SKILLS AND TRAINING FOR COMPOSITES MANUFACTURING AND USE IN THE UK: AN ANALYSIS

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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. As the term 'technician' is currently used by policy-makers in the UK, it denotes people occupying technical roles that require either level 3 or level 4/5 skills. Consequently, the class of 'technicians' encompasses both 'skilled trades' and also 'associate professional/technical' roles.
2. 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 through policies designed to increase both the status and the number of technicians in the UK economy.
3. This report investigates the role played by technicians in an industry that is of growing importance for the UK economy, namely composites. A composite is a mixture of two materials which, when appropriately combined, has new properties that neither of the individual materials taken alone possesses. These properties are often highly attractive for manufacturers and include high strength-weight ratios and excellent resistance to fatigue and corrosion. The UK produces around £1.6 billion worth of composite materials, components and structures every year, adding around £1.1 billion to UK national output. Prospects for growth are very good, with increases in demand being driven by developments in the aerospace and wind energy industries in particular.
4. The goal of the research described in this report is to inform policy by examining how organisations that make and work with composite materials acquire and use the technicians they need. 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 composites – the aerospace, chemicals and space sectors.
5. More specifically, the research reported below focused on five sets of questions.
    - First, in what roles are technicians who work with composites in the UK typically employed?
    - Second, what levels of skill and qualifications do the people occupying technician roles – and certain other key manufacturing roles – typically have?
    - Third, how do employers who work with composites fill technician – and also certain semi-skilled – roles?
    - Fourth, do the organisations that work with composites suffer from any skill shortages?
    - Fifth, and finally, what – if anything – should government do to help firms that work with composite materials in their efforts to acquire the skilled workers they need?
6. Data were collected via interviews with thirteen sector-level organisations, including government departments, industry bodies, national skills academies, and sector skills councils, and through case studies of 35 employers. The case

study organisations included: companies that manufacture composite materials; organisations that use those materials to manufacture composite parts for the aerospace, defence, marine, high-end automotive and space industries; firms that machine and assemble – but do not fabricate – composite parts and structures; organizations that carry out research and development on composites; and firms that maintain, repair and overhaul civil aircraft (MROs).

7. In most cases, the laminators who manufacture composite parts tend to be semi-skilled workers and so do not count as technicians. More specifically, rank-and-file laminators who use resin infusion, carbon pre-preg and wet lay-up techniques to fabricate composite parts typically require no more than level 2 skills to carry out their duties effectively. Consequently, they count as semi-skilled workers rather than technicians. Where those techniques are used, the only laminators who tend to be skilled at level 3 – and so qualify as technicians – are team leaders and supervisors. In contrast, the laminators who employ more automated methods of production, such as filament winding and automated fibre placement/ tape-laying, tend to need at least level 3 skills and so do count as technicians.
8. Key technicians roles in firms that work with composites include team leader or supervisor, machinist, non-destructive testing technician, mechanical testing technician, maintenance technician, aircraft fitter, aircraft mechanic, and category 'A' licensed engineer in the case of 'skilled trades' roles; and manufacturing, production and process engineer, draughtsman or junior design engineer, quality engineer, and category 'B' licensed aircraft engineer in the case of 'associate professional/technical' roles.
9. The occupants of 'skilled trades' roles tend to possess a level 3 qualification in some form of engineering. The occupations of 'associate professional/technical' roles tend to be qualified at least to level 4/5, possessing at a minimum HNCs, HNDs or Foundation Degrees in engineering. In addition, those people who fill the role of licensed aircraft engineers must also possess the relevant category of license. Specialist, rank-and-file laminators who use non-automated methods of production to make composite parts for the aerospace, marine, automotive and defence sectors tend to possess only level 2 skills, sometimes – but not always – certificated via an NVQ2.
10. Technicians account for between 10% and 45% of the workforce of the organisations that manufacture and/or use composites materials and parts. The precise share tends to be lowest (i) in those chemicals firms that employ semi-skilled process operators to manufacture composites materials, and (ii) in those firms that rely on semi-skilled laminators to fabricate composites components for the automotive, defence, and marine sectors. The share of technicians in the workforce tends to be highest in the aerospace sector, where firms typically make extensive use of technicians either (i) to machine, assemble, test, and quality assure composites parts, even when the parts in question are made by semi-skilled laminators (in the case of aerospace manufacturers), or (ii) to maintain, repair and overhaul aircraft (in the case of MROs).
11. In most cases, the majority of the technicians employed by firms working with composites have been acquired via external recruitment, with apprenticeship typically accounted for less than 20% of the current technician workforce. The principal exceptions to this finding are to be found in the aerospace sector. Typically, the aerospace manufacturers report that apprenticeship

training accounts for over 30% of their technician workforce (and sometimes, especially in those cases where firms are planning to use automated methods of production, over half of the technician workforce). Practice varies between the MROs visited for this study: around half, including most of smaller firms, have tended in the past to recruit most of their technicians ready-made from the external labour market; the other MROs estimate that 40-60% of the technicians they currently employ have been trained internally.

12. The picture is very different in the case of the semi-skilled laminators who fabricate composite parts in many of the automotive, defence, aerospace and marine firms. Given the limited supply of good quality laminators on the external labour market, such firms have tended to rely on in-house training to acquire the majority of the laminators they need. However the training does not take the form of an apprenticeship. Rather, the firms in question tend to hire unskilled workers and then use in-house, on-the-job training programmes to equip those recruits with the level 2 skills they need to become effective composites laminators ('external upgrade training').

13. Shortages both of technicians who can work with composites and also, especially, of semi-skilled composites laminators currently leave many firms struggling to recruit workers who are skilled at working with composite materials. Employers are responding to this problem by increasing their reliance on various kinds of in-house training: external upgrade training in order to fill semi-skilled laminator roles; apprenticeship training as a means of developing new technicians who can work with composites; and the provision of additional training to equip those technicians who are established employees but are (only) skilled at working with metallic parts with the skills required to work with composites.

14. External upgrade training involves employers recruiting people who do not necessarily possess any prior knowledge of engineering in general or composites in particular, and then providing the specific training required to fill a particular role – in the composites industry, typically that of a laminator – within their organisation. In contrast to apprenticeship training, upgrade training tends to be: more closely tailored to the requirements of a specific role in a particular organisation; provided informally, on-the-job, without any off-the-job technical education; and it is oftentimes uncertificated. External upgrade training has proved to be the most important source of semi-skilled composites laminators for the vast majority of organisations that fabricate composites parts using wet lay-up, carbon pre-preg and resin infusion techniques.

15. An apprenticeship is 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 equips people with intermediate-level skills. 26 of the 35 case study organisations train apprentices, with 14 having started their apprenticeship scheme since 2006.

16. The majority of the firms involved in aerospace and space manufacturing which offer apprenticeships differentiate explicitly between those apprentices who are destined for skilled trades roles and those who will occupy associate professional/technical occupations upon completing their training, offering separate training programmes with different entry requirements for the two groups of trainees. 'Craft apprentices', as those apprentices who are in training for skilled trades roles are often known, usually aim to achieve qualifications at level 3 in subjects such as aeronautical engineering (for aircraft fitters),

mechanical engineering (for machinists), and electrical/electronic or mechanical engineering for those fitters who make mechanical and/or electronic/ electronics components. 'Technical apprentices' – as those in training for associate professional/technical occupations are often known – aim to achieve qualifications at level 4 (e.g. HNC) or level 5 (Foundation Degree, often as part of a Higher Apprenticeship) in subjects such as aerospace/aeronautical engineering, manufacturing engineering, mechanical engineer, or electrical/ electronics engineering, with a view to filling roles such as draughtsman, junior design engineer, manufacturing engineer, production engineer, and quality engineer. Apprentices who are destined for roles that will involve them working with composites will take modules on topics such as pre-preg laminating, vacuum-bagging and curing, de-moulding, trimming, assembling, machining, testing, repairing, and the electrical bonding of composite parts.

17. Those firms in the defence, high-end automotive, and marine industries, as well as the organisations carrying out R&D on composites materials, which take apprentices typically have them study mechanical engineering or, in the case of the marine firms, marine engineering and boat-building and maintenance. Apprentices take modules in composites manufacturing as part of their training programme. These apprenticeship programmes typically do not involve separate streams for craft and technician roles.

18. The most common form of apprentice training offered by MROs sees trainees take level 3 qualifications in aeronautical engineering or aerospace engineering and maintenance. Those who complete their apprenticeship are ready to work as unlicensed aircraft mechanics. Those who wish to become licensed engineers will spend a fourth year, if they aspire to a category 'A' license, and a fifth year, if they wish to acquire a category 'B' license, taking the relevant examinations and acquiring the requisite practical experience. The three MROs in the sample that have decided to develop a significant capacity to repair and modify composite components and structures are investing in purpose-built composites training facilities and incorporating modules on composite materials into their apprenticeship programmes.

19. The organisations that train apprentices usually mentioned one or more of the following four reasons for doing so. First, just over two-thirds of the organisations that take apprentices emphasised that the use of apprenticeship training enables them to acquire specialist technician skills in a context where there is a limited availability of the relevant kind of worker on the external labour market. Second, around half of the organisations highlighted the way in which training apprentices helped them to plan for the orderly succession of an ageing technician workforce. Third, around one third of the firms in question also mentioned the way in which apprenticeship training affords them an opportunity to introduce young people to the organisation's culture and to instil in them the values, standards and norms of behaviour desired by the employers, such as a sense of the standards to which work must be completed, an acceptance of the need to take responsibility for ensuring that those standards are met, and a willingness to call others to account if poor practice is witnessed. Fourth, and relatedly, around one-quarter of the organisations which take apprentices also emphasised that 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 who initially trained them.

20. Organisations in sectors where composite components and structures are increasingly replacing metallic ones, including most aerospace manufacturers, need to retrain at least some of their workers so they know how to deal with composite materials. Four of the aerospace manufacturers visited for this study make extensive use of such training. Three have developed extensive, structured in-house training programmes so that their aircraft fitters can learn how to work with composite materials. These programmes typically involve an initial period of training away from the shop floor, in a dedicated training facility run by specialist trainers, after which trainees receive a further period of on-the-job training, under the tutelage of a more experienced worker. In most cases, this training is uncertificated

21. Employers face two main impediments to their efforts to offer high-quality training for their semi-skilled laminators and apprentices. The first concerns availability, with several employers struggling to persuade local colleges to offer modules in working with composite materials. Second, even when colleges do offer such training, its quality is said to be deficient, with colleges being accused of lacking the facilities and instructors required to teach best practice techniques for working with composites. It appears that there is only a small number of colleges and private training providers that offer high-quality composites training, making it hard for those employers who want to train workers actually to do so.

22. While some employers have worked closely with their local colleges to develop training programmes, and while some large employers in particular have developed their own training workshops so as to be able to provide training in-house, these options are unrealistic for smaller firms which lack the critical mass of apprentices required to justify either a college or the firms themselves investing in a specialist composites training facility. There appears to be a clear need to expand provision for high-quality training in working with composite materials.

23. Policy-makers can help to deal with this problem in a number of ways, for example by:

    - helping to disseminate information about the availability of those (currently, relatively small number of) training providers that are able and willing to offer high-quality training in working with composite materials;
    - sharpening the incentives that encourage further education colleges to invest in their workshops and to offer high-quality practical training;
    - exploring the extent to which some of the large, publicly-funded organisations involved in composites research can contribute to training apprentices, including via periods of block release for trainees from firms located in other regions;
    - encouraging those large private-sector firms – typically drawn from the aerospace and marine sectors – that have invested in their own training facilities to open up them up to trainees from other firms, either as a means of helping to cover the fixed costs of running the facilities or as a way of supporting firms in their own supply chain ('over-training'); and
    - exploring whether the requirements of professional registration can help to provide both a more robust and useful set of standards by reference to which the level of skills and quality of training in composites can be judged than the current National Occupational Standards, and also a framework for career development for semi-skilled and, especially, technician-level workers in the sector.

SECTION 1 INTRODUCTION

Successive governments have argued that raising the number of skilled technicians in the UK workforce, especially in sectors such as manufacturing, is essential for improving the performance of the UK economy. 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' (Technician Council 2012). As it is currently used by policy-makers in the UK, the term 'technician' denotes people occupying technical roles that require 'intermediate' – that is, level 3 or level 4/5 – STEM (science, technology, engineering and mathematics) skills. Consequently, the category encompasses both 'skilled trades' and also 'associate professional/technical' roles (Jagger et al. 2010; Technician Council 2012).

Policy-makers' concerns about technicians are rooted in the perception that there are ongoing skills shortages at the technician level in the UK economy (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 the number of apprentice technicians (BIS 2010a: 7, 15, 18; HM Treasury and Department of Business, Innovation and Skills 2010: 18-19; House of Commons Library 2011: 4-6). In a related development, the government's acceptance of many of the recommendations of the recent Richard Review of Apprenticeships has been motivated by a desire to increase both the demand for, and supply of, high-quality apprenticeship training places with a view, ultimately, of increasing the number of qualified technicians in the UK economy. Perhaps most notably, Richard's recommendation that the criteria for what counts as an apprenticeship be tightened, in particular by requiring that (almost) all apprenticeships aim at general, transferable level 3 skills and involve mandatory off-the-job vocational education; his support for a new, more holistic assessment of apprentices' all-round competence; and his determination to sharpen the incentives for training providers to respond to the needs for employers by channeling government funding for apprenticeships via the latter, are all (admittedly fallible) attempts to increase the quality, attractiveness and (ultimately) the number of apprentices being trained (Richard 2012; BIS 2013; Lewis 2014).

The policy goals of increased numbers of technicians 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. The research reported in this paper helps to achieve such an understanding by investigating the duties, skills, and training of the technicians – and semi-skilled workers – employed.

Composites are mixtures of two materials which, when appropriately combined, have new properties possessed by neither of the individual parts taken alone. The properties in question are often highly attractive for manufacturers in various industries, and include: low weight, thereby facilitating savings on running costs and carbon emissions (something especially important for aerospace applications); high strength-weight ratios (useful in particular for applications to the production of turbine blades for wind energy production); and excellent resistance to fatigue and corrosion (important for use in sectors like the high-end automotive, aerospace, space, and aerospace industries, whose products have to work well in extreme environments) (BIS 2009: 6-7).

The UK produces around £1.6 billion worth of composite materials, components and structures every year, adding around £1.1 billion to UK national output. Most of that value is generated through the manufacturing of composite components and structures, most notably for the marine, renewable energy, automotive and – above all – aerospace industries (the latter accounts for around 60% of the value of composite components made in the UK). Prospects for growth are very good, with increases in demand being driven by developments in the aerospace and wind energy industries in particular. The industry has a presence throughout the UK, with especially notable concentrations of activity in the south-west, north-west and south-east of England, and in the midlands (BIS 2009: 12, 15-20; UKTI 2010: 6-7, 10, 15).[1]

Such a sector is naturally of interest to policy-makers such as the current government, who profess to want to rebalance the UK economy away from financial services and towards manufacturing, to increase the number of apprentices in training, and thereby to promote the fortunes of UK manufacturing and to catalyse export-led growth. 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).

The goal of the research described in this report is to inform policy by examining how the UK composites industry uses technicians – and, as we shall see, certain categories of semi-skilled worker – and how it acquires and/or develops those it needs. More specifically, the paper seeks to answer five sets of questions:

- First, in what roles are technicians who work with composites in the UK typically employed?
- Second, what levels of skills and qualifications do the people occupying technician roles – and certain other key manufacturing roles – typically have?
- Third, how do employers who work with composites fill technician – and certain semi-skilled – roles? Two sub-questions arise. First, do employers acquire those workers primarily by hiring experienced technicians from the external labour market, or by using in-house training? Second, and relatedly, to the extent that employers rely on in-house training to fill technician roles, what form does such training take?
- Fourth, do the organisations that work with composites suffer from any skill shortages?
- Fifth, and finally, what – if anything – should government do to help firms that work with composite materials in their efforts to acquire skilled technicians?

