is not taking apprentices said that this was partly because of difficulties in finding the right college course and also because of poor experiences with an FE college when they had taken a customer service apprentice in the past.

It is interesting to note, however, that one potentially significant deterrent to the use of apprenticeships, namely the possibility that once they have completed their training apprentices will leave the organisation that has sponsored them, thereby depriving their employer of the opportunity to recoup its investment in them, appears not to be a problem in practice. While those employers that offer, or are considering offering, apprenticeships are clearly conscious of the possibility that their newly qualified apprentices will be poached, in no case were concerns sufficient to deter them from training young people. (Poaching did not feature at all in the reasons given by those organisations that were not interested in apprenticeships for their decision not to train young people.) The most common reason for this, mentioned by six of the employers interviewed for this study, centred on the belief that, if coupled with the possibility of promotion,

21 For similar findings about the need to invest time and effort in ensuring appropriate college provision, see Unwin and Fuller (2004: 17-18), Lewis and Gospel (2011: 33), and Lewis (2012: section 4.2.3).

22 Problems with finding colleges willing to offer HNCs in electronics are also reported by some university engineering and physics departments that take apprentices (Lewis and Gospel 2011: 38). For more general concerns about whether the incentives that encourage the FE sector to provide training in STEM disciplines are sharp enough, see Skills Commission (2011: 10-11, 23-27) and Wolf (2011: 60).

the provision of providing apprentice training can signal to young people that they are valued by their employer and that they will have the chance to develop their career within their current organisation, rather than having to move elsewhere to do so, thereby helping to build loyalty and commitment to the employer that initially trained them.[23] Perhaps most notably, one large employer – which has taken apprentices for over 15 years – pointed out that over 80% of the apprentices that have been trained over that period remain with the organisation, primarily because they can see that there are well-defined career paths from an apprenticeship to senior roles. The point, then, which appears to have been taken on board by most if not all of the organisations in the sample considered here that are (considering becoming) involved in apprenticeship training, is that if apprenticeships are complemented by other HR practices concerning continued training and career progression, they can help to persuade apprentices that their future lies with their current employer rather than elsewhere, thereby building loyalty, reducing turnover and helping firms to ensure that they earn a positive return on their investment in training.[24]

5.3 CAREERS: ONGOING TRAINING AND PROFESSIONAL DEVELOPMENT

The previous discussion of career paths leads on to the question of the kind of ongoing training that the firms considered here provide for their more established technicians. A variety of different forms of training was mentioned by interviewees. First, 10 of the organisations that employ technicians have supported some of them to do Foundation Degrees or full honours degrees, usually in physics or engineering, and occasionally in management, typically part-time via a local university. One space prime estimates that around 50% of its apprentices ultimately move on to take full degrees. Second, seven organisations mentioned informal, typically uncertificated, training, either provided in-house by more experienced staff or delivered by external equipment suppliers, as an important source of skills development for more established technicians. Third, ESA-certified operators need to be retrained every two years if they are to retain their status, and this is another oft-mentioned example of ongoing training.

Concerns about the status of technician-level occupations in relation to professional occupations have recently led to increased interest amongst policy-makers and professional bodies in developing opportunities for technicians to progress to higher levels of formal qualifications and professional recognition (for example, through formal registration as technicians with the possibility to progress further to chartered engineer and scientist status) (Skills Commission 2011: 17-18, 30-35; Technician Council 2012). As noted above, three of the downstream organisations in the sample considered here have had their apprenticeship schemes accredited by the IET and the IMechE, so that their apprentices will be eligible for an EngTech award upon completion of their training. Though some of the remaining firms offering, or considering offering, apprenticeships have been visited by professional bodies in the relatively recent past, and some supported their graduates to achieve Chartered Engineer status, they are not planning to

23 For similar points, see Ryan *et al*. (2007: 140-41).

24 There is a sense, indeed, in which some companies may have been *too* successful in enabling their former apprentices to progress up through their organisation. For instance, one of the reasons given by one employer for deciding to supplement its long-standing 'technician' apprenticeship programme, which was designed to take apprentices up to level 4 (HNC), with a separate 'craft' scheme designed specifically for those workers who are unlikely to want, or to be able, to progress beyond level 3, is that it wishes to train more people who are likely to remain in hands-on, shop floor roles - as machinists, mechanical fitters and composite laminators - for a substantial period of time, rather than quickly moving on to hands-off, managerial positions as most of its level 4 apprentices are wont to do.

have their apprenticeship schemes accredited so their apprentices can register for EngTech. They typically cite a lack of awareness or interest amongst their technicians, reinforced by a degree of uncertainty about how registration might benefit the organisation as a whole, as reasons for their current lack of interest in technician registration. There clearly remains considerable work for the Technician Council to do in raising the profile of technician registration in the space industry.