The structure of the report is as follows. Section 2 provides important background information about the nature of composite materials. Section 3 outlines the research methodology used in the study. Section 4 starts the presentation of the study's findings, examining the workforce employed by organisations that use composite materials with respect to three main sets of issues: the kind of roles that are filled by technicians and by semi-skilled workers; the skills – and, as a proxy for skills, the qualifications – their workers need to fill those roles successfully; and whether those workers were acquired by their current employer via the external labour market or through some form of in-house training. Section 5 continues with

1 Additional detail on the composites industry can be found in UKTI (2010: 6-10) and Composites Leadership Forum (2013: 6-7).

the presentation of the results, but shifts attention towards the workforce planning strategies that employers who use composites are currently adopting in order to satisfy their need for technicians in the medium to long term. Section 6 summarises the discussion and offers recommendations for policy.

SECTION 2 THE NATURE OF COMPOSITE MATERIALS

2.1 THE NATURE OF COMPOSITE MATERIALS

A composite is a mixture of two materials which, when combined in the appropriate way, creates a new material with properties that are not possessed by either of the constituent parts taken in isolation. The two constituent materials in question most commonly take the form of a bulk material or 'matrix', most commonly a polymer-based resin, and a set of fibres that, when added to the matrix, enhance its mechanical properties (e.g. strength, stiffness, resistance to fatigue and corrosion). In such cases, therefore, a composite is a material consisting of fibres embedded in a polymer resin matrix. A wide range of resins and fibres can be used. The most common poly-based resin systems used are epoxy, vinyl ester and polyester. Glass fibre is commonly used in boat-building, while carbon fibre is more commonly used in aerospace and automotive applications. Aramid (Kevlar) fibres are used in military applications, where impact resistance is important.[2]

For many purposes, composites have notable advantages over their metallic counterparts such as aluminium. The resin systems have attractive properties for manufacturers because they can be easily formed into relatively complex shapes. Taken on their own, however, resin systems have poor mechanical properties. This is where the reinforcement of the resin system by the fibres becomes important. Very crudely speaking, if layers of fibre are impregnated with resin, shaped by being laid in a mould, and are cured (hardened) and consolidated by being exposed to heat and pressure, then – thanks to the resulting alignment of the fibres within the material – the composite parts that are produced are lighter, stronger, and more resistant to corrosion and fatigue than those fashioned from metal. Moreover, structures can be made with fewer physically separate components when they are made out of composites rather than metal – in the jargon, the part count is lower – so that there is less need for labour-intensive assembly work, making the manufacturing process quicker and cheaper (BIS 2009b: 6-7, 16; SEMTA 2009: 45-46; SEMTA and NSAPI 2011: 19; Aerospace Growth Partnership 2012: 15).[3]

There exist a number of different techniques for the production – or 'lamination', as it is also known – of composite parts. The techniques in question vary in their level of sophistication and, therefore, in the demands they make – both in terms of practical skills and also of underpinning knowledge – of the laminators who use them. Consequently, a short account of some of the main techniques used in the manufacture of composite components will be useful for understanding the skills and training that laminators need. We shall consider five techniques here: wet lay-up; resin infusion; carbon pre-preg-laminating; filament winding; and automated fibre placement/automated tape-laying. Only the final two techniques involve automation. We shall consider each in turn.

2.1.1 Wet lay-up

The simplest technique for the fabrication of composite parts, which is perhaps most often used in the marine sector, involves so-called 'wet lay-up'. This 'bucket and brush' method, as it is also known, begins with dry glass fibre material being

2 For helpful introductory guides to composites, including descriptions of the relevant manufacturing techniques, see ACG (2011), Gurit (2012), and the Inter-agency Composites Group (undated).

3 For a very useful overview of the UK composites industry, see UKTI (2010).

positioned in a mould by hand so that it has the thickness and direction required to suit the load-bearing requirements of the structure under construction (e.g. a boat hull). Second, polyester resin is mixed with a catalyst and accelerator in a bucket and then rolled into the fibre using a brush in order to ensure that it is spread evenly across the fibre. The properties of polyester resin are such that the composite will cure or harden without the application of heat or pressure as part of the manufacturing process. Wet lay-up is commonly used in the marine sector, for the manufacture of boats.

2.1.2 Resin infusion

Like wet lay-up, resin infusion begins with dry carbon or glass fibre being placed in a one-sided mould. However, rather than resin being applied by hand, as in wet lay-up, the mould is vacuum-bagged and the resin is drawn into it under pressure, after which the part is placed in an autoclave and/or oven, and heat and/or pressure are applied to ensure that the fibres align in the way required to produce the desired structural properties. Resin infusion is often used in the marine sector, where it promises to facilitate both the use of less resin, and therefore of lower costs, and also greater consistency in production, and therefore more reliably high-quality outputs, than wet lay-up. It is also used to make composite parts for the aerospace, defence and high-performance automotive industries.

2.1.3 Carbon pre-preg laminating

This involves the laminator taking pieces of woven carbon-fibre fabric material, which have already been impregnated with resin – hence 'pre-preg' – and placing them in a mould, which is then vacuum-bagged and placed under pressure, before being cured (baked) in an oven or autoclave to ensure that the layers of carbon-fibre material consolidate properly in order to form a component that has the appropriate structural properties. Carbon pre-preg is widely used for the manufacture of composite parts for the aerospace, defence, high-performance-automotive, and space industries. Because carbon pre-preg material has already been coated with a resin that begins to cure (harden) once a certain temperature is exceeded, the material must be kept refrigerated. Once it has been removed from the refrigerator, carbon pre-preg only has a limited 'shelf-life' or period of time before it becomes stiff and unusable.

2.1.4 Filament winding

Filament winding is an automated method of production used primarily to make cylindrically-shaped composite components or structures such as pipes, tanks, oars, yacht masts, missile casings, and – in the case of one of the case study organisations considered here – the inner core of satellites. The method involves strips – tows, or filaments – of carbon or glass fibre being passed through a bath of resin before being wound around a rotating mould known as a mandrel. Automation makes it easier to control both the tension of the tape and the speed at which the mandrel rotates, improving both the cost-effectiveness and the reliability of the production process compared with non-automated approaches. Once the deposition of the fibres is complete, the mandrel can be placed in an oven and/or autoclave for curing, after which the mandrel can be removed to leave the hollow part.

2.1.5 Automated methods for producing composite parts

While many composite parts, in particular those with geometrically complex shapes, are still made by hand using wet lay-up, carbon pre-preg and resin infusion, the use of modern automated production technologies such as Automated Tape

Laying (ATL) and Automated Fibre Placement (AFP) is increasing as manufacturers attempt to increase the speed, consistency, repeatability and reliability of their production processes so as to enhance quality, improve productivity and reduce costs (BIS 2009b: 20, 28-29; Inter-agency Composites Group 2013: section 3.1). The introduction of such productivity-enhancing technology is likely to become increasingly important if, as expected, companies that use labour-intensive methods of production are increasingly likely to be undercut by rivals from lower-wage economies (BIS 2009: 15, 28; UKTI 2010: 12-13, 16).

SECTION 3 RESEARCH METHODOLOGY

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

The process of data collection had two main stages. The first involved a series of thirteen interviews with various sector-level organisations, such as the Department of Business, Innovation and Skills, the National Composites Network, the Composites Skills Alliance, national skills academies, learned societies, and sector skills councils. These interviews, along with secondary sources such as reports and policy documents concerning the UK composites industry, were used both to acquire information about key issues associated with the composites workforce and also to inform the choice of case study organisations.

The second stage of the project involved the collection of data about technician duties, skills, recruitment, and training from total of 35 employers. Information was collected via 39 semi-structured interviews with a total of 49 interviewees, whose ranks included technicians, HR, training, apprenticeship, and production managers, managing and technical directors, chief engineers, heads of manufacturing, heads of composites design, training instructors, heads of technology, and directors of engineering, using a schedule piloted in the early cases. The interviews were carried out between July 2011 and June 2012 and averaged a little over 60 minutes in length. Notes were written up and, where gaps were revealed, these were filled by email follow-ups. Primary and secondary documentation was also collected where available.

The case study organisations were involved in the manufacture and use of composites in a variety of different ways, and included:

- companies that manufacture the composite materials, such as carbon pre-preg, out of which composites parts are made;
- companies who take composite materials produced by other organisations and use them to manufacture composite parts for so-called tier 1 firms in the aerospace, defence, high-end automotive and space industries;
- firms that make and/or repair boats and yachts;
- firms that machine and assemble – but do not fabricate – composite parts and structures;
- organisations that carry out research and development on composite materials and/or on techniques for manufacturing and machining composite parts; and
- firms, known as MROs, that maintain, repair and overhaul civil aircraft, either as their sole line of business or as part of a commercial airline.

The case studies are summarised in Table 1. The table also provides information – where relevant – on the principal methods of production used by those organisations in the sample who actually fabricate composite parts, as well as various aspects of the workforce employed by the case study organisations.

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

Type of organisation	Number of cases	Composites manufacturing techniques[a]	Average total workforce	Average share of technicians in the total workforce (%)	Average share of level 2 laminators in the total workforce (%)
(i) Aerospace parts manufacturer	4	CPP, RI, AFP/ ATL	1,600	46	22[b]
(ii) Automotive parts manufacturer	5	CPP	120[c]	24[c]	34[c]
(iii) Defence parts manufacturer	2	CPP	125	30	47
(iv) Space parts manufacturer	2	WLU, CPP, FW	1,560	12[d]	0[d]
(v) Boatbuilding and repairs	3	RI, WLU	1300	Unknown	22
(vi) Composites R&D	4	WLU, CPP, FW, AFP/ATL	115	22	0
(vii) Composites materials makers	4	N/a	290	15	3
(viii) Machining and assembling composite parts	2	N/a	2500	34	0
(ix) MROs	5	[Repairing, testing composite parts]	595	45	0
(x) MROs /airlines	4	[Repairing, testing composite parts]	13,200	11	0

NOTES

a: The acronyms used in the Table are: AFP/ATL (automated fibre placement/automated tape-laying); CPP (carbon pre-preg); FW (filament-winding); RI (resin infusion); and WLU (wet lay-up).

b: Based on three firms only (the fourth does not employ any level 2 laminators; its inclusion reduces the average share of level 2 laminators in the total workforce to 17%).

c: Based on data from three firms only.

d: On average, these two firms employ around 18 composites technicians, all but one or two of whom have level 3 skills in working with composite materials.

Considering the sample of firms visited for this study, we find the following pattern of use of the various methods of composites production:

- wet lay-up is used principally by firms in the marine sector, with occasional use being made of it by some automotive, aerospace, and research and development companies;
- resin infusion is also quite commonly used by boat-builders and also by aerospace manufacturers;
- the technique most frequently used by the organisations considered in this study is carbon pre-preg laminating, which is the primary method of production employed by the aerospace, space, defence, and motorsport companies in the sample;
- filament winding is employed both by one of the satellite manufacturers, where it is used to manufacture the carbon fibre core of satellites, and also by one of the research and development organisations, who use it to design parts for the renewable energy industry.
- one aerospace manufacturer, and one research and development organisation, make extensive use of automated fibre placement/tape laying to produce aircraft parts.

Table 1 also provides information about the pattern of employment in the organisations visited in the study, including their technician workforce and their employment of specialist, semi-skilled laminators. And it is to a more detailed discussion of the workforce employed by these organisations that we now turn our attention.

SECTION 4 RESULTS 1: THE CURRENT TECHNICIAN WORKFORCE: SIZE, ROLES, QUALIFICATIONS, AND ORIGINS

This section of the report outlines the research project's findings concerning issues such as: the duties and qualifications associated with typical technician roles; the size of the technician workforce; and how organisations that work with composite materials have hitherto gone about satisfying their need for technicians.

4.1 TYPES OF TECHNICIAN AND THE NATURE OF TECHNICAL SUPPORT

Several different types of technician are employed in the composites industry. A selection of common roles, including both 'Skilled Trades' and 'Associate Professional/ Technical Occupations', will be described below in order to give a flavour of the kinds of jobs that are filled by technicians in the sector. Brief summaries of the roles in question, along with the section of the report in which they are discussed, can be found in Table 2.

Several points should be kept in mind whilst considering the descriptions that follow. First, the selection of roles provided below is by no means comprehensive, and many important – and common – roles have been excluded. Second, no organisations will employ each and every one of the different kinds of technician described below. For example, composites laminators will not be found in firms that assemble – rather than manufacture – composite components. An attempt will be made in what follows to give a sense of the types of organisation that employ particular kinds of technician. Third, the technicians employed by one particular firm may be assigned duties that combine elements of more than one of the roles outlined below. For instance in some research and development firms, the same person may fabricate prototype composite parts and also machine and test them; the licensed aircraft engineers who work in MROs may both carry out composite repairs and also undertake non-destructive testing (NDT) that might in some organisations be carried out by specialist NDT technicians; smaller composite parts manufacturers sometimes combine the duties of machinists and fitters/trimmers in one role; and laminating team-leaders in some firms carry out some of the duties that in other firms might be assigned to specialist quality inspectors. Fourth, there may well also be instances where the boundaries between the roles occupied by more experienced technicians and those occupied by less experienced and/or more practically inclined graduates become blurred (as in the case of roles such as production/manufacturing engineer, quality engineer, and junior design engineer). These caveats notwithstanding, the following should provide a faithful introduction to the type of roles occupied by technicians in composites.

4.1.1 Composites laminators

Laminators are the people who make the composite parts. The type and level of skills that laminators require depends upon the particular methods being used to fabricate the parts in question. More specifically, as we shall see, interviewees reported that the rank-and-file laminators who use resin infusion, carbon pre-preg and wet lay-up techniques to produce composite parts require no more than level 2 skills to carry out their duties effectively. As a result, they count as semi-skilled workers rather than technicians. In organisations that employ specialist laminators and which use the three techniques just mentioned, the only laminators who tend

to be skilled at level 3 – and so qualify as technicians – are team leaders and supervisors who require a higher level of skills in order, for example, to carry out the trouble-shooting and quality-assurance duties associated with their role. In contrast, the laminators who use more automated methods of production, such as filament winding and – in particular – automated fibre placement and automated tape-laying, tend to possess at least level 3 skills. Such workers do, therefore, count as technicians.

Table 2: Typical technician roles in firms that make and/or use composite materials

Section of report	Role	Predominantly found in these kinds of organisation	Skill level
4.1.1	Composites laminators	Parts manufacturers,[a] boat-builders	Level 2 (non-automated methods of production), level 3-4 (automated methods)
4.1.2	Fitters/trimmers	Parts manufacturers	2-3
4.1.3	Machinists	Parts manufacturers, boat-builders, space firms, specialist firms that machine/assemble composites[c], research and development organisations	3
4.1.4	Production/process engineers	Parts manufacturers, space firms, specialist firms that machine/assemble composites	4, 5
4.1.5	Draughtsmen/junior design engineers	Parts manufacturers, space firms, specialist firms that machine/assemble composites	3, 4
4.1.6	Quality engineers	Parts manufacturers, space firms, specialist firms that machine/assemble composites, materials makers	4, 5
4.1.7	Non-destructive testing (NDT) technicians	Parts manufacturers, space firms, specialist firms that machine/assemble composites, materials makers, MROs	3, 5
3.1.8	Mechanical testing technicians	Materials-makers, research and development organisations	3
3.1.9	Aircraft fitters	Aerospace parts manufacturers, specialist firms that machine/assemble composites	3
3.1.10	Aircraft mechanics and licensed aircraft engineers	MROs	3 (mechanics, Category A licensed engineer), 4/5 (Category B licensed engineer)
3.1.11	Chemical process operators	Materials-makers	2 or 3
3.1.12	Maintenance technicians	Materials-makers	3

Notes:
a: The term 'Parts manufacturers' denotes the categories of organisation labelled (i)-(iv) in Table 1.
b: Team-leaders/supervisors/leading hands using non-automated production methods – such as wet lay-up, carbon pre-preg and resin infusion – tend to have level 3 skills.
c: Firms in category (viii) in Table 1

4.1.1.1 Wet lay-up, carbon pre-preg and resin infusion

Consider first the skills that workers involved in wet lay-up, resin infusion and carbon pre-preg laminating are thought to need. Interviewees reported that workers using these techniques need to be accurate, careful and methodical in following best-practice procedures. They must also be able to sustain the high levels of concentration required to follow those procedures to the letter for long periods of time. In short, in the words of the head of technology at one aerospace company that uses carbon pre-preg techniques to manufacture composite parts, 'We want people who are dexterous, who pay attention to detail, stick to the instructions they've been given and don't vary the process … If they do what they're told, you'll end up with a good part.' Some examples of good practice are as follows:

- Laminators need to prepare their moulds by coating them with the right amount of a 'release agent' designed to ensure that the finished part can be removed from the mould without damaging either the part or the mould. They must also take pains to use the correct tools to remove the finished part from the mould, again so as to avoid damaging it.
- In the case of wet lay-up, laminators must be very careful to weigh out the appropriate quantities of resin and catalyst so as to ensure that the material produced has the desired properties. They must also take pains to stir the 'ingredients' together carefully; if they are not evenly distributed throughout the mixture, then air bubbles might be introduced which weaken the structure of the composite material that is ultimately formed.
- Carbon pre-preg must be stored at the appropriate temperature; workers must be conscious of the material's limited shelf life, taking care to ensure that it is used before it becomes too hard to manipulate into the mould.
- Workers involved in carbon pre-preg laminating require the manual dexterity to position the pieces of pre-impregnated carbon fibre material appropriately in the mould, in particular by making sure that the plies go right into the corners of the mould and are not creased. Otherwise, the layers of composite material will not consolidate properly, and 'voids' or air pockets will arise in the resin that will prevent the finished part from possessing the appropriate structural properties.
- Laminators need to take good care of their mould tools if the latter are to yield high-quality parts. It is important to keep the mould tools clean, by removing excess resin and release agents. When cutting the pieces of carbon fibre material, pre-preg laminators must avoid cutting into the surface of the mould, damage to which will prevent it from producing high-quality parts.
- In the case of both carbon pre-preg and resin infusion, laminators must understand how to vacuum-bag the part properly. Failure to position and seal the bag properly will mean that the resin will not be distributed properly amongst the fibres, and the part will not have the desired structural properties. In the most extreme cases, if the part is bagged improperly, then when the vacuum is created and the bag shrinks, it will press against the sharp corners of the part and burst, ruining the part completely.
- Laminators must also know precisely what temperatures and pressures are appropriate for curing certain parts if the desired structural properties are to be achieved.

- Especially in the case of carbon pre-preg and resin infusion, laminators must adhere to high standards of cleanliness, so as to avoid contamination with dirt or other foreign bodies whose presence in the mould or between the layers of carbon fibre material would prevent the plies from consolidating properly, thereby ruining the part.

Interviewees argued that laminators are more likely to adhere strictly to best practice if they understand why it is important to do so, something that is perhaps best achieved by making sure that they appreciate the potentially serious consequences of failing to follow the correct procedures. Two examples should suffice to make the point: the failure to remove a sheet of backing paper from some carbon pre-preg material led ultimately to a Formula 1 racing car team having to scrap a £10,000 gearbox cover; while another interviewee reported how a small stone had fallen out of a laminator's shoe into a mould and been cured into an aircraft part, being detected only when the part underwent non-destructive testing and causing the £70,000 part to be ruined. In other words, failure to follow best practice production methods leads to high rates of scrappage, excess costs and – ultimately – to a lack of competitiveness and lost orders.

Finally, while it is very important for laminators to adhere to good practice, speed is also very important. Laminators of all kinds must be able to work quickly enough for the company to be able to produce the parts in a commercially viable way. This is especially important in the case of those firms that are producing composite parts for the motorsport industry, where the period between the receipt and dispatch of an order can be very short indeed.

All of the organisations – both employers and sector-level institutions – that ventured an opinion stated that the rank-and-file laminators who fabricate composite parts using wet lay-up, resin infusion and carbon pre-preg techniques are semi-skilled, requiring no more than level 2 skills in laminating. The reason is that, as we have seen, such methods of production rely primarily on the relatively low-level hand skills of the workers, and on the workers being willing to follow instructions carefully and methodically, rather than on an ability to operate machinery or read engineering drawings of the kind that would be typical of somebody with level 3 skills. As one technical director put it when describing these methods of production, 'It's semi-skilled, hand crafts' work. While it was commonly acknowledged that resin infusion and carbon pre-preg laminating demand greater levels of skills and understanding on the part of laminators than wet lay-up, because laminators need to be able to vacuum bag the parts properly and apply the right temperature and pressure in order to cure the part, interviewees were adamant that the laminators who use those techniques still require only level 2 skills to carry out their duties effectively. As a result, they count as semi-skilled workers rather than technicians. Consistent with this, none of the case study employers referred to their rank-and-file pre-preg, wet-up or resin-infusion laminators as 'technicians'.

Two other pieces of evidence that support the claim that most of the laminators who undertake non-automated methods of production of composite parts are semi-skilled workers rather than technicians. First, as we shall see in more detail below, when companies train rank-and-file laminators in-house, then their skills are certified (if at all) to level 2. Second, the workers in question are typically paid a lower wage (sometimes explicitly referred to as 'the semi-skilled rate') than the occupants of roles where a level 3 qualification is the norm (e.g. aircraft fitters). The upshot of all this is that a majority of the laminators who undertake

non-automated methods of production do not count as 'technicians', as that term is currently used.

The small number of laminators who are qualified to level 3 (usually NVQ only) typically amount to no more than about 10% of the composites workforce, and tend to occupy roles variously described as supervisor, leading hand or team leader. While such workers may do hands-on work – most notably laminating geometrically complex parts that might prove to be too difficult for less experienced workers – their duties tend to centre less on hands-on work and more on tasks that require a slightly higher level of skills and knowledge, such as: allocating work between the members of their team; checking that vacuum-bagging and autoclave processes have been set up properly; providing advice and guidance for the semi-skilled laminators about how to interpret the instructions found in the ply-books on how to laminate parts; trouble-shooting; doing first-line monitoring of the quality of the parts being produced, by checking and signing off the work carried out by the junior laminators in their team; identifying opportunities to improve the production process; and the on-the-job training and mentoring of new laminators.

4.1.1.2 Filament winding

The laminators employed by the two companies in the sample that used filament winding were qualified to level 3 in mechanical engineering. Interviewees reported that level 3 skills were required for an adequate understanding of the automated production process, an issue upon which we shall elaborate immediately below.

4.1.1.3 Automated fibre-placement and automated tape-laying

While there is some uncertainty around the precise level of skills and knowledge that the machine operators who use automated fibre placement and automated tape-laying for the production of composite parts must possess, there was broad agreement amongst interviewees that they must be skilled at least to level 3 and quite possibly to level 4. (The uncertainty over the precise level of skills arises because of the novelty of this technology.)

The interviewees reasoned as follows. While graduate-level engineers will write the programmes that govern how the machine will deposit the carbon fibre in order to make the composite part, the operators still have a key role to play. As one interviewee put it, 'they don't just look at a screen and press a green button'. This is *not* because the operators need good hand skills. On the contrary, one of the principal benefits of using automated manufacturing processes is precisely that it leads to a reduced reliance on the dexterity and hand skills of individual workers, thereby increasing not only the speed but also the consistency of the production process. Or, as one source put it, the use of automated processes is designed to 'to increase throughput and reduce errors by minimising human involvement in the production process.'

However, human involvement is not entirely eliminated from automated methods of production. In particular, in order to ensure that the automated processes works smoothly and efficiently, the operators must have a well-developed understanding of how the machines work, so that they can monitor the production process, assess accurately whether it is going well (e.g. whether the bundles of fibres being deposited are of the right thickness, whether the gaps between them are the right size, and whether they are oriented in the right way around the mould), and tweak the operation of their machine to optimise its performance. The operators must also have sufficient knowledge to be able to make sound judgements about

whether any problems that arise are routine ones they themselves can solve – something it is important for them to do wherever possible, given that pre-preg carbon fibre degrades very quickly once it is removed from the freezer, so that stoppages in the production processes can be very costly in terms of lost materials – or whether the difficulties are sufficiently complex to justify halting production and calling a supervisor or engineer for assistance. The machine-operators need to have level 3 or 4 qualifications – interviewees differed in their opinion of the precise level of skills required – in mechanical engineering, with a large dose of composites engineering in particular, so that they have the requisite understanding of how the automated process is supposed to be working, of when and how to adjust the operation of the machine, and of when to call for help (cf. SEMTA and NSAPI 2011: 15). The qualifications at level 3 typically include an NVQ and a technical certificate, such as a BTEC qualification in aerospace engineering, while the level 4 qualification is a technical certificate only (usually an HNC).

4.1.1.4 Summary

Overall, then, in the case of composites laminators it can be seen that technician roles are typically confined either to team-leaders/supervisors or to specialist laminators who use filament winding or other, more sophisticated automated methods of production.

Specialist composites laminators are most commonly found in the organisations that specialize in manufacturing composites parts – essentially those in categories (i)-(iv) in Table 1 – and in the firms that specialize in boat-building (category [v]). A minority of the materials-makers, and research and development firms, also have dedicated laminators. In the other research and development firms, and in MROs, people who do laminating tend to do so only as part of a broader portfolio of duties.

4.1.2 Fitters/trimmers

Once a composite part has been fabricated and removed from the autoclave, it is passed from the laminators to people known as fitters/trimmers. They take the part and use hand-held or bench-mounted tools to complete the manufacturing process by: trimming off excess material; drilling holes into the part and attaching (threaded) fittings so that different parts can be joined to each other; and putting the parts in jigs and then using adhesives to join ('bond') them together to make bigger assemblies. Especially in companies making parts for sports cars, fitters may also polish or lacquer parts to ensure that they achieve a suitably polished appearance. Considerable care is needed in all these activities, because poor-quality trimming, drilling or polishing can cause the layers of composite material to come apart at the edges ('delamination'), ruining it.

Fitters need to be able to read engineering drawings, so they know the size and location of any holes that need to be drilled into the composite parts, and they also need to be able to use various mechanical tools (drills, cutting tools, etc.) in order to do their job. Consequently, to a much greater degree than laminators, fitters need to be trained in engineering. Typically, they have level 2 or – perhaps more commonly where CNC machines are used to drill the parts – level 3 skills in mechanical engineering. The ability to work under pressure to meet tight deadlines is important, especially in motorsport where – as noted above – orders often need to be completed within very short timeframes. Specialist fitters/trimmers were found in firms manufacturing parts for the aerospace, automotive, defence and space industries.

4.1.3 Machinists

Fifteen of the organisations visited for this study employ specialist machinists who use manual and CNC machine tools for cutting, turning, milling and drilling composite materials in order to produce a variety of parts. The operators of CNC machines usually work from 3-D CAD files and engineering drawings provided by junior design engineers or draughtsmen (see Section 4.1.5 below), but will programme, set and operate the CNC machines themselves. Machinists may also be involved in making the patterns, mould tools, jigs and fixtures required for the manufacture and assembly of composite parts.[4] Machinists will typically be qualified to level 3 in mechanical engineering – or, in the case of the marine sector, in boat building, maintenance and repair – possessing both technical certificates and NVQs in one of those frameworks.

It is important – not least for the machine operators themselves – to realise that machining composites is different from machining metals, not only because different cutters and drills are used, but also because rather different techniques are needed. In the words of one interviewee, you need to 'get away from the metal mindset – institutionalized metallicism' because 'everything changes when composites [rather than metals] are being used': the rate at which the material is fed into the machine, the type of cutters or drills that are used, the speed at which the drill head must rotate, the angle at, and force with which, the drill is placed against the material, are all different in the case of composites compared with metals. Machinists therefore require specific training in machining composite parts – 'they need to understand *our* methods' – as indeed do the aircraft fitters who assemble parts of aircraft (who need to be trained in the appropriate techniques for drilling, reaming and fastening together composite components). This is usually provided via (usually uncertificated, though sometimes certificated) in-house training in the case of experienced workers but is increasingly being incorporated into formal, certificated training programmes in the case of apprentices. Machinists are usually qualified to level 3 in mechanical engineering.

4.1.4 Production/process engineers

In addition to contributing to the design of the final product, technicians with level 4/5 skills will also be intimately involved in developing, implementing and optimising the production processes and systems through which that product is made. In particular, technicians occupying associate professional/technical roles such as those of a manufacturing or production engineer will define the processes through which production workers manufacture outputs, by writing a set of work instructions that specifies for the benefit of the laminators the procedures that should be followed in order to build a particular component or (sub-)assembly. More specifically, in the case of carbon pre-preg laminating, process engineers will write the 'ply-book' or 'lay-up book' that specifies key aspects of the production process such as: the dimensions of the pieces of carbon fibre material or 'plies' that are to be used to make the part in question; the order in which the plies should be laid into the relevant mould; how the different plies should be oriented towards each other; the extent to which the plies should overlap; how many layers, and what overall thickness of material, should be used to build the part; where to position the tubes in the vacuum bags into which the mould is put for curing; and the pressures, temperatures, and periods of time for which the part has to be vacuum-bagged,

4 The first stage in the manufacture of many composite parts is the production of a 'pattern' or replica of the part in question. The pattern, which is made out of an easily shaped material like epoxy resin, is used to make the moulds into which fibre will be laid in order to produce the final composite part.

'de-bulked' and cured. In doing this, as one chief engineer put it, the production engineers 'translate what the designers do into practical information for the shop floor.' Production engineers must also ensure that the procedures and systems they create comply with any quality assurance requirements set by customers or external regulatory bodies (ISO, AS9110, etc).

Manufacturing/production/process engineers will typically also oversee the day-to-day activities of the production workers in their team, responding to queries and dealing with relatively straightforward problems. Another common duty is that of continually reviewing procedures, especially in the light of apparent failures in procedures and processes, in order to identify opportunities to reduce waste, eliminate the causes of defects, and enhance the speed with which operations are carried out, thereby improving the efficiency of the production process.

People working as production/manufacturing engineers tend to be qualified to at least level 4/5, possessing HNCs, HNDs or Foundation Degrees, usually in engineering but sometimes also in polymer science. There may in this case be a blurring of the boundary between technician-level roles and graduate-level roles; the role of a production/process engineer may be occupied either by technicians of the kind just described or by more practically-oriented graduates.

4.1.5 Draughtsmen/Junior design engineers

One role occupied by workers with level 4/5 vocational qualifications is that of a junior design engineer or draughtsman. As those job titles suggest, such workers will be involved in the design of various kinds of component. More specifically, while graduate-level engineers will produce a broad schematic overview of a particular structure or system, specifying the broad properties it must possess, draughtsmen will use 2D and 3D CAD programmes such as CATIA to flesh out that broad outline by developing more detailed designs of the individual components. Notably, while the junior engineers and draughtsmen operate within the broad requirements set out by the graduate-level engineering designers, they exercise discretion and bring their own expertise to bear in deciding how precisely the engineer's broad schematic designs are to be realised. They may also be involved in helping to design the mould tools and jigs that are used in the fabrication of composite parts. In all these ways, the technicians in question make an important contribution to turning the chartered engineers' general schematic ideas into concrete reality.

In making this contribution, vocationally educated technicians may well be able to advise the graduate-level engineers who occupy more senior positions within the organisation about the ease with which the composite components and structures can actually be laminated. The technicians' experience of how work is actually carried out on the shop floor – and, in particular, their awareness of the difficulties that can arise in realising certain kinds of design – can enable them to provide very valuable advice and feedback to ostensibly better qualified, but in terms of hands-on laminating often less knowledgeable, graduate engineers about how to design components in ways that make them as easy to laminate as possible. For example, one high-end automotive company said that over the past three years it had greatly improved the process through which new composite components were made by having vocationally-educated composites laminators in its design office who 'have a feel for' what composite materials can and cannot be made to do and what types

– kinds of design – of part can be made quickly and reliably and which cannot.[5] Laminators can also advise on tooling design, by providing design teams with advice about what kinds of tool lends themselves to easy and straightforward lay-up. And by having such people in their design team, the organisation was able to integrate their R&D department with the shop floor and thereby achieve a better end-product (cf. UKCES 2012: ix).

The role of junior design engineer/draughtsman tends to be occupied by people with qualifications pitched at level 4/5, most notable HNCs and HNDs, as befits a role that falls under the heading of 'Associate Professional/Technical Occupations'.