6. CONCLUSIONS

We return in this conclusion to the five questions posed in the Introduction, summarising what the evidence gathered for this study suggests about how they can be answered.

Q1: In what roles are technicians employed in the UK Space industry and what are their principal duties?

Judging from the case studies carried out for this project, the vast majority of technicians employed in the industry are to be found in the upstream part of the sector, in roles connected with the manufacture, assembly, and testing of space hardware. A small number of IT technicians can be found in a minority of downstream companies.

Q2: What qualifications do the technicians who work in the space industry typically possess?
The majority of the technicians employed in the space industry are qualified to level 4, the most common qualification being an HNC. Technicians with level 3 qualifications tend to be confined to roles centring on machining and fabrication, composite laminating, and mechanical or PCB assembly.

Q3: How do the organisations in the space industry who need technicians acquire them? What balance do they strike between recruitment and (different forms of) training?

The most common route through which technicians have entered the space industry involves them receiving vocational education and training, along with work experience, in another industry, after which they are recruited into space and given appropriate (upgrade) training to ensure both that they have the specific skills required to work in the industry and also that they are fully conversant with the extremely high standards, and very rigorous quality assurance procedures, that characterise space manufacturing. However, for reasons to be discussed in the next paragraph, this tendency for most firms to rely primarily on a mixture of recruitment and upgrade training seems set to change, with more upstream space manufacturers taking on apprentices.

Q4: Fourth, are there skills shortages? And if there are, is government policy helping to alleviate them?

There do indeed appear to be skills shortages, with recruitment – both of 'space-ready' technicians and also of experienced technicians from other industries who can form the raw material for upgrade training – proving to be increasingly difficult. Given the rapid growth of the space industry, and also the difficulties that employers in other sectors are finding in hiring experienced technicians, the increasing shortage of technicians ought not to be surprising. Employers appear to be responding to the increasing difficulty of recruitment by turning towards apprenticeship training.

The fact that more organisations in the space sector are planning to take apprentices provides some hope that the aspiration, expressed in the recent Space IGS report, that there should be a significant increase in the number of apprentices trained in, and for, the space sector will be fulfilled (Space IGS 2010a: 45). Significantly, however, the Space IGS report also notes that, 'Government must guarantee that sufficient training and apprenticeship schemes exist to meet this demand' (Space IGS 2010a: 20). The evidence gathered for this report indicates that it is not transparently clear that the relevant training infrastructure is in place. In particular, some employers who are considering taking apprentices are experiencing difficulties in finding colleges that are willing to offer the relevant off-the-job training, while those employers that already take apprentices are often disappointed at the quality of the support they receive from colleges. These issues will need to be addressed if the potential for organisations in the space industry to offer high quality apprenticeships, and thereby to satisfy the industry's growing needs for technicians, is to be realised. At the very least, policy-makers need to consider whether the incentives currently confronting further education colleges provide sufficient encouragement for them to offer off-the-job training ('technical certificates') in the subjects, and at the levels, desired by advanced manufacturers such as those found in the space industry. Another, more radical possibility that might be worth exploring further, and which has been mooted for other industries, would be for the smaller firms that wish to take apprentices to 'piggy back' on the established apprentice training schemes already being offered by one or two of the larger space organisations, with the smaller organisations' apprentices spending most of the first year or two of their training with the larger organisation before returning for the final year or two of their training to their 'real' employer.[25]

Q5: What provision do employers make for the ongoing training and career development of their technicians?

Finally, the vast majority of the organisations visited for this study who employ technicians view them as a valuable resource whose careers should be nurtured, both through the provision of additional training (including sponsorship to foundation or full degree level) and also through affording them the possibility of a career advancement and promotion within their organisation. For the most part, however, that concern does not yet extend to offering technician apprentices the opportunity to register with a professional body.

Overall, then, the evidence presented here suggest that the space industry is one in which, even allowing the fact that a high proportion of its workforce is qualified at last to degree level, there is a significant - and expanding - for role for technicians. Growing imbalances between supply and demand in the technician labour market appear to be encouraging more and more employers in the industry to turn toward training their own technicians in-house, via apprenticeship programmes. While little use is currently made of technician registration, the combination of a highly skilled technician workforce, along with employers who take seriously the career development of their technicians, and are willing to invest in doing so, suggests that there is reason to be cautiously optimistic that technician registration may well become considerably more popular in the sector.