4.1.6 Quality engineers

As their job title suggests, quality engineers are responsible for various aspects of the quality of a firm's operations. Accordingly, they will conduct inspections of manufacturing operations, and of samples of the output of those operations, to make sure that the appropriate procedures are being adhered to and that products conform to the desired specifications. They will check the calibration of the relevant measuring equipment and also the quality of the tooling used to laminate composite parts. They will also be responsible for developing quality procedures, deciding how often work will be sampled, specifying how data will be recorded and analysed, and defining suitable performance indicators, and they will train personnel in carrying out these procedures. Their duties will also include ensuring that procedures are adequately documented so as to demonstrate compliance with relevant external standards (e.g. aerospace quality assurance systems such as AS9010 and AS9102, and/or specific customer requirements). They will investigate, diagnose and remedy the underlying causes of sub-standard work, where products do not comply with the requisite standards and specifications, and of late delivery to customers, and they will propose measures designed to improve the quality of the outputs being produced and to reduce the costs thereof.

The role of quality engineer is typically occupied by people with level 4-5 qualifications (HNCs, HNDs, Foundations Degrees) in engineering plus relevant experience, or by graduates. They may also be qualified in the Six Sigma approach to quality improvement and registered with the Chartered Quality Institute.

4.1.7 Non-destructive testing technicians

Specialist non-destructive testing (NDT) technicians are found in a majority of the organisations visited for this study, including both manufacturers and organisations involved in aircraft maintenance, repair and overhaul. The testing will be carried out by specialist NDT technicians in the case of some MROs, subsequently being signed off by licensed engineers, and by the licensed engineers themselves in others.

Such workers use a variety of techniques – including X-ray methods, dye-penetrant testing, lap shear testing, and eddy-current, magnetic particle and ultra-sonic inspection (A-, B- and C-scan) – to test for defects – such as voids, porosity, and inadequate adhesive bonding – that would compromise the integrity of newly made or repaired/modified composite components and assemblies. They must also prepare the paperwork required to certify the integrity of components and structures that pass the tests. The occupants of these roles will typically be

5 Draughtsmen and junior design engineers thus exemplify the point made by Evan (1963: 7) who, in characterising the difference between engineering technicians and chartered engineers comments that, 'The technician possesses skills that the professional [chartered engineer] does not have … The hallmark of the technician, especially at the higher levels, is his unique blend of some professional knowledge and manual or instrumental skill.'

apprentice-trained in mechanical engineering to level 3 (BTEC/C&G) or – a little less often – to level 4/5 (HNC/FD). They will also typically possess specialist NDT qualifications, most commonly being certified to NDT level 2 or – slightly less often – to level 3.

4.1.8 Mechanical testing technicians

Several employers – in particular, materials makers, specialist composites research and development facilities, and some of the high-end automotive companies – also employ a small number of mechanical testing technicians (typically no more than four in any one organisation). As their job title suggests, the occupants of these roles are involved in manufacturing (laminating) prototype composite parts and in building and operating experimental rigs and pieces of apparatus in order to carry out various kinds of mechanical tests on those specimens (e.g., impact, in-plane sheer, tensile compression and fire-resistance tests, and testing for aerodynamics in motorsport parts). In the words of one technical director, these workers 'put the material through its paces.' Mechanical testing technicians typically have level 3 qualifications in some form of mechanical engineering.

4.1.9 Aircraft fitters

Aircraft fitters are production workers who are involved both in the manufacture and assembly of aircraft structures and also in the task of fitting out of those structures with the electrical and electronic equipment required to build a flight-worthy aircraft. For the purposes of this study, we shall focus on mechanical fitters, for it is such workers – rather than the electrical counterparts – who are likely to work with composite materials.[6]

This category of worker is found in the two case study organisations that manufacture large aircraft structures. Mechanical fitters need to be able to: read engineering drawings, interpret technical specifications, and use measuring tools in order to be able to mark out materials such as aluminium panels and composite wing spars and ribs in preparation for assembly; use hand and machine tools in order to drill, turn, and mill those parts to prepare them for assembly; fit the prepared parts into jigs or fixtures; and then assemble them in order to form the relevant aircraft structure (wing, fuselage, nacelle, etc).[7] Fitters will also be involved in inspecting and testing the sub-systems and systems they have assembled using a variety of manual and electrical/electronic instruments. They may well also be required to collect and record data for use in quality-improvement projects. Aircraft fitters will typically have done an apprenticeship and will possess level 3 qualifications in aeronautical engineering.

As was noted in Section 4.1.3 above for the case of machinists, aircraft fitters need to be conversant with the specific techniques required for fitting composite – as distinct from metallic – parts. Fitters therefore need specific training in the appropriate methods for drilling, reaming and fastening together composite components. This is usually provided via (usually uncertificated) in-house training in the case of experienced workers, and through the inclusion of the relevant modules in the formal, certificated training programmes undertaken by apprentices. Machinists are usually qualified to level 3 in mechanical engineering.

6 For more on aerospace fitters, see Lewis (2012a: 5-6).

7 Some assembly tasks – e.g. the riveting of structural parts – are typically carried out by semi-skilled (level 2) operators.

4.1.10 Aircraft mechanics and licensed aircraft engineers

We move on now to examine some of the main technical roles found in organisations involved in the maintenance, repair and overhaul of aircraft (MROs). The mechanics and licensed engineers employed by such organisations carry out maintenance and repair work on aircraft, inspecting, testing, servicing and – where necessary – repairing or replacing – aircraft components and modules, either in situ or after removal from the aircraft, and carrying out fault diagnostics and repairs where required.

It is especially significant for the purposes of this report that the duties of such workers may well involve the inspection, testing, repair and/or replacement of various composite components and structures. Given the increasing use of composites in the manufacture of aircraft components and structures, there is clearly going to be a rise in MROs' demand for composites-savvy technicians. In performing such duties, the mechanics and licensed engineers may be required to carry out the non-destructive testing of composite parts and structures, and to use hand and machine tools, in order to carry out repairs (e.g. by fabricating composite patches for repairs to an aircraft's wings or fuselage). For all this work, mechanics and licensed engineers must be able to read and interpret the relevant aircraft maintenance manuals and technical specifications in order to be able to interpret test results and determine the need, feasibility and method of repairing or replacing damaged or malfunctioning components and systems.

Interviewees reported that, while some MROs have extensive capabilities in composites, many prefer to outsource all but the most straightforward composites repairs by sending the relevant parts either back to the manufacturer or to an MRO that specialises in composites work (cf. BIS 2009: 27). The sample of MROs visited for this study supports that description. Three of the case study organisations have invested in both the physical and human capital required to develop a significant composites capability, up to and including the autoclaving of composite parts. Consequently, they have both the equipment, and also the appropriately trained mechanics and licensed engineers, required to test and repair a wide range of composite components, including airframe structures (e.g. wings, fuselage), nacelles, radomes, side panels from jet engines, flying controls, and thrust reversers. The other six MROs have thus far chosen not to invest to the same extent, and are as a result restricted to carrying out relatively simple repairs (e.g., interior components like overhead luggage bins, and door and floor panels, or small-scale repairs to external components such as fairings).

Aircraft mechanics are usually time-served apprentices with level 3 qualifications (NVQs and BTECs/City and Guilds) in aerospace/aeronautical engineering. While mechanics will be involved in carrying out much of the work involved in servicing, testing, maintaining, modifying and repairing aircraft, the fact that they are unlicensed implies that they must at all times be supervised by a licensed engineer and cannot certify any of the work they do, which must instead be inspected and signed off by an appropriately-licensed engineer. Licensed aircraft engineers – that is to say, aircraft mechanics who have passed the relevant European Aviation Safety Agency examinations and gained the practical experience required to acquire the relevant license – are able to certify that the repairs have been carried out properly and that the aircraft in question is now fit to be released into service and, depending on the particular license they hold, will possess qualifications pitched at levels 3-5 in the National Qualifications Framework.

Those MROs that have decided to develop their capacity in composites have tended to send at least some of their licensed engineers on courses offered by manufacturers such as Boeing, so as to develop their knowledge of, and competence in, the techniques involved in testing and repairing composite materials. Upon returning to the MRO that employs them, those workers can then pass on their skills and knowledge to the other licensed engineers and mechanics.[8]

4.1.11 Chemical process operators

The industrial plants in which composite materials are produced on a day-to-day basis are operated by people known as chemical process operators. The occupants of such roles control the working of the plant, starting and shutting down pieces of equipment (e.g., pumps and compressors); opening and closing valves; changing pump speeds; offloading raw materials from tankers and loading finished products onto tankers; 'pigging' or maintaining pipes; measuring and adding chemicals to the vessels in which the chemical reactions involved in the production process take place; using the instruments out on the plant to monitor volumes, levels and rates of flow of chemicals to make sure that the chemical processes are taking place safely and efficiently; preparing equipment for maintenance; and doing routine safety checks around the plant.

All four of the composite materials manufacturers visited for this study have process operators. The firms in question can be divided into two broad categories, depending on how skilled their process operators need to be. In the first category, comprising three firms, most process operators are currently semi-skilled workers, possessing only level 2 skills. In these organisations, only senior process operators who have taken on supervisory responsibilities are qualified at least to level 3. In the fourth firm, however, process operators typically possess level 3 skills (with level 3 qualifications in, primarily, Polymer Processing and Related Operations). The reason is that they use more complex production methods – that require operators to have a higher level of understanding and skills – than the first three plants.[9]

4.1.12 Maintenance technicians

Technicians of this kind are employed at all four of the composite materials manufacturers visited for this study. They are responsible for carrying out both routine (preventative) maintenance on the mechanical equipment and systems found in chemical plants, and also for dealing with faults and breakdowns. Three broad categories of maintenance technician are normally distinguished: mechanical technicians, who deal with equipment such as pumps, valves, compressors, pipes, condensers, heat exchangers, fans, and various other kinds of mechanical, hydraulic and pneumatic systems; electrical technicians who look after the electrical systems (power and lighting) and equipment (motors, pumps, agitators, compressors, etc.) on the plant; and control and instrumentation technicians, who calibrate, maintain and – where necessary – repair the instruments through which the operation of the plant is monitored and controlled. These technicians typically possess level 3 skills in mechanical, electrical or instrumentation engineering, as appropriate.[10]

8 For more on the duties, skills and training of licensed aircraft engineers, see Lewis (2012a: 11-16).

9 For more on this issue, see Lewis (2013a: Section 3.1.1).

10 A more detailed account of the duties carried out by the occupants of such roles, and the skills they are required to possess, can be found in Lewis (2013a: Section 3.1.2).

4.2 THE SIZE OF THE TECHNICIAN WORKFORCE

33 of the 35 case study organisations provided usable data on the size of their technician workforce (see Table 1).

The highest share of technicians in the workforce is to be found in the aerospace parts manufacturers and MROs that are not part of an airline – that is, in categories (i) and (ix) respectively in Table 1 – where technicians account for around 45% of the workforce on average. With the exception of one firm that uses automated methods of production to make composite aircraft structures, and whose laminators are qualified to level 3-4, the aerospace manufacturers are organisations whose technicians occupy roles – such as machinists, aircraft fitters, production/process engineers, quality engineers, and NDT technicians – that involve them machining, testing, and helping to design and quality assure composite parts, but not actually doing laminating. The actual fabrication of composite parts tends to be carried out by semi-skilled laminators, who account for a little over 20% of the workforce in such organisations. Similarly, in the case of the MROs, technicians tend to occupy the roles of aircraft mechanic and licensed aircraft engineer. Such organisations tends not employ specialist laminators of any kind; if a replacement composite part needs to be made, it will be done by the mechanics and licensed engineers as part of their broader array of duties. The story is similar in the case of the MROs which are part of airlines, the only difference being that in such cases the share of technicians in the total workforce technicians is driven down to just over 10% as a result of the very large number of non-engineering employees (see category [x] in Table 1).

We consider next the two organisations that machine and assemble – without manufacturing – composite parts and structures: category (viii) in Table 1. On average, around one-third of the workers employed in these two organisations count as a technician. The workers in question tend once again to be machinists, aircraft fitters, production/process engineers, quality engineers, and NDT technicians. Neither of the two firms fabricates composite parts, so neither employs specialist laminators, at any skill level.

Things are rather different in the next two categories of firm, which are comprised of companies that manufacture composite parts for the automotive and defence industries: categories (ii) and (iii) in Table 1. These firms rely on semi-skilled laminators to fabricate composite parts, using relatively labour-intensive production processes such as carbon pre-preg laminating and resin infusion. Consequently, semi-skilled laminators tend to make up a relatively large share of the total workforce in these organisations, averaging around one third of the total workforce in the automotive firms in the sample and close to one half of the total workforce in the two defence companies. The share of technicians in the total workforce is correspondingly reduced, falling to an average of around one quarter in automotive and to one third in the defence firms. Boat-building also tends to make considerable use of semi-skilled laminators, with such workers accounting for just over one-fifth of the total workforce employed in such firms on average.

Technicians also account for a relatively small share of the total workforce in the two satellite manufacturers, averaging just over 10% of the total workforce. In this case, however, the reason for the relatively limited employment of technicians is very different from that which pertains in the case of the automotive and defence firms just considered. Whereas the share of technicians in the total workforce employed by the automotive and defence firms was driven down by the relatively

large numbers of semi-skilled laminators they employ, the share of technicians in the space manufacturing workforce is driven down by the very large number of graduates employed by satellite manufacturers. Both space firms do have small dedicated composites manufacturing units. In one, the specialist laminators tend to be qualified to level 3, largely because they need that level of skills to be able to master the automated method of production used in that firm. The other firm has just one or at most two level 2 laminators to carry out the pre-preg laminating of simple composite parts.

A similar story can be told about the four case study organisations carrying out research and development on composites materials and production processes: category (v). Technicians account for no more than about 20% of the workforce employed in these organisations, largely because – being engaged in high-level research and development – they tend to rely on graduates. The fact that these organisations make prototype composite parts rather than mass produce components for sale implies that they do not have the volume of production required to justify employing specialist semi-skilled laminators. Hence, any simple wet-up, carbon pre-preg or resin infusion laminating that needs to be done is carried out, not by specialist laminators, but by skilled (level 3) craftsmen as part of their broader array of duties (e.g. machining, building test rigs).

We turn finally to the materials makers. The one company where a majority of process operators were qualified to level 3 estimated that around a third of its workforce are technicians. In the other three firms, where most process operators have only level 2 skills, the share of technicians in the workforce averages only 10%. Taken across the four firms, the average share of technicians in the workforce is relatively low, being driven down by the preponderance of semi-skilled operators to around 15%.

4.3 QUALIFICATIONS

This section draws out and summarises the findings concerning the qualifications typically possessed by technicians working in sectors that use – or make – composite materials.

First, and perhaps most significantly, the evidence indicates that in the case of the laminators who fabricate composite parts, technician roles are mostly confined either to team-leaders/supervisors or to specialist laminators who use filament winding or other, more sophisticated automated methods of production. Such workers tend to have either an NVQ3 or an Advanced Apprenticeship. Specialist, rank-and-file laminators who use non-automated methods of production to make composite parts for the aerospace, marine, automotive and defence sectors tend to possess only level 2 skills, sometimes – but not always – certificated via an NVQ2.

In the case of the organisations that manufacture and/or machine composite parts for the aerospace, space, automotive and defence industries, there is a reasonably clear distinction between roles – such as machinists, aircraft fitters, and unlicensed aircraft mechanics – for which a level 3 qualification is the norm, and which therefore fall into the category of 'skilled trades', and roles like production/ manufacturing engineer, quality engineer, draughtsman, and licensed aircraft engineer, for which qualifications such as an HNC, HND or Foundation Degree are required, and which therefore fall under the heading of 'Associate Professional/ Technical Occupations'. However, the distinction between the two occupational classifications

is not always completely clear cut: NDT technicians are qualified to level 3 in some organisations, and to level 4 in others; and in the case of companies that use automated methods for fabricating composites parts, the qualification level – and, more specifically, the underpinning knowledge – required of the technicians who operate the (rather novel) automated type-laying or fibre placement machines lies somewhere around level 3-4, while the level of hand skills required of such technicians is typically said to be no more than level 2.

The evidence indicates that the question posed by Mason (2012: 4) – concerning whether the distinction between 'Skilled Trades' and 'Associate Professional/ Technical Occupations' continues to exist in today's industries – can be answered in the affirmative; it does indeed still capture an important distinction between the qualifications and duties associated with the occupants of different sets of roles in these industries. That answer is only reinforced by the fact that the aerospace and space firms visited for this study offer separate training programmes – with different entry requirements, content and exit qualifications – for those apprentices who are destined for 'Skilled Trades' and 'Associate Professional/ Technical Occupation' roles (see Sections 5.3.1.1 and 5.3.1.2 below and Lewis 2012a: 23-25).

4.4 SOURCE OF THE CURRENT TECHNICIAN AND SEMI-SKILLED LAMINATOR WORKFORCE

How were the skilled technicians and semi-skilled laminators who currently work for the case study organisations visited for this project acquired? Three alternative possibilities may be distinguished.

The first is external recruitment, which involves the employer recruiting the technician or laminator 'ready-made' from the external labour market. In such cases, the workers in question are already sufficiently skilled at kind of work they will be required to do that little if anything beyond induction training is required before they can work productively in their new role.

Second, and in sharp contrast, the employer might obtain its technicians by training them in-house, via its own apprenticeship scheme. An apprenticeship is a contract between an employer and a (traditionally, young) person that combines a structured programme of on-the-job training and productive work with part-time, formal technical education (Steedman *et al.* 1998: 11; Lewis 2013). Apprenticeship training, which is usually formally certificated, equips people with intermediate (level 3-5) skills of the kind required to fill roles that fall under the heading of 'Skilled Trades' or 'Associate Professional and Technical Occupations' in the UK's Standard Occupational Classification system. It follows from this that any training for roles whose occupants need only be semi-skilled (i.e. require no more than level 2 skills) will not count as an apprenticeship, as it does not aim at the level 3-5 skills that are the hallmark of apprenticeship training (cf. Steedman 2010: 3; Richard 2013 4-5, 33-35).

A third possibility also involves the employer playing a role in training workers, but in a rather different fashion from what is involved in apprenticeship. This third approach will be referred to here as 'upgrade training'. It involves the employer taking people – who may be recent recruits or more established employees, and who may have a broad range of ages, prior levels of skill and qualifications – and giving them the specific training required to fill a particular role – which could be a semi-skilled (level 2) or a skilled (level 3) role – within their organisation. In contrast to apprenticeship training, upgrade training tends to be: closely tailored

to the requirements of a specific role in a particular organisation; often provided informally, on-the-job, without any off-the-job technical education; and is also often uncertificated. It will be useful for what follows to distinguish between two categories of upgrade training: external upgrade training, which involves unskilled people being recruited by an organisation from the external labour market and given the (upgrade) training required to fill a particular job (e.g. a semi-skilled laminator); and internal upgrade training, whereby people who already work for an organisation in a particular role requiring a certain level of skill (e.g. semi-skilled composites laminator) are given upgrade training so as to be able to move up to a new role that requires a higher level of skill (as, for example, when a semi-skilled aircraft assembler is trained to become a skilled aircraft fitter, or a semi-skilled composites assembler is trained to become a skilled composites team leader). Upgrade training is more limited in breath, depth, generality, and duration than apprenticeship training, and tends therefore to be considerably cheaper than an apprenticeship (Ryan 1995: 30-32; Ryan *et al*. 2007: 130, 137).

What balance did the organisations visited for this study strike between these three different ways of obtaining their technicians and semi-skilled laminators? Data on this issue proved hard to obtain, the origins of many technicians being lost in the mists of time, so the findings expressed below need to be treated with some caution. Nonetheless the following points seemed to be supported by the estimates provided by interviewees.

The three aerospace parts manufacturers that rely on non-automated methods of production report that the vast majority (90%) of their level 2 laminators have been trained in-house via external upgrade training programmes. Two of these three firms also make a significant use of apprenticeships to acquire their technicians, with perhaps 30% of their technician workforce having been acquired through that form of in-house training. This estimate refers to the technician workforce as a whole in these organisations, not just those who specialise in working with composite materials. Given that – as we shall see in Section 5.1 below – firms are finding it extremely difficult to recruit workers who are skilled at dealing with composite materials from the external labour market, and are relying on apprenticeship training to fill the gap, it seems likely that the figure of 30% will if anything underestimate the share of the composite-focused workforce that was acquired via apprenticeship training. The third firm reported that it had little history of training and had recruited almost all its technicians from the external labour market. The fourth company – which uses automated production methods to manufacture composite parts – reports that in-house apprentice training is being used to fill a majority (over 50%) of its (technician-level) laminator roles.

The two defence companies adopted similar approaches to each other for acquiring the skilled workers they need. Most of their technicians were recruited from the external labour market, with a small but not insignificant contribution to their technician workforce being made by apprenticeship training (which accounts for perhaps 10-20% of their technicians). Both companies have relied heavily on external upgrade training to acquire the semi-skilled laminators who fabricate composite parts using carbon pre-preg material. In both cases, the training was provided through a structured, in-house, on-the-job programme. The training was uncertificated and was provided to recruits many of whom had no background in engineering whatsoever. This external upgrade training accounts for upwards of 90% of the semi-skilled laminators in the two organisations.

The situation is similar in the case of the five companies that make parts for the automotive and motorsport industries. In all of these firms, the vast majority of technicians were recruited from the external labour market: only two of the firms reported that a contribution to their technician workforce had been made by apprenticeship training; and even in those cases the number of technicians trained via the firm's own apprenticeship training programmes was thought to be small (under 20% of the technician workforce). All the firms relied on a combination of external recruitment and upgrade training to acquire their semi-skilled laminators: two had made extensive use of external upgrade training, which accounted for over 80% of their laminators; while two relied more heavily on external recruitment, estimating that it accounted for over 75% of their laminators. (The fifth firm reported that it too relied for its laminators on a combination of external upgrade and recruitment, but was unable to estimate their respective importance.)

None of the three marine companies supplied data on the origin of their technicians, though the fact that two have long-standing apprenticeship schemes indicates that at least some of their technicians came via that route. More data was available on the origins of their semi-skilled laminator workforce: two firms relied primarily on the external upgrading of new recruits, with some external recruitment; while the third relied on an unspecified mixture of external recruitment and external upgrading.

The two space companies had both made some use of apprenticeship training to acquire their technician workforce, estimating that between 10 and 20% of their technicians had been acquired via that route. (The remainder were recruited.) Only one of the two firms employed any semi-skilled laminators, with the very small number of workers having been acquired via a balanced combination of recruitment and external upgrading.

Of the four research and development organisations, three recruited virtually all of their technicians ready-made from the external labour market. In the fourth, around 20% of technicians came through an apprenticeship scheme, the remainder being recruited. These organisations do not have semi-skilled laminators, so no use is made of external upgrade training to acquire such people. The story is similar with the four firms that manufacture composites materials. Three recruited almost all of their mechanical maintenance technicians, with just one having an apprenticeship scheme that had produced around 15% of its maintenance technicians. (These were the same three firms whose process operators were required to have only level 2 skills.) Only in the case of the fourth materials maker were process operators usually qualified to level 3. This firm had a long-standing apprenticeship scheme, through which it trained not only maintenance technicians but also some of its level 3 process operators. However, the firm was unable to estimate the proportion of its technicians who had come up through that route.

Finally, of the nine MROs in the sample, seven were able to provide rough estimates of the origins of their technicians. Five firms indicated that apprenticeship had played a major role in the acquisition of their technicians: one estimated that about 40% of its licensed engineers had been trained via its own apprenticeship scheme, while the other four indicated that between one half and two-thirds of their technicians were developed internally. Only two firms indicated that training played a very small role: one, which was the smallest in the sample, reported that the vast majority of their technicians were recruited, with fewer than 10% being

trained in-house; while one larger MRO also relied heavily on recruitment, with 70-80% of its technicians being hired from the external labour market.

Overall, therefore, the picture that emerges is one in which – with the exception of companies working in the aerospace sector, including MROs – most of the technicians employed by firms working with composites have been acquired via external recruitment. (In the other sectors – and with the possible exception of marine, where data on the source of the technician workforce proved impossible to come by – apprenticeship accounted for less than 20% of the current technician workforce). Matters are rather different, however, when it comes to the origins of the semi-skilled laminators who fabricate composite parts in many of the automotive, defence, and – to a lesser degree – marine firms, where there was much more reliance on in-house training, albeit of the upgrade variety rather than apprenticeships. In defence, automotive, marine, as well as in aerospace, many firms have made considerable use of external upgrade training, acquiring a majority of their semi-skilled laminators in that way. As well shall see in Section 5.1 below, this reliance on in-house training reflects the very limited availability of good semi-skilled laminators on the external labour market.

SECTION 5 RESULTS II: THE FUTURE TECHNICIAN WORKFORCE

The previous section of the report focused on attributes of the current technician workforce in organisations that work with composite materials. This section of the report shifts in focus to the question of the case study organisations' plans to meet their future need for technicians. In other words, in what follows we shall investigate the workforce planning strategies currently being used by the aerospace companies in the UK.

This is an important issue, principally because – as we shall see – many firms are struggling to recruit workers who are skilled at working with composite materials. The problem arises at all skill levels; there are reported to be shortages of both semi-skilled composites laminators and skilled technicians. Employers are responding to the difficulty of hiring such workers by falling back on three kinds of in-house training: external upgrade training, in the case of semi-skilled laminator roles; apprenticeship training, as a means of developing new technicians who can work with composites; and the provision of additional training to equip those technicians who are established employees but are (only) skilled at working with metallic parts with the skills required to work with composites.

5.1 RECRUITMENT

It was almost universally said that it is currently hard to acquire good, experienced composites laminators from the external labour market. Three aerospace parts manufacturers, both defence firms, two of the three boat-builders, and four of the five companies that manufacture composite parts for the high-end automotive industry, all said that it was very difficult to recruit high-quality, experienced workers. There are two aspects to this problem: the first is just a shortage of applicants; whilst the second is that the limited number of people who do apply are often of poor quality, in the sense that they all too often have a distinctly limited awareness of good practice in the sector when it comes to dealing with composite materials.[11] As one interviewee put it, commenting on his efforts to recruit experienced laminators to work at its rapidly expanding defence composites production facility, *'It's … nightmare.'* Similar comments were made by other interviewees:

> *'It's tremendously difficult to recruit laminators … You pay a lot for not a lot.' (Composites production manager, automotive parts manufacturer.)*

> *' "Composites laminator" is a broad phrase … They might call themselves experienced laminators but they're not very good … They're a bit slapdash.' (Composites facility production manager, space manufacturer.)*

11 More specifically, firms that are trying to recruit laminators from the external labour market argued that they were of poor quality either because they are unaware of best practice techniques for the sector in which they were ostensibly trained or because, having received training for one sector (e.g. in wet lay-up for boat-building) they were unaware of the techniques and standards that are appropriate for the sector that is trying to recruit them (e.g. carbon pre-preg for aerospace). For instance, interviewees from aerospace firms talked about how, if a laminator who had worked in another sector cut through a ply of composite material, his/her response would be to fill the cut with filler and then continue to add more layers of composite material, a practice that might be acceptable in some industries but not in aerospace (where the part would be ruined).

> *'You get people who think they can do the job and then they create havoc … [they] do more harm than good.' (Commercial director, automotive parts manufacturer.)*
>
> *'We've had people who called themselves laminators [apply] because they'd stuck formica tops onto chipboard or helped fix their mate's boat.' (Composites project manager, marine company.)*

Similar problems are common, though perhaps slightly less pronounced (perhaps because of the possibility of upgrading the existing technician workforce) at the technician level. Two large aerospace manufacturers – one of which both builds and machine-assembles composite components, the other of which assembles composite parts made elsewhere – found it straightforward to hire experienced technicians, who were attracted by the relatively high pay and good career prospects offered by these large organisations. One relatively large research and development facility also found it easy to recruit technicians, largely because of the closure of a composite part manufacturing plant located nearby. These firms were, however, in the minority. In contrast to their experiences, three other aerospace composite parts manufacturers, three of the four research and development organisations, one satellite manufacturer, both defence firms, two automotive parts manufacturers, and one marine firm all said that they had problems in recruiting technician-level workers such as machinists, NDT technicians, production engineers and quality engineers. Some of the most acute difficulties have been experienced by manufacturers that have sought to recruit staff skilled in composites manufacturing. Two of the three case study employers who were involved in the fabrication of composite components and structures have found it well-nigh impossible to hire anything like enough people – either as permanent employees or contractors – who are skilled at working with composite materials, whether they be (semi-skilled) laminators or technicians. As a senior interviewee from one of those organisations said of its efforts to recruit skilled technicians *'We're still looking for them … It's been a nightmare.'* Similar comments were made as follows:

> *'The skills just aren't out there … there aren't enough technicians.' (Manager, composites research and development organisation.)*
>
> *'[I]t's a relatively small industry and it's growing … [so] it's quite difficulty to recruit unless you're lucky.' (Manager, composites materials maker.)*
>
> *'There are big skills shortages locally in engineering and particularly in … working with composite materials.' (Director, boat-building company.)*
>
> *'We couldn't get people at level 3 and above.' (Materials-maker.)*[12]

Moreover, while it is possible for those employers who have worked extensively with metallic components in the past to offer some of their existing technicians internal upgrade training so that they become skilled at working with composites, as for example when two of the aerospace manufacturers offered their existing aircraft fitters additional training in drilling composites materials, this does not completely resolve the problem either in those cases where the firms do not have workers suitable for internal upgrading or in those (many) cases where the firms in question are expanding and so need additional staff.

12 As another recent report on the composites industry has stated, 'There are examples of newly developed manufacturing kit in UK factories where they have no staff to run it' (Avalon Consultancy Services Limited 2012: 30).

The evidence indicates, therefore, that firms that deal with composites materials face significant problems in recruiting both semi-skilled laminators and technicians.[13] Faced with such difficulties, employers have increasingly turned to various forms of in-house training in order to acquire the workers they need. More specifically, as we shall discuss in the next two sections, employers have tended (i) to respond to the difficulty of recruiting high-quality semi-skilled composites laminators by making increasing use of external upgrade training in order to develop those workers in-house, and they have also tended (ii) to turn towards a combination of apprenticeships and internal upgrade training as a means of acquiring the skilled technicians they need. As one aerospace parts manufacturer that has recently developed both of these approaches puts it, 'We had a problem sourcing core skills, so we decided to re-introduce apprenticeships and introduce a lot of vocational education and training through the NVQ route.'

5.2 UPGRADE TRAINING OF SEMI-SKILLED COMPOSITES LAMINATORS

5.2.1 Nature and scale of the training

It was noted above that one method for employers to develop workers' skills in-house involves what is known as 'upgrade training'. This involves the employer taking people with a broad range of ages, skills and qualifications, and who may be either recent recruits or long-standing employees, and giving them the specific training required to fill a particular role – either at level 2 or at level 3, for example – within their organisation. In contrast to an apprenticeship, therefore, upgrade training tends to be: more closely tailored to the requirements of a specific role in a particular organisation; often provided informally, on-the-job, without any off-the-job technical education; and is also often uncertificated. These attributes means that upgrade training is typically shorter, narrower, less thorough, and, therefore, cheaper, than apprenticeship training. Two categories of upgrade training may be distinguished: internal upgrade training, which involves people who already work for an organisation in a particular role requiring a certain level of skill being given the additional training required for them to advance up the organisation's job hierarchy to a new role that requires a higher level of skill; and external upgrade training, which involves organisations recruiting unskilled people from the external labour market and giving the specific training required to fill a particular job (e.g. a semi-skilled laminator).

External upgrade training has proved to be the most important source of semi-skilled composites laminators for the vast majority of the organisations that fabricate composites parts using wet lay-up, carbon pre-preg and resin infusion techniques. As noted in Section 4.4, three aerospace manufacturers, two defence firms, two automotive parts manufacturers, one research and development organisation, and two marine firms have all already responded to the dearth of high-quality, experienced laminators on the external labour market by relying on external upgrade training. This reliance on external upgrade training is set to continue in the future. Indeed, a third automotive manufacturer, which has hitherto relied on external recruitment to acquire its semi-skilled laminators, has recently instituted an external upgrading scheme as a response to the increasing difficulties of recruiting experienced workers of this kind. The scale of involvement ranges from, at the top end of the scale, several hundred workers in the case of some of the aerospace manufacturers, through – in the middle of the scale – 50 or 60 workers in the case of

13 Similar findings are reported in NCN (2009: 3), UKTI (2010: 25), Aerospace Growth Partnership (2012: 18, 20) and in SEMTA and NSAPI (2011: 3). On the pressing need for additional technician skills more generally, in sectors other than aerospace, see UKCES (2010a: 6, 30-34, 2010b: 182) and *The Economist* (2012: 34).

some of the automotive and defence firms – to 20-30 people in the case of one of the research and development organisations.