25 For a similar suggestion, see ADS Group (2012: paragraph 5.2). Also see Rolls Royce (2012: point 8).

REFERENCES

ADS Group (2012). 'Apprenticeships: Written Evidence Submitted by ADS Group Limited.' House of Commons Select Committee on Business, Innovation and Skills. Available online at: http://www.publications.parliament.uk/pa/cm201012/cmselect/cmbis/writev/1843/app095.htm. Accessed 24th April 2012.

Barley, S.R. and B.A. Bechky (1994). 'In the Backrooms of Science: The Work of Technicians in Science Labs.' *Work and Occupations*, 21: 85-126.

BIS (2009). *Skills for Growth: The National Skills Strategy*. Cm 7641. London: TSO.

BIS (2010a). *Skills for Sustainable Growth: Strategy Document*. London: 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 Economics Paper No. 3. London: Department of Business, Innovation & Skills. Available online at: http://www.bis.gov.uk/assets/biscore/economics-and-statistics/docs/10-624-bis-economics-paper-03. Accessed 30th January 2012.

BIS (2010c). *Manufacturing in the UK: An Economic Analysis of the Sector*. London: Department of Business, Innovation and Skills.

Bishop, C. (2008). *SPACE: The Skills Need*. Leicester: British National Space Centre.

HM Treasury and Department of Business, Innovation and Skills (2010). *The path to strong, sustainable and balanced growth*. London: HM Treasury and BIS. Available online at: http://www.bis.gov.uk/assets/biscore/corporate/docs/p/10-1296-path-to-strong-sustainable-and-balanced-growth.pdf. Accessed 24th April 2012.

HM Treasury and Department of Business, Innovation and Skills (2011). *The Plan for Growth*. London: HM Treasury and BIS. Available online at: http://cdn.hm-treasury.gov.uk/2011budget_growth.pdf. Accessed 24th April 2012.

Hogarth, T., L. Gambin and C. Hasluck (2012). 'Apprenticeships: Where Next?' *Journal of Vocational Education and Training*, 64: 41-55.

House of Commons Library (2011). 'Apprenticeships Policy.' Standard Note SN/EP 3-052. Updated 04 November 2011. London: House of Commons.

Jagger, N., M. Sigla and F. Sumption (2010). *SET Based Technicians: Lessons from the UK and European Labour Force Surveys*. Report 475. Brighton: Institute for Employment Studies.

Lewis, P. (2012). *Flying High? A Study of Technician Duties, Skills, and Training in the UK Aerospace Industry*. London: The Gatsby Charitable Foundation.

Lewis, P. and Gospel, H. (2011). *Technicians under the Microscope: A Study of the Skills and Training of University Laboratory and Engineering Workshop Technicians*, London: The Gatsby Charitable Foundation. Available online at: http://www.kcl.ac.uk/sspp/departments/management/people/academic/lewisgatsbyreport.pdf

Lewis, P., P. Ryan and H. Gospel (2008). 'A Hard Sell? The Prospects for Apprentice Training in British Retailing.' *Human Resource Management Journal*, 18: 3-19.

NSTSG (2011). *A National Space Technology Strategy for the UK*. Swindon: National Space Technology Strategy Group.

OECD (2004). *Space 2030: Exploring the Future of Space Applications*. Paris: Organisation for Economic Cooperation and Development. Available online at: http://www.space-library.com/0404OECD_Space2030-1_2To1.pdf. Accessed 30th January 2012.

OECD (2011). *The Space Economy at a Glance*. Paris: Organisation for Economic Cooperation and Development.

Oxford Economics (2009). The Case for Space: The Impact of Space Derived Services and Data. Oxford: Oxford Economics. Available online at: http://www.stfc.ac.uk/resources/pdf/case-for-space.pdf. Accessed 5th February 2012.

Rolls Royce (2012). 'Apprenticeships: Written Evidence Submitted by Rolls Royce.' House of Commons Select Committee on Business, Innovation and Skills. Available online at: http://www.publications.parliament.uk/pa/cm201012/cmselect/cmbis/writev/1843/app040.htm. Accessed 24th May 2012.

Ryan, P., P.A. Lewis and H. Gospel (2006). 'Educational and Contractual Attributes of the Apprenticeship Programmes of Large British Employers.' *Journal of Vocational Education and Training*, 58: 359-83. (With H. Gospel and P. Ryan.)