While there is, of course, considerable variety in the details of the external upgrading schemes used by the different organisations, certain broad features seem to be shared by most if not all of the training programmes.

- First, the training programmes do not presuppose that trainees possess any prior knowledge of engineering in general or composites in particular. On the contrary, in most if not all cases a majority of trainees have no previous experience in any form of engineering. (Firms are typically looking for people with a high level of dexterity and an eye for detail.)
- Second, the programmes typically involve an initial period of training away from the shop floor, during which time trainees are given a sense of what composite materials are and how they need to be treated (e.g., the need to refrigerate carbon pre-preg materials, and the damage that can be done if a composite part is dropped or struck with, say, a trolley). This initial period of instruction will also see the trainees being taught the basic laminating techniques used by the company in question (e.g. wet lay-up or resin infusion in the case of boat-builders, or carbon pre-preg in the case of automotive parts manufacturers). The length of this initial period of training away from the shop floor varies considerably between different employers, ranging from 2 to 8 weeks.
- Third, once the trainee has passed through the initial training programme they move on to the shop floor where they continue their training on-the-job, with the support of a more experienced worker (typically, a laminating team-leader or supervisor). Trainees usually start by working under close supervision on parts that are geometrically simple and therefore easy to laminate. As the quality and speed of their work increases, they will move on to laminating – including vacuum-bagging, where appropriate – more complex parts and, eventually, to working with only the same level of supervision as qualified workers. Trainees are usually also rotated around various stages of the production process, so that in addition to laying down the carbon fibre material in the appropriate mould and vacuum-bagging the part, they also gain experience of de-moulding, trimming, finishing, and bonding/assembling components once they have been cured. Again, there is considerable variety in the duration of the training – probably related to how extensive the process of job rotation is – with programmes ranging from 3 ½ months to 2 years in length.
- Most of the training in question, including the initial period of training away from the shop floor, is provided in-house by more experienced employees. Some companies have employed experienced workers specifically to act as trainers, while others have brought in external experts – from local FE colleges or private training providers – to provide the initial period of training. The on-the-job training that follows is obviously provided by experienced workers, usually – as noted above – those occupying roles such as lead laminator, team leader and supervisor.
- Sometimes the training is formally certificated, with trainees being awarded an NVQ2 at the end of the programmes, and sometimes not. Five of the ten organisations that use external upgrade training – two aerospace firms, two marine companies, and one automotive parts firm – formally certificate the training received by their semi-skilled laminators, but the other five firms do not.

5.2.2 Rationale for the use of upgrade training

The primary reason for the use of upgrade training as a means of acquiring semi-skilled laminators lies in the difficulty, reported in Section 5.1 above, of recruiting experienced workers of this kind who are of high quality in the sense that they are aware of – and able to adhere to – best practice in fabricating composite parts. The difficulty of recruiting good laminators leaves firms with little option but to rely on some form of in-house training. The question that remains concerns the particular form of in-house training that is used. The answer is straightforward. Given that, as we have seen, the rank-and-file laminators who use non-automated methods of production are almost invariably required to possess only level 2 skills, then apprenticeship, which aims at level 3 skills, is not the appropriate form of in-house training. External upgrading, which equips people with the desired level of skills without requiring long periods of off-the-job (college) training, promises to be a rapid and relatively inexpensive way for firms to acquire the laminators they need.

Employers elaborate on the merits of such training by pointing out that good in-house training helps to ensure that laminators are working to a common, high set of standards, so that 'everyone knows what quality of work is acceptable and what isn't'. In particular, as one employer put it, the advantage of taking inexperienced people is that they provide 'a blank canvas you can mould': 'We want virgin people with no knowledge who we can train in our techniques.' In this way, in the words of another employer, training people from scratch helps firms to avoid 'contaminating our processes' by taking people who'd learned poor practice/acquired bad habits elsewhere. Good training, employers averred, ensures not only that workers know that they need to work in particular ways but also that they understand why they need to do so, so that they will be more likely to stick to the appropriate procedures. Such training leads to concrete benefits, employers argued, in the form of reductions in the frequency with which parts have to be reworked or entirely scrapped.

5.3 APPRENTICESHIP

5.3.1 Definition and involvement

An apprenticeship is 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 equips people with intermediate-level skills (Steedman et al., 1998: 11; Lewis 2013b).

Of the 35 case study organisations, 26 offer apprenticeships. Of the 26 organisations, 14 – three aerospace companies, two MROs, three automotive firms, both defence companies, two R&D organisations, one marine and one materials-maker – have started their apprenticeship scheme since 2006. Further details of the apprenticeships in question can be found in Table 3 and the succeeding paragraphs.

Table 3: Approaches to apprenticeship training: a summary

Type of organisation	Total number of case study organisations	Number of organisations that train apprentices	Average intake of apprentices[a]	Frameworks in which apprentice are trained	Average apprenticeship Intensity (%)[b]
Aerospace	6	5	32	Mechanical manufacturing engineering, aerospace engineering, aeronautical engineering	14
Space	2	1	20	Mechanical and electrical engineering	8
Defence	2	2	2	Mechanical engineering	6
Automotive	5	3	6	Mechanical engineering, manufacturing engineering	17[c]
R&D organisations	4	2	3	Mechanical manufacturing engineering	33
Marine	3	2	14	Marine engineering, boat-building and maintenance	Unknown
Materials-makers	4	2	N/a[d]	Mechanical engineering, polymer processing	N/a[d]
MROs	9	9	24	Aeronautical engineering, aerospace engineering and maintenance	10

Notes:
a: includes both craft and technical apprentices
b: Apprenticeship intensity is defined as the total number of apprentices in training in an organisation divided by of the total number of workers currently employed in such roles that organisation.
c: apprenticeship intensity figure based on data from only two of the three companies that train apprentices.
d: the two materials-makers that take apprentices do so only irregularly, making the notion of an 'average intake' inapplicable.

5.3.1.1 Apprentice training in aerospace manufacturing

Consider first the six firms that are involved in aerospace manufacturing, a group that is taken here to include both the four companies that fabricate composite parts (category [i] in Table 1) and also the two that machine and assemble composite components and structures made elsewhere (category [ii] in Table 1). Five of these six firms have apprenticeship schemes, three of which have been introduced since 2007. (The firm that does not currently take apprentices is a small composites component-maker that, by its own admission, does not have a history of training workers.)

Of these five organisations, two hold the SFA contract to deliver the apprenticeships and therefore take formal responsibility for the organisation of the apprenticeship training programme themselves. (These are the only two case study organisations in the sample to do so.) In the other three cases, the SFA contract is held by a specialist private training provider or FE college, which takes formal responsibility for arranging and coordinating the various elements of the apprentices' training. The number of well-qualified applicants comfortably outstrips the number of places on offer in all cases, with some firms mentioning ratios of applicants to places of over 20 to 1. Completion rates are over 90% in every case.

All but one[14] of the five firms differentiate explicitly between those apprentices who are destined for skilled trades roles and those who will occupy associate professional/ technical occupations upon completing their training, offering separate training programmes with different entry requirements for the two groups of trainees:

- 'Craft apprentices', as those apprentices who are in training for skilled trades roles are often known, usually aim to achieve a qualification at level 3. In keeping with the role descriptions provided in Section 4.1 above, the qualifications tend to be NVQs and BTEC or City & Guilds level 3 awards in subjects such as aeronautical engineering (for aircraft fitters), mechanical engineering (for machinists), and manufacturing engineering (for composites team leaders).
- 'Technical' apprentices, on the other hand, aim from the outset is to achieve qualifications at level 4 (e.g. HNC) or level 5 (Foundation Degree, often as part of a Higher Apprenticeship) in subjects such as aerospace/aeronautical engineering, manufacturing engineering, and mechanical engineering, with a view to filling roles such as draughtsman, junior design engineer, manufacturing/ production engineering, and quality engineer.[15]

The apprenticeships taken by these workers will involve modules on various aspects of working with composite materials, such as – depending on the specific role for which the apprentice is being trained, and the precise nature of the work being done in the firm at which the apprentice is being employed – pre-preg laminating, vacuum-bagging and curing, de-moulding, trimming, assembling, machining, testing, repairing, and the electrical bonding of composite parts.

The entry requirement for these craft apprenticeships is typically four GCSEs (including mathematics, English and a science) at grade C. Unsurprisingly, entry requirements for technical apprentice training programmes are usually higher than for the corresponding craft apprenticeships, ranging from four GCSEs at grades A-C (including mathematics, English and a science) to A-levels in mathematics and physics for those young people taking Higher Apprenticeship programmes that in some cases are intended to lead ultimately to a full honours degree.[16]

The average intake of apprentices – of both kinds, taken together – in the five organisations in this group who take them is around thirty per annum. Comparisons of apprenticeship activity between different employers and at different times are potentially clouded by differences in skilled employment, with larger employers taking on more apprentices simply because they have to sustain a larger technician workforce. An allowance can be made for this by calculating what is known as the *apprenticeship intensity* of a particular firm's training programme, that is the total number of apprentices in training as a percentage of the total stock of workers currently employed in technician roles in that organisation. This averages around 14% in this group of organisations.

14 The exception is a company that carries out post-fabrication processing (e.g. machining) of composite parts, which currently trains (craft) apprentice CNC machinists to level 3 in mechanical engineering.

15 The division between the craft and technical streams is not, of course, hermetically sealed. The firms in question typically allow talented and able craft apprentices to shift onto the technical route by taking HNCs and Foundation Degrees.

16 See Lewis (2012a: 29-31) for a detailed discussion of the use of Higher Apprenticeships in the aerospace industry.

5.3.1.2 Apprenticeship training in space manufacturing

The story is similar in the case of the one space firm that currently takes apprentices. The company in question has both craft and technical apprenticeship schemes. The technical apprenticeship scheme is a long-standing training programme, designed to equip young people with the skills required successfully to fill various associate professional/technical roles.[17] The SFA contract for the apprentices is held by a local further education college. On average, twelve apprentices – who have achieved five GCSEs passes, including B grades in mathematics and a science – join the programme each year, with a view to obtaining an HNC in a mechanical or electrical engineering. These apprentices will take modules in bonding and assembling composites materials as part of their training. At over 90%, completion rates are very high.

More recently, the company has also set up a craft apprenticeship programme. This has lower entry requirements and is intended for people who are likely to work in craft roles, such as CNC machinists and composites laminators, rather than leave the shop floor to work in associate professional/technical roles. These workers, who are typically required to have C or even D grades in GCSE mathematics, English and science, are studying for level 3 qualifications in mechanical engineering and will take modules in composites fabrication and machining as part of their training. At present, eight such apprentices are being recruited each year. The overall apprenticeship intensity in this organisation, taking into account both its craft and technical apprenticeship programmes, is 8%.

The second space company does not currently take apprentices but is seriously contemplating doing so, because of the shortages of skilled workers it is experiencing as it expands the scale of its operations. One possible destination for an apprentice is its composites fabrication facility, whose manager would like to take on a trainee.

5.3.1.3 Apprenticeship training in defence manufacturing

The two firms that principally manufacture composite parts and structures for the defence industry have both (re)started taking apprentices since 2006. Neither holds the SFA contract for the apprenticeships. Neither firm sets minimum GCSE requirements for the apprentices, though the training provider and college who held the SFA contract may have done so. Both organisations have four apprentices in training. While one takes only craft apprentices, who are working towards an Advanced Apprenticeship in mechanical engineering, the other distinguishes explicitly between craft and technical streams: all are studying for qualifications in mechanical engineering, but the former are aiming for an Advanced Apprenticeship in mechanical engineering while the latter's initial goal is an HNC in the same subject. Apprentices are taking modules in composites manufacturing, where available.

5.2.1.4 Apprenticeship training in automotive manufacturing

Three of the five organisations that focus on manufacture composite parts for the automotive industry have begun taking apprentices since 2007. In all three cases, the SFA contract is held by a local further education college. There is an average of six apprentices in training at each of these three firms. Apprentices are studying for Advanced Apprenticeships in mechanical engineering, taking composites modules as part of that training programme. At 17%, the intensity of apprentices at the two firms that supplied the necessary data is high, reflecting the fact these firms are expanding rapidly and as a result need to increase the size of their technician workforce.

17 For more on these roles, see Lewis (2012b: 11-12).

5.3.1.5 Apprenticeship training in R&D organisations

One of the organisations involved in composites R&D has taken apprentices since 2007, while the other has just begun the process of recruiting its first apprentice. Both of these organisations are growing rapidly and, while they have on average three apprentices currently in training, given the current small size of their technician workforce this translates into a very high apprenticeship intensity of 33%. Moreover, in one case in particular, there are ambitious plans to increase the scale of apprenticeship training on offer.

More specifically, the organisation with the longer-established apprenticeship programme is about to open its own training centre and has ambitious plans for the number of apprentices it will train, not only for its own needs but also for other local firms (both large and small). All of these will be trained in engineering but not all will work with composites. Once the centre is open, the organisation will hold the SFA contract to train the apprentices. At present, apprentices in training for the centre's composites research group – who are required to have five GCSEs at grade C or above in mathematics, English and a science – take Advanced Apprenticeship in mechanical manufacturing engineering, including modules on composite materials.

The second R&D organisation is currently attempting to recruit its first apprentice. The successful candidate will be required to have passed five GCSEs, with B grades in mathematics and science, and will study for an Advanced Apprenticeship in mechanical engineering in the first instance. The organisation hopes to take on more apprentices in due course.

5.3.1.6 Apprenticeship training in marine organisations firms

The two large case-study organisations drawn from the marine industry both have large, well-established apprenticeship training schemes. These two firms have an average of 80 apprentices in training at any one time. Despite their size, however, both devolve formal responsibility for organising their apprenticeships to a third party (in one case, a further education college, in the other a private training provider). Apprentices typically need to have passed GCSEs in mathematics, English and (in one case) a science. They study for level 3 qualifications in frameworks such as marine engineering, carpentry, and boat-building and maintenance. Of course, not all of these apprentices will be trained to work with composite materials. The (unknown) fraction who do so receive such training as part of their apprenticeship will learn, for example, about the wet lay-up and bonding of composite materials and about composite mould-making.

5.3.1.7 Apprenticeship training in composite materials-makers

Two of the four materials-makers take apprentices. One, whose process operators work are typically skilled to level 2, took on two apprentice maintenance technicians in 2011. The apprentices are studying for level 3 qualifications in mechanical, and electrical and instrumentation, engineering. Their training is organised by a local Group Training Association (GTA). In the second case, a composite materials-maker has taken on apprentices not only in engineering but also, because its process operators are typically qualified to level 3, in polymer processing.

5.3.1.8 Apprenticeship training in MROs

All nine MROs included in this study train apprentices (with seven also possessing the license required to train category licensed aircraft engineers). By far the most common way of organising the apprenticeship training, adopted by eight organisations, involves the apprentices spending much of their first year on

block release, either at a local college or sometimes in the MROs' own training workshops, taking an NVQ2 in performing engineering operations in order to develop their basic hand skills and awareness of health and safety, and starting a level 3 qualification, mostly commonly a City & Guilds but sometimes a BTEC certificate, in aeronautical engineering or aerospace engineering and maintenance. On-the-job training in the workplace will commence in the second year of the apprenticeship, with the off-the-job training for the City and Guilds or BTEC award continuing via day release, so that the apprenticeship framework will be completed by the end of year 3 of the programme. The young people who complete this 3-year portion of the training are ready to work as unlicensed aircraft mechanics.

The three MROs in the sample that have decided to develop a capacity to repair and modify composite materials are investing in purpose-built composites training facilities, and are incorporating modules on composite materials into their apprenticeship training programmes, so that their apprentices and licensed engineers are able to judge the severity of damage to composite components and structures and to repair or replace them as necessary (in accordance with the manufacturers' manuals). Even in the case of the MROs that prefer to outsource the repair of composite parts by sending them either to a specialist MRO or back to the manufacturer, however, it is important that staff at all levels are aware of the basic properties of composite materials and of the kind of behaviour that is required in dealing with them. So, to take a commonly-mentioned example, it is important in the case of airline-based MROs that all staff, ranging from licensed engineers and mechanics to baggage-handlers, know that if something is dropped onto or driven into a composite part, then although that part might look undamaged, its structural integrity may have been compromised, so that it is necessary to call an expert to have it tested.

In the case of the seven organisations that also train licensed engineers, young people who wish to achieve licensed engineer status will spend a fourth year, if they aspire to a category 'A' license, and a fifth year, if they wish to acquire a category 'B' license, taking the relevant EASA examinations and acquiring the requisite practical experience. All being well, they should then – after a total of five years training – be able to qualify as category 'B' licensed engineers, after which – as noted in Section 3.1.8.3 above – they will need to spend an additional 4-6 months working on a particular type of aircraft in order to gain the type license that enables them to issue certificates of release.[18]

Only the two MROs associated with airlines hold the SFA contract to train apprentices. The remaining seven devolve formal responsibility for organising the training to a private training provider. The average annual intake across all these organisations is around 24 apprentices per annum, a figure that falls to an average intake of around 15 apprentices if one very large airline-based MRO, which currently takes upwards of 100 apprentices each year, is excluded from the calculations. Apprenticeship intensity is a around 10%. Apprentices are normally required to have 4-5 GCSEs at grades A-C, including English, mathematics and – usually – a science. Completion rates tend to be high, typically being cited as 90% or above.

18 The ninth MRO takes a rather different approach, aiming to take people up to category 'B' licensed engineer status via a four-year programme that involves them doing a Foundation Degree rather than a conventional apprenticeship. For more on this, see Lewis (2012a: 16).

5.3.2 Rationale

The 26 organisations that take apprentices usually mentioned one or more of the following three reasons for doing so.

The first, mentioned by twenty of the firms in question, is that apprenticeship training enables them to acquire specialist technician skills in a context where there is a limited availability of the relevant kind of worker on the external labour market (see Section 5.1 above). The need to train more workers is especially pronounced in the eleven organisations – mostly drawn from aerospace, but also including organisations involved in defence, automotive, and research and development – that are expanding and so need to increase the size of their technician workforce, sometimes very considerably. The most striking example of this is probably to be found in those organisations that make composite components and structures for the aerospace industry, where expanding firms are finding it extremely difficult or impossible to hire experienced technicians and as a result have little option but to fill the gap by training these workers in-house.[19] As one expanding aerospace manufacturer put it when commenting on why they had recently begun to train apprentices, 'We want to address the skills gaps that's looming'. Even in those cases – typically involving large organisations that offered above-average pay and career prospects – where employers felt that they would not find it too difficult to recruit skilled workers, they were reluctant to do so on a large scale, the reason being that – since many of those workers would come from firms in their own supply chain – such recruitment would indirectly damage their own organisation. As one interviewee put it, 'There are [almost] no skilled workers outside and [even] if we can find them we will hurt ... our business partners.'

The second major rationale for training apprentices, mentioned by twelve of the 26 case study organisations that do so, is succession planning. The merits of apprenticeship as a tool for succession planning were mentioned especially frequently by firms in the aerospace industry; aerospace manufacturers and MROs accounted for eight of the twelve organisations that cited significant succession planning as an important reason for taking apprentices. (The other four organisations came from the defence, marine, material-making, and space industries.) Three aerospace firms cited an average age for their technicians in the fifties, while a fourth did not provide a figure for the average age but mentioned that 40% of its workforce is due to retire within the next ten years (cf. SEMTA 2009: 13, 15).[20] This age profile was attributed by several interviewees, both in aerospace firms and sector-level bodies, to the fact that many companies scaled backed, or closed entirely, their apprenticeship training schemes in the 1990s and early 2000s, relying instead on recruiting experienced middle-aged technicians (e.g. from the armed forces), thereby leading to the present situation where there is a dip in the profile of the technician workforce in the region of 35-45 years of age (cf. SEMTA 2009: 17).[21] In all the cases, and not just those from aerospace, apprenticeships are being used as a means of succession planning, with a view to creating – or maintaining – a workforce with a more balanced age distribution.

19 For a similar point, see Composites Leadership Forum (2013: 5).

20 One analysis of Labour Force Survey data indicates that around a third of all Science, Engineering and Technology technicians – defined so as to include both Skilled Trades and Associate Professionals – are 50 years of age or older (Mason 2012: 19-20).

21 Also see Steedman (2011: 2), where data showing a decline in the number of level 3 apprentices trained each year in Britain between 1996 and 2010 can be found.

Third, and finally, apprenticeship training is appreciated by at least some firms because of the way it helps them to shape the values of young workers. This benefit of apprenticeship was mentioned by nine employers, for whom the values in question include a sense of the standards to which work has to be done in the industry in question, an acceptance of the need to take responsibility for ensuring that those standards are met, and a willingness to call others to account if poor practice is witnessed. As one interviewee put it, 'You get so much more than skills from an apprenticeship … you learn values … it's character building.' This is, of course, easier to do with young people, whose habits and standards are less ingrained, than with older workers, who have already developed more ingrained ways of thinking. As one apprenticeship training manager put it, 'To get them [to adopt] the values of the organisation, we want them young.'[22]

One important value that several employers argued is promoted by apprenticeship is loyalty, most notably in the sense that newly qualified apprentices are thought to be likely to remain with the organisation that trained them rather than being lured away by other firms. Only one of the firms that offers apprenticeships – a relatively small manufacturer of composite parts for the defence industry – expressed serious concerns about the poaching of its newly trained apprentices by other employers. In contrast, six employers argued that apprenticeship was a means of building loyalty and reducing labour turnover. These employers argued that, by offering their apprentices good training followed by a realistic prospect of promotion up through the organisation, they are able to demonstrate to young people that they are valued, that the employer is willing to invest in them, and that they have a good opportunity to develop their career within the organisation. This, the employers argued, reduces the likelihood that the young people will want to leave (cf. Ryan *et al*. 2007: 140-41; Lewis 21012a: 29, 2012b: 31-32).

5.4 COMPOSITES TRAINING FOR PEOPLE WHO ARE ALREADY TECHNICIANS

This kind of training is especially needed by those organisations – mostly firms in aerospace manufacturing and in the MRO sector – where composite components and structures are increasingly replacing metallic ones. As a result, workers who hitherto have been accustomed to working with metallic parts must be trained in the different ways of working required when dealing with composites.

Four of the aerospace manufacturers visited for this study make extensive use of such training. Three in particular have developed extensive, structured in-house training programmes so that their aircraft fitters can learn how to work with composite materials. The programmes, which last between 8 and 12 weeks, are often highly structured and cover issues such as:

- the nature and properties of composite materials;
- the particular manufacturing techniques required for drilling, reaming (i.e. finishing the surface of), fastening together, electrically bonding (earthing), and carrying out the non-destructive testing of composite parts; and
- the appropriate behaviour to adopt around composites (e.g. the need to be aware of how long carbon pre-preg material has been kept outside of the freezer, because it begins to degrade once it is no longer being refrigerated; the need to report incidents when carbon fibre material or parts have been

22 For similar observations by employers in other sectors, see Ryan *et al*. (2007: 140, 145-46), Lewis *et al*. (2008: 7, 15), Lewis (2012b: 27) and Hogarth *et al*. (2012: 10).

dropped or been subject to some of impact, even though they might look undamaged, because such incidents can damage the material or parts in ways that are invisible to the naked eye; and the importance of workers who are fabricating composite parts not having loose objects in their pockets which might fall into a mould and be cured into a part, thereby ruining it).

These programmes typically involve an initial period of training away from the shop floor in a dedicated training facility run by specialist trainers, after which trainees receive a further period of on-the-job training under the tutelage of a more experienced worker. In most cases, this training is uncertificated. In keeping with the discussion of the advantages of apprenticeship training in Section 5.3.2 above, one interviewee from an in-house composites training school noted that it was typically harder to train experienced workers – whose habits have been formed by their experience of working with metals – than it was to train the firm's apprentices, whose approach to doing work had yet to become established and was therefore more malleable. The fourth company, which is much smaller than the other three, relied on training from its US-based parent company to upgrade its machinists so they could work successfully with composite materials.[23]

The need for the extensive retraining of a firm's existing workforce along the lines just described is less pronounced in those case study companies which, because they have worked with composite materials from the time they were established, have never had to make the switch from metallics to composites. Nonetheless, those firms do need to offer training to those technicians – such as machinists – whom they hire from the external labour market and who are experienced at working with metals but not with composites. Two companies, one defence firm and one automotive company, in the sample visited here reported that such workers received in-house training, typically in the form of an initial introduction to composites followed by a period of shadowing and informal, on-the-job training from experienced workers.

As noted in Section 4.1.10 above, only three of the MRO case study organisations have invested in both the physical and human capital required to develop a significant composites capability, up to and including the autoclaving of composite parts. The MROs that have decided to develop their capacity in composites have tended to send at least some of the their licensed engineers on courses offered by manufacturers such as Boeing so as to develop their knowledge of, and competence in, the techniques involved in testing and repairing composite materials. Upon returning to the MRO that employs them, those workers can then pass on their skills and knowledge to the other licensed engineers and mechanics, thereby ensuring that those workers learn how to work with composite components and structures.

23 The need alluded to in this paragraph for the provision of training designed to introduce people to the nature of composite materials, and to the kinds of behaviour that are appropriate when dealing with composites, arises not just in the case of technicians but also in the case of workers at all skills levels, ranging from unskilled storemen to highly qualified graduates. Interviewees from several employer organisations as well as a number of sector-level bodies highlighted the need for short – one day, for example - training courses designed to inform workers at all skill levels about how to behave around composite materials, in particular about the fact that it is possible to damage (parts made out of) such materials – for example, by dropping or knocking them - without that damage being visible to the naked eye. Workers need to be aware, in particular, that accidents that would not damage a metallic part could compromise the integrity of a composite structure, even though it might appear to be all right, and that all such incidents need to be reported so that the part can be subject to appropriate testing.

5.5 IMPEDIMENTS TO TRAINING

5.5.1 Problems

Fifteen of the case study organisations, along with several of the sector-level bodies, aired concerns about the availability of decent quality training in the techniques required for working with composite materials, whether they be training for semi-skilled laminators or for apprentices. Employers mentioned two main problems.

The first concerns the availability of training courses. Four of the employers who take – or who wish to take – apprentices have struggled to find colleges willing to offer all the modules in composites that they would like their apprentices to have. As one employer put it, 'You can't get the courses you want,' so that the choice of modules then becomes 'a big compromise.' Or, in the words of another composites manufacturer, 'For the first two apprentices the units weren't there' so apprentices end up doing fewer composites units than they really need. In a similar vein, one case study employer that had in the past sent its semi-skilled laminators for externally certificated training had ceased to do so because the provider stopped offering the training in question. Another two firms stated that there would be doubts about the willingness of their local college to continue to train their apprentices, because the decision of another employer no longer to send its apprentice to that college had called into question the financial viability of the apprenticeship programme in question. There appears, therefore, to have been little improvement in situation described in a 2009 report which remarked of the composites industry that, 'there is a shortage of the necessary skills at nearly all levels, as training is difficult to identify and access' (BIS 2009: 4).

As these examples suggest, problems with the limited availability of college courses in composites reflect at least in part the incentives facing further education colleges (cf. NCN 2009: 3-4). The number of apprentices or other trainees that smaller firms in particular wish to send for training is insufficient, given the rewards available to colleges for engaging in other kinds of training, for it to be worthwhile for colleges to make the significant investment in facilities, equipment and tutors required to offer a wide range of high-quality training in composites. More specifically, as the recent Richard review of apprenticeship training in the UK has noted, the funding on offer to providers for training an apprentice in a particular framework reflects a bureaucratic formula based on (estimates of) the amount of learning involved and tuition costs. However, because the funding rates for various frameworks do not always accurately reflect the costs of delivering those frameworks, providers have an incentive to focus on providing training for those frameworks where the margin between the funding on offer and the cost of delivery is greatest, which are not necessarily those most desired by employers or those whose prioritisation is in the public interest. As Richard puts it:

> *[A]pprenticeship funding drives a system which is too provider-driven and not sufficiently responsive to employers, and which does not promote efficiency or adequately incentivise quality … Too many resources are being dedicated to those apprenticeships that deliver the biggest margins instead of those apprenticeships that generate the highest value for society. (Richard 2012: 107, 108; also see Wolf 2011: 60)*

The upshot, according to one sector-level interviewee, is that there are only two specialist training providers, and five or six colleges, that provided high-quality composites training. And the concrete manifestation of this problem can be found

in the difficulty that employers who use composite materials have had in persuading colleges to offer the off-the-job training ('technical certificates') and/or the high-quality practical training required by their apprentices, simply because the financial incentives confronting providers encourage them to offer training in 'cheaper' frameworks, such as customer services and business administration, instead. Such difficulties lend additional support to the evidence gathered by Richard, who reports that, 'Stakeholders were critical of the current provider-led system, observing that some providers have a tendency to deliver frameworks that are ''easy to deliver'', profitable and can attract large numbers [of apprentices], rather than delivering what industry wants or needs' (p. 85) (cf. Ryan and Unwin 2001: 108-09).[24]

The second problem facing employers who wish to train workers in dealing with composites concerns the quality of training on offer. Even when the relevant modules are offered, some employers sometimes argue, its quality is deficient. Several employers who had looked to local colleges for help in training either semi-skilled laminators or apprentices stated that in their experience college tutors were all-too-often unfamiliar with the techniques and materials currently used in industry and with the standards to which work should be done (six cases). As one HR and training manager said: 'Most FE colleges I visit look and feel ten years out of date', lacking both the facilities and equipment (e.g. clean rooms) and expert tutors required to teach skills to best practice techniques for working with composites. After having seen how some of the laminators he sent for NVQ2 training at a local college were treated, one interviewee commented that he 'came out feeling that it was a certificate assembly line', with colleges being uninterested in doing anything more than the bare minimum required to award the NVQ. The upshot, in the opinion of another employer, is that the NVQ certificate 'is not worth the paper it's written on.'

5.5.2 Potential solutions

While these problems are serious, they are not insurmountable. Four employers have worked closely with their local colleges to develop training programmes in those colleges both for apprentices and semi-skilled laminators. Four other large employers have chosen instead to invest in their own training workshops so as to provide the instruction in practical skills in-house. But it is significant that these are relatively large organisations which either have enough apprentices to make it worthwhile for local colleges to incur the fixed costs of setting up a training programme with a significant composites component (in the case of three of the first four firms), or are so in need of training in composites for their apprentices and other employees that they are willing to incur the costs of developing their own training facilities (in the case of the second four organisations). These options are not, however, realistic for smaller firms, who – taken individually – lack the critical mass of apprentices required to justify either a college or the firms themselves investing in a specialist composites training facility.

Moreover, there appear to be a relatively small number of specialist external training providers who are able and willing to work as consultants to help smaller firms develop the skills of their semi-skilled laminators, and also to train people occupying level 3 roles such as supervisor and composites team leader so that they can hone the skills of the laminators within their teams (a 'train-the-trainer' approach). Something along these lines has been adopted by two of the smaller employers in

24 Similar problems with college provision are reported by Lewis and Gospel (2011: 33), in the case of university science and engineering departments that train apprentices, and by Lewis (2012a: 31-32), in the case of employers in the space industry. Also see Wolf (2011: 126).

the case study organisations. What these cases suggest is that, while it is currently (too) hard to find good training, it is not impossible, and there needs to be better dissemination of information amongst employers about the availability such external providers, especially those who are willing to travel to workplaces.[25] The approval of composites training providers, as recently commenced by the National Skills Academy for Process Industries (NSAPI), can help to ensure that employers are more aware of the quality of the training offered by the providers with whom they are considering engaging. Approval should help to ensure that employers can be confident that their workers will learn current best practice in good facilities.

Clearly, though, there is also a need to expand provision (cf. Composites Leadership Forum 2013: 4). Closer collaboration between employers, and between employers and educational institutions, should help to aggregate demand from them, so that student numbers exceed the minimum required to make it worthwhile for universities/colleges to offer the relevant modules. Two of the case study organisations visited for this study are located in the same geographical area and at the time of writing are discussing how to collaborate, both with each other and with other local composites-using firms, so that taken together they generate enough trainees to persuade a local college to develop a greater capacity for training in composites. There is also potential for two of the major composites research organisations visited as part of this study, both of which are at least in part publicly funded, to contribute significantly to the solution of the problems posed by the lack of high-quality training providers. Both organisations are in the process of developing training centres, including for technicians. Trainees at such centres will have the opportunity to learn current best practice in working with composite materials in specialist facilities, as informed by the research into composites manufacturing techniques carried out at the organisations in question. Access to such training could be extended beyond firms situated in close geographical proximity to other centres by the provision of block release courses and related accommodation for trainees from firms in other parts of the country. Beyond this, as argued by Lewis (2012a: 38-39, 2012b: 34-35) and by Richard (2012: 107-08), policy-makers need to consider changing the funding regime facing colleges so that they are confronted with sharper incentives to offer training for apprenticeships in STEM subjects.