Ryan, P., P.A. Lewis and H. Gospel (2007). 'Large Employers and Apprenticeship Training in the UK.' *British Journal of Industrial Relations*, 45: 127-53.

Science Council (2011). *Science Technicians in the Workforce: Supporting their Development Needs*. London: The Science Council. Available online at: http://www.sciencecouncil.org/sites/default/files/Science%20technicians%20in%20the%20workforce%20-%20FINAL.pdf. Accessed 26th April 2012.

SEMTA (2009). *Skills and the Future of Advanced Manufacturing: A Summary Skills Assessment for the SSC Advanced Manufacturing Cluster*. Available online at http://www.semta.org.uk/pdf/ADVMFG%20Report%20Mar10.pdf Accessed 23rd May 2011.

SEMTA (2011). *Apprenticeship Framework: Higher Apprenticeship in Engineering Technology*. Watford: SEMTA.

Sennett, R. (2008). *The Craftsman*. London: Penguin Books.

Shapin, S. (1989). 'The Invisible Technician.' *American Scientist*, 77: 554-63.

Skills Commission (2011). *Technicians and Progression*. London: Policy Connect. http://www.policyconnect.org.uk/sites/default/files/Technicians%20and%20Progression%20-colour%20final(2).pdf. Accessed 28th April 2012.

Smith, A. (2011). 'The New Space Economy: Vision for the Future.' Available online via http://www.intellectuk.org/component/docman/. Accessed 12th February 2012.

Space IGS (2010a). *A UK Space Innovation and Growth Strategy 2010 to 2030*. Executive Summary and Recommendations. Swindon: UK Space Agency. Available online at: http://www.bis.gov.uk/assets/bispartners/ukspaceagency/docs/igs/space-igs-exec-summary-and- recomm.pdf. Accessed 29th January 2012.

Space IGS (2010b). *Markets and Wealth Creation*. Swindon: UK Space Agency. Available online at: http://www.bis.gov.uk/assets/bispartners/ukspaceagency/docs/igs/s-igs-wg1-markets-and-wealth-creation-volume3.pdf. Accessed 12th February 2012.

Spilsbury, M. and R. Garrett (2011). 'The Future Demand for Technicians and Underlying STEM Skills.' London: The Gatsby Foundation. Available online at http://www.gatsby.org.uk/pdfs/Technical_Education_21C/The%20future%20demand%20for%20technicians.pdf . Accessed 13th June 2011.

Steedman, H., H. Gospel and P. Ryan (1998). *Apprenticeship: A Strategy for Growth*. London: Centre for Economic Performance, LSE. Available online at: http://eprints.lse.ac.uk/20248/1/Apprenticeship_A_Strategy_For_Growth.pdf. Accessed 22nd April 2012.

Technician Council Technician Council (2011). 'The Technician Council'. Available online at http://www.techniciancouncil.org.uk/. Accessed 4th November 2011.

Technician Council Technician Council (2012). 'Professional Technician.' Available online at: http://www.professional-technician.org.uk/about.php. Accessed 24th April 2012.

Unwin, L. and A. Fuller (2004). *National Modern Apprenticeship Task Force Employers: Their Perspectives on Modern Apprenticeships*. University of Leicester: Centre for Labour Market Studies.

UK Space Agency (2010). *The Size and Heath of the UK Space Industry*. Swindon: UK Space Agency. Available online at: http://www.bis.gov.uk/assets/bispartners/ukspaceagency/docs/10-1195-size-and-health-uk-space-industry-2010. Accessed 30th January 2012.

UK Space Agency (2011). *UK Space Agency Education, Skills and Outreach Strategy*. Swindon: UK Space Agency. Available online at: http://www.bis.gov.uk/assets/bispartners/ukspaceagency/docs/strategy/uk-space-agency-education-strategy-march-2011.pdf. Accessed 13th February 2012.

UKCES (2010a). *Skills for Jobs: Today and Tomorrow. Volume 1: Key Findings*. Wath-upon-Dearne: UKCES. Available online at: http://www.ukces.org.uk/assets/ukces/docs/publications/national-strategic-skills-audit-for-england-2010-volume-1-key-findings.pdf. Accessed 24th April 2012

UKCES (2010b). *Skills for Jobs: Today and Tomorrow. Volume 2: the Evidence Report*. Wath-upon-Dearne: UKCES. Available online at: http://www.ukces.org.uk/assets/ukces/docs/publications/national-strategic-skills-audit-for-england-2010-volume-2-the-evidence-report.pdf

Wolf, A. (2011). *Review of Vocational Education – The Wolf Report*. London: Department for Education.