5.5.3 Standards, training, careers and professional registration

One pre-requisite for high-quality training is that employers and training providers have a sense of what such training involves. At present in the UK, the most commonly used reference point for judging the quality of vocational education and training is provided by the relevant set of National Occupational Standards (NOSs). These provide a description of the skills, knowledge and understanding required to undertake a particular task or job to a nationally recognised level of competence. In doing so, they are supposed to help formalise training requirements for employers and employees. There are, however, problems with the use of NOSs, both in the composites industry in particular and more generally.

One problem with the NOSs used in the composites industry, referred to by various firms, sector-level bodies and training providers, is that the NOSs used through most of the first decade of the twenty-first century tended to be embedded within the training frameworks for particular industries and were therefore heavily oriented towards the requirements of those industries, rather towards composites

25 For a similar example from the chemical industry, see Lewis (2013: Section 4.2.5).

manufacturing *per se*. The upshot is that people who were trained under the auspices of one of these frameworks tended to be trained rather narrowly in the composites manufacturing techniques appropriate for that industry (e.g. wet lay-up for the marine industry) and so struggled if they had to learn how to work in other industries (e.g. carbon pre-preg for the aerospace industry). In order to overcome the rather fragmented approach to composites training that resulted, a more generic sets of standards for assessing training was required, which placed less emphasis on the specific kind of composite parts produced by a particular sector and more on the general process of composites manufacturing, so that people are more able to work across with a variety of processes and sectors. And it was in order to promote a more unified approach to composites training that the NOSs for composites were rewritten in 2011.[26]

However, while rewriting the NOSs so that they encourage less sector-specific training might well help overcome one of the ways in which composites training has been fragmented, it leaves another form of fragmentation unchallenged. This second form of fragmentation is intrinsic to the nature of the NOSs and of the NVQs they underpin. The problem is that under the NVQ assessment methodology that currently prevails in education and training in the UK, the national occupational standards used to define competence have to take the form of comprehensive descriptions of the performances ('outcomes') that need to be mastered in particular job roles (e.g. composites laminator). In an attempt to ensure both that these outcomes are sufficiently general and context-independent that they can be used in any workplace, and also that they are so clear, precise and unambiguous as to convey exactly what the assessor has to look for (to permit reliable assessment), the outcomes in question have to be described in a very detailed, specific and atomised fashion. The problem is that such an approach tends to promote a fragmented approach to the assessment of competence. While it is true that in order to gain an NVQ, trainees have to demonstrate the ability to achieve all the relevant outcomes – all the individual *competences* – they only have to do only singly, in isolation, over an extended period time. What they do *not* have to demonstrate is the all-round, holistic *competence* to deploy several *competences* at the same time, in a suitably integrated fashion, to solve a problem, as is so often expected of technicians doing jobs in a real workplace. When it comes to assessing *overall* competence, therefore, the problem with NVQs is that, thanks to the fragmented nature of the assessment process, all too often it is only isolated, atomistic skills – rather than the holistic problem-solving ability required of a technician – that is assessed. The upshot is that, as the Richard Review has put it, apprentices can 'tick off the many tasks involved but not, in the end, be genuinely employable and fully competent' (Richard 2012: 50; also see Wolf 1995: 2-5, 15-32, 54-67, 99-125; Eraut 2001: 94-97).

Happily, there is an alternative approach to the assessment of competence which holds out the promise that these problems can be avoided, at least in the case of apprentice technicians. The model in question can be found in the requirements for professional registration set out by various professional engineering institutions in the UK. The *UK Standard for Professional Engineering Competence* – or UK-Spec, as it is known – specifies the requirements that must be satisfied for various levels of professional registration for people who work as engineers, namely Engineering Technician, Incorporated Engineer and Chartered Engineer

26 For more details, see http://www.netcomposites.com/news/semta-develops-series-of-new-national-occupational-standards-to-support-composites-sector/7031.

(Engineering Council 2010).[27] Apprentices who register for the Engineering Technician award must demonstrate that, by the end of their apprenticeship, they have acquired the technical expertise and knowledge required to enable them to 'apply proven techniques and procedures to the solution of practical engineering problems … and [to] carry supervisory or technical responsibility' (Engineering Council 2010: 8). Those who do so become eligible for Engineering Technician (EngTech) status upon successful completion of their apprenticeship. In this way, the standards for professional registration focus on the development of a worker who is competent in the sense that (s)he is able to '[u]se engineering knowledge and understanding to apply technical and practical skills' and who can therefore '[c]ontribute to the design, development, manufacture, construction, commissioning, operation or maintenance of products, equipment, processes, systems or services' (Engineering Council 2010: 8-9).[28]

The key point about the approach to the assessment of competence involved in professional registration is that the UKSPEC describes the required competence in a way that is both generic and holistic. The descriptions are generic in the sense that they are pitched at a high level of abstraction and therefore cover technician occupations in all of the various sub-disciplines of engineering.[29] And they are also holistic in the sense that they are based on a notion of competence that 'integrates knowledge, understanding, skills and values … [and so] goes beyond the ability to perform specific tasks' (Engineering Council 2010: 6; cf. Richard 2012: 54-55). And by relying on a more holistic, and generic notion of competence, the approach to assessment adopted by the engineering institutions can help to avoid the problems posed by the fragmented approach to assessment associated with NVQs, thereby helping to ensure that only those technicians are certified as competent who are able to identify and integrate theoretical and practical knowledge in order to solve practical engineering problems. On this view, therefore, the outcome of an apprenticeship training programme should be workers who are competent in the (broad) sense that they are able to carry out the duties normally associated with the occupation for which they are being trained to the level expected by employers, not just as that occupation is defined by the particular employer to which they are apprenticed but as it is understood by the broad swath of firms in the relevant industry or sector (Richard 2012: 6-7).[30]

The approach advocated above, with more of an emphasis on ascertaining an individual's all-round competence, as exemplified by professional registration, rather than on the isolated assessment of individual competences, as all-too-often witnessed with NVQs, also offers the potential to address some of the other problems facing the composites industry. By offering a more holistic, and reliable, indication of a person's skill, it may help to overcome of the problem, referred to by several interviewees, that there is 'no real training standard within the industry', so that employers are uncertain what skills a particular worker possesses. An

27 The UKSPEC is regulated by the Engineering Council, which in term licenses the various professional engineering institutions – such as the Institute of Mechanical Engineers and the Institute of Electrical and Electronic engineers, to name but two – to assess their members and to place on their registers those who can demonstrate the required competence.

28 In addition to possessing the relevant technical skills and knowledge, people who wish to register as an Engineering Technician must also demonstrate their commitment to maintaining their competence in the future, to working within professional codes of practice, and to participating actively within the engineering profession. For a full statement, see Engineering Council (2010: 9-10).

29 One of the duties of the various professional engineering bodies who are licensed to place people on the register of Engineering Technicians is to interpret the generic requirements set out in the UK Spec and explain how they apply to their own particular branch of engineering (Sherman not dated: 2, 6).

30 At present, however, only five of the employers visited for this study – four aerospace manufacturers and one MRO – register their apprentices for the EngTech award.

additional potential benefit, noted by three employers and also by some sector-level commentaries (see NCN 2009: 3-5), concerns the lack of a career structure in the composites industry. As one report states, there is 'no coherent framework [for training] linked to career progression' so employers 'have no way of assessing the competency [*sic*] of an individual against an industry standard' (NCN 2009: 4). Registration offers a potential way of dealing with this problem, for two main reasons. First, as noted above, the requirements for the various awards offered by the professional engineering bodies constitute a clear set of standards by reference to which a person's all-round competence can be judged. Second, the fact that the awards in question – EngTech, IEng., etc. – constitute a hierarchy means that they can form the basis for a career structure, in the sense that a person who has achieved the competence, etc., required to earn an EngTech award will be able to understand from the requirements for I.Eng what (s)he needs to do to progress to the next stage of his/her career. Equally, that person's employer will also be able to derive from the requirements for professional awards a sense of how it might develop the employee's career.

As another report on the composites sector put it: '

> *The Engineering Council through the professional institutions offers professional registration as Engineering Technician (Eng Tech), Incorporated Engineer (IEng) or Chartered Engineer (C.Eng). Given that safety-critical components are made of composites, it would be appropriate for personnel to be required to register within this system and for employers to seek that level of commitment …In this way, relevant national occupational standards and qualifications … subject to review and rationalisation [in the form of professional standards of all round competence], could provide a coherent and progressive framework of work-based qualifications linked to recognised career pathways'* (NCN 2009: 8, 5).

Encouraging the development of professional standards for the occupation of 'composites technician', along the lines sketched by Richard (2012; also see Gatsby 2013), might therefore help both to provide a more reliable benchmark by reference to which workers' competence can be judged and also a clearer and more robust framework for career development for such workers.

SECTION 6 SUMMARY AND POLICY RECOMMENDATIONS

This section summarises this study's findings on the five questions posed in the Introduction to the report.

Q1: In what roles are workers experienced in working with composite materials employed in the UK?

Consider first those firms that actually make composite parts, as distinct from those – in particular, two of the aerospace firms and the MROs – that machine, assemble and repair composite parts made elsewhere. The evidence gathered for this study indicates that, in the vast majority of cases, most of the workers involved in fabricating composite parts use non-automated methods of production such as wet lay-up, resin infusion and carbon pre-preg laminating, and so require only level 2 skills. (Only in the two aerospace and space companies that use automated methods of production, and in the research organisations that develop automated methods of production, do laminators typically possess level 3 skills.) Accordingly, in the aerospace, automotive, defence and marine companies visited for this project that fabricate composite parts, semi-skilled laminators account on average for anything between 20% and 50% of the workforce. So far as the actual fabrication of composite components is concerned, technician-level roles tend to be confined to composites team-leaders, machinists, manufacturing, production and quality engineers, and NDT technicians. Especially in the automotive and defence firms, such roles typically account for only 20-30% of the total workforce. The share of technicians in the workforce is higher, at around 45%, in the firms that manufacture composite parts for the aerospace industry. This is in large part because the aerospace manufacturers in question often also build, fit and assemble metallic, electrical and electronic components and systems for aircraft, for which tasks skills at level 3 or above are required, whereas the defence and automotive parts manufacturers do not undertake as much non-composite work and so need fewer technician-level skills.

The share of technicians in the workforce tends to be relatively high (35-45%) in those aerospace firms that machine and assemble, rather than manufacture, composite parts, and also in those MROs that are not part of airlines. Such organisations do not fabricate composite parts and therefore do not need the cadre of semi-skilled laminators that drives down the share of technicians in the workforce in automotive and defence manufacturers. The two aerospace manufacturers that machine and assemble composite parts do, however, need to have technicians who are familiar with the techniques required in machining, assembling and testing composite parts. In a similar vein, the MROs that wish to test and repair composite materials themselves – rather than outsourcing such work – require their mechanics and licensed engineers to be familiar with the techniques required for testing and repairing composite parts.

Q2: What levels of skill and qualifications do the people occupying technician roles in the chemical industry typically possess?

Specialist, rank-and-file laminators who use non-automated methods of production to fabricate composite parts for the aerospace, marine, automotive and defence sectors tend to possess only level 2 skills, sometimes certificated by an NVQ2. In

organisations that use non-automated methods of production, the only laminators who are required to have level 3 skills are the team-leaders/supervisors who oversee shop-floor production. In the case of organisations that use automated methods of production such as filament winding or automated fibre placement/tape-laying, however, rank-and-file laminators tend to have level 3-4 skills, typically acquired via an apprenticeship in something like manufacturing engineering.

Whatever manufacturing techniques they use, employers dealing with composites also employ (i) workers who need level 3 skills in craft or skilled trades roles such as machinists, mechanical testing technicians, and NDT technicians, and (ii) people who require skills at level 4/5 to fill associate professional/technical roles such as production/manufacturing engineer, quality engineer, and draughtsman/junior design engineer. Such workers tend to have qualifications such as (i) an apprenticeship or (ii) an HNC, HND or – less commonly – Foundation Degree in subjects such as mechanical or – in the relevant sectors – aerospace or marine engineering. In the case of MROs, technician-level workers tend to possess either apprenticeships in aerospace or aeronautical engineering, in the case of unlicensed aircraft mechanics, or category 'A' or category 'B' licenses, in the case of licensed aircraft engineers.

Q3: How do employers who use composite materials acquire the workers they need?

The semi-skilled laminators who fabricate composite parts in many of the aerospace, automotive, defence, and – to a lesser degree – marine firms tend to be home-grown. The case study firms from these sectors tended to make considerable use of external upgrade training, acquiring a majority of their semi-skilled laminators by hiring unskilled people from the external labour market and offering them structured, but often uncertificated, in-house training schemes to teach them how to laminate. This reliance on in-house training reflects the scarcity of good semi-skilled laminators on the external labour market.

The picture is rather different in the case of technician-level workers. Over half of the case study firms from the aerospace sector, broadly understood to include firms involved in aerospace manufacturing as well as MROs, have made significant (30%+) use of apprenticeships as a means of acquiring their technicians. In contrast, most of the technicians currently employed by firms working with composites outside of the aerospace sector have been acquired via external recruitment. In those other sectors – and with the possible exception of marine, where data on the source of the technician workforce were not available – apprenticeship accounted for less than 20% of the current technician workforce.

Q4: Fourth, are there skills shortages?

Many case studies organisations, drawn from all the sectors considered in this study, reported that they face significant problems in recruiting both semi-skilled laminators and technicians. There appear to be shortages of people acquainted with best practice at working with composite materials at all skill levels in all the sectors. As a result, employers are turning to in-house training in order to acquire the workers they need, whether that be external upgrade training as a means of obtaining semi-skilled composites laminators or a combination of apprenticeships and internal upgrade training as a means of acquiring skilled technicians. However, the efforts of these organisations to train workers are often impeded by the paucity of high-quality training providers.

Q5: Fifth, what – if anything – should government do to help employers in the chemicals industry in their efforts to acquire skilled technicians?

A number of recommendations for policy emerge from the findings presented above, connected primarily with helping firms to acquire the skilled labour they need and thereby to deal with the shortages of workers skilled in dealing with composite materials.

The first concerns the role of further education colleges in apprenticeship training. While, as we have seen, employers that work with composites are making more and more use of in-house training, the evidence gathered for this report suggests that the training infrastructure they need is not always in place. More specifically, employers are often let down by the quality of the support they receive from colleges, either because of a reluctance to offer any training at all or because of the poor quality of the training when it is offered. Determining the right way of addressing these problems requires the collection of additional evidence, but possible solutions include:

- better dissemination of information about the availability of those (currently, relatively small number of) training providers able and willing to offer high-quality training in working with composite materials;
- exploring the extent to which some of the large, publicly-funded organisations involved in composites research can contribute to training apprentices, including via periods of block release for trainees from firms located in other regions (cf. BIS 2009: 25-26);
- a closely related approach which would involve encouraging those large private-sector firms – typically drawn from the aerospace and marine sectors – that have invested in their own training facilities to open up them up to trainees from other firms, either as a means of helping to cover the fixed costs of running the facilities or as a way of supporting firms in their own supply chain (a phenomenon known as 'over-training' [Lewis 2013c]);
- sharpening the incentives that encourage colleges to invest in the workshops and tutors needed to offer good training in composites;
- providing college lecturers with secondments in industry, so that they can learn more about current best practice in working with composites; and
- exploring in detail whether the requirements of professional registration can provide both (i) a more robust and useful set of standards by reference to which the quality of skills and training in composites can be judged than the current National Occupational Standards, and also (ii) a framework for career development for semi-skilled and, especially, technician-level workers in the sector.

Some promising initiatives are already under way, with the Composites Skills Alliance taking the lead in attempting to improve the scale and quality of college provision in composites (see Composites Skills Alliance 2012). But much remains to be done if the skills base required for UK, composites-using industry to be competitive in international markets is to be developed.

